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Free Trade Zones, Green Finance Policies, and Corporate Green Transition: Evidence from Chinese A-Share Listed Companies

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Abstract

Against the backdrop of ongoing global green transition and trade liberalization, there remains a lack of sufficient micro-level evidence to determine whether institutional openness can improve corporate environmental performance and long-term sustainable development through the development of green finance. Based on data from Chinese A-share listed companies from 2013 to 2024, this paper utilizes the quasi-natural experiment created by the phased establishment of pilot free trade zones and employs a multi-period difference-in-differences model to examine their impact on corporate green transition and the transmission mechanism of green finance policies. The study found that the establishment of pilot free trade zones has significantly promoted the green transformation of enterprises. An analysis of intermediary effects suggests that green finance policy support may constitute a potential transmission channel; however, since its indicators primarily reflect the intensity of policy activities, they cannot yet directly identify the role of actual financing flows. Further analysis of transmission mechanisms reveals that alleviating enterprises' financing constraints and attracting long-term institutional investors are key channels for promoting corporate green transition. Additionally, an analysis of spatial effects indicates that the development of pilot free trade zones not only benefits the green transition of enterprises in pilot cities but may also generate positive spillover effects on neighboring cities through cross-regional linkages. This paper reveals the environmental benefits of trade liberalization policies and their financial transmission mechanisms, expands research on the relationship between institutional openness and corporate green behavior, and provides policy insights for emerging economies seeking to balance economic openness, environmental protection, and sustainable development goals. However, as the study sample primarily consists of Chinese listed companies, the cross-national applicability of the findings requires further verification.

Keywords: trade liberalization; financial resource allocation; financing constraints; green innovation; spatial spillovers

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1. Introduction

As global climate change continues to worsen and resource and environmental constraints grow increasingly stringent, the transition to a green and low-carbon economy has emerged as a core developmental trend for the global economy. Driven by the continuous enforcement of the Paris Agreement and the worldwide advancement of carbon emission reduction actions, various economies have progressively embedded green development concepts into their macroeconomic policies and industrial development frameworks. Enterprises, too, face the practical imperative of transitioning from traditional, high-input,

high-emission models to green, low-carbon, and innovation-driven models [1]. As key actors in resource consumption, pollution emissions, and technological innovation, the green transition of enterprises not only relates to the achievement of global emission reduction targets but has also become a vital pathway to enhancing long-term competitiveness and achieving sustainable development. However, projects related to green technology R&D [2], clean production [3], and energy conservation and emissions reduction [4] are typically characterized by long investment cycles, substantial upfront costs, and uncertain returns; as a result, financing constraints have become a major factor limiting corporate green transition [5]. Consequently, how to optimize capital allocation through the financial system, reduce financing costs for green projects, and channel funds toward green industries [6] has gradually emerged as a key policy issue in global efforts to promote corporate green transition. In this global green transition process, China, as a major world economy, also faces the practical requirement of advancing economic development in tandem with a green and low-carbon transition. With the introduction of the "dual carbon" goals, China has continued to advance the development of its green financial system and is exploring new paths for green development through institutional innovation and regional openness. Against this backdrop, pilot free trade zones—as key platforms for China to deepen reform and opening-up and promote institutional openness—have gradually extended their influence from the fields of trade and investment to those of financial resource allocation and green development. Consequently, a question worthy of in-depth study is whether the establishment of pilot free trade zones—a typical policy of institutional openness—can generate green development effects that extend beyond the realms of trade and investment. If so, does their role stem in part from the improvement of regional green financial systems?

Based on existing research, a relatively robust body of work has been established regarding the economic effects of pilot free trade zones. The existing literature primarily examines the impact of pilot free trade zones from the perspectives of trade and investment [7], corporate innovation [8], resource allocation [9], industrial upgrading [10], economic growth [11], and environmental governance [12]. It is generally acknowledged that institutional openness can alter corporate behavior by reducing institutional transaction costs, optimizing the business environment, promoting the flow of factors of production, and strengthening market competition. However, compared with economic growth and innovation performance, there remains a lack of sufficient discussion on the micro-level mechanisms through which pilot free trade zones influence corporate green transition. In particular, existing research often interprets environmental effects as a direct result of liberalization policies, while rarely explaining the intrinsic link between institutional opening-up and corporate green transition from the perspective of financial resource allocation. In fact, green transition is not merely a technical issue; it is also characterized by significant financing constraints [13]. Enterprises need continuous and stable long-term financial input to carry out the research and development of green technologies, complete upgrades to clean production equipment, and build supporting pollution control facilities [14]. If the regional financial system fails to effectively recognize the environmental benefits and long-term value of green projects, enterprises—even if they are willing to undergo a green transition—may struggle to translate green investments into concrete actions due to high financing costs and mismatches in financing terms. Therefore, whether pilot free trade zones can improve the supply of green capital through financial institutional innovation may be a key entry point for explaining their green effects. Against this backdrop, this paper aims to examine how institutional openness promotes corporate green transformation through green finance policies and to assess its impact on corporate environmental sustainability. Specifically, this paper focuses on addressing the following three research questions: First, does the establishment of pilot free trade zones significantly promote corporate green

transformation? Second, do green finance development policies serve as an intermediary by alleviating financing constraints and attracting long-term institutional investors? Third, do the green transition effects of free trade pilot zones vary depending on firm characteristics, and do they generate spatial spillover effects? To answer these questions, this paper conducts an empirical analysis using a multi-period difference-in-differences model based on data from Chinese A-share listed companies from 2013 to 2024, with the aim of providing empirical evidence on how institutional openness and green finance reforms can synergistically promote corporate sustainability.

The potential marginal contributions of this paper are primarily reflected in the following three aspects. First, it broadens the research perspective on the environmental effects of the policy environment in pilot free trade zones. Existing research on pilot free trade zones has primarily focused on areas such as trade, investment, innovation, and economic growth. This paper further extends the research perspective to corporate green transformation, identifying the environmental spillover effects of institutional opening-up at the micro-firm level and providing new empirical evidence for understanding the multidimensional policy effects of pilot free trade zone development. Second, it incorporates green finance into the analytical framework of institutional openness and corporate green transition, revealing the financial resource allocation mechanisms underlying the green effects of pilot free trade zones. Rather than merely examining the correlation between openness policies and green transition, this paper further identifies the mediating role played by green finance, thereby integrating trade liberalization, financial institutional innovation, and corporate green behavior into a unified logical chain. Third, this study further expands the dimensions for identifying the effects of corporate green transformation. Building on an examination of green technological innovation and environmental performance, this paper distinguishes between substantive green innovation and strategic environmental performance, analyzing whether policies genuinely alter enterprises' green production and innovation activities, thereby providing more detailed micro-level evidence for evaluating the quality of green development under openness policies.

The remainder of this paper is organized as follows: Part II reviews the relevant literature and examines the theoretical links among pilot free trade zones, green finance, and corporate green transition; Part III presents the research hypotheses and describes the data sources, variable definitions, and research methods; Part IV reports the empirical results and conducts robustness tests, mechanism analysis, heterogeneity analysis, and tests for spatial spillover effects; Part V summarizes the research conclusions and discusses policy implications, research limitations, and directions for future research.

2. Literature Review and Hypothesis Formulation

2.1. Free Trade Pilot Zones and Corporate Green Transition

As important policy tools for promoting institutional openness and economic transformation, the economic and environmental impacts of pilot free trade zones have attracted widespread attention. Existing research primarily examines the effects of pilot free trade zone development in terms of economic growth [15], trade and investment [16], corporate innovation, and resource allocation. Relevant studies indicate that by reducing institutional transaction costs, improving the business environment, promoting the flow of capital and technology, and strengthening market-oriented mechanisms, free trade pilot zones can optimize regional resource allocation and, in turn, influence enterprises' production and operational decisions [17,18]. As research continues to deepen, some studies have begun to focus on the environmental effects of free trade pilot zones, suggesting that liberalization policies may influence regional environmental quality through technological progress, industrial restructuring, and improved resource allocation efficiency. Furthermore, the envi-

ronmental effects of pilot free trade zones stem not only from traditional trade liberalization but also from institutional innovation and policy synergies. On the one hand, pilot free trade zones can facilitate the flow of green technologies and advanced factors of production, creating favorable conditions for enterprises' green innovation; on the other hand, local governments can utilize the platform of pilot free trade zones to improve environmental governance and green development policies, thereby generating synergies between open policies and environmental governance [19].

As a core platform for China's institutional opening-up, free trade pilot zones, in theory, influence enterprises' green transition primarily through three channels. First, the institutional opening-up brought about by free trade pilot zones reduces institutional transaction costs and optimizes the business environment, making it easier for enterprises to access green technologies, clean equipment, and environmental management expertise from both domestic and international markets. Second, free trade pilot zones facilitate the flow of capital, technology, and talent, thereby lowering the costs for enterprises within their jurisdictions to engage in green R & D and upgrade to clean production practices. Third, the development of free trade pilot zones is often accompanied by stricter environmental governance requirements and higher environmental disclosure standards, which compel enterprises to upgrade their production methods and reduce pollutant emissions [20,21]. Taking these channels into careful consideration, the institutional opening-up effects of free trade pilot zones should have a positive net impact on enterprises' green transition. Based on this, we propose:

Hypothesis 1. *All other things being equal, the establishment of pilot free trade zones can significantly promote the green transition of enterprises.*

2.2. Green Finance and the Green Transition of Enterprises

By incorporating environmental factors into the process of financial resource allocation and directing capital toward green industries and low-carbon projects, green finance has become a key financial tool for driving the transition to a green economy. Existing research primarily examines the economic and environmental effects of green finance from the perspectives of green credit [22], green bonds [23], pilot zones for green finance reform [24], and green investment [25]. Most studies have found that green finance can provide financial support for enterprises' green development by alleviating corporate financing constraints, reducing the financing costs of green projects, and strengthening environmental risk pricing. At the corporate level, the impact of green finance on green transition is primarily reflected in green technological innovation, pollution reduction, and improved environmental performance. On the one hand, green finance can alleviate the funding constraints enterprises face in green R & D and environmental protection investments, thereby increasing corporate investment in green technological innovation; on the other hand, when financial institutions and investors incorporate environmental factors into their financing and investment decisions, they can impose sustained environmental constraints and incentives on enterprises, prompting them to optimize production methods and reduce pollution emissions [26].

In terms of mechanisms of action, pilot free trade zones can improve regional green finance systems and broaden enterprises' access to green financing through financial institutional innovation and policy support. On the one hand, green finance policies provide long-term financial support for enterprises' green R & D and clean production by lowering the financing costs of green projects and alleviating financing constraints; on the other hand, green finance can guide long-term institutional investors to focus on corporate environmental performance, thereby strengthening incentives for green innovation and promoting sustainable business practices. However, insufficient environmental disclosure may lead to misallocation of green capital, while strict green financing standards may also

increase enterprises' compliance costs, indicating that the promotional role of green finance is influenced by regulatory quality and information transparency. The introduction of the European Union's Corporate Sustainability Reporting Directive (CSRD) further underscores the importance of enhancing the transparency and reliability of sustainability disclosures. Based on this, we propose:

Hypothesis 2. *Green finance development policies play a mediating role between the establishment of pilot free trade zones and corporate green transformation.*

2.3. Spatial Spillover Effects of Pilot Free Trade Zones

The green development effects of free trade pilot zones are not limited to the regions where policies are implemented but may also spread to surrounding areas through regional economic linkages and the flow of factors of production. Existing research indicates that institutional openness can promote the cross-regional flow of capital, technology, and talent, thereby driving the diffusion of green technologies and optimizing resource allocation [27]. At the same time, green finance policies and environmental governance practices may improve the green development environment in surrounding regions through interregional policy learning and demonstration effects, thereby fostering corporate green technological innovation and sustainable transformation.

From the perspective of the mechanism of action, the environmental dividends of pilot free trade zones are not limited to the cities where policies are implemented. Green technologies, clean production practices, and green finance standards spread to surrounding areas through the flow of factors of production, industrial linkages, and knowledge spillovers among cities. Enterprises in surrounding cities may benefit from the radiating improvements brought by green institutions, even if no pilot free trade zone has been established locally. However, these spillover effects are constrained by geographical frictions. As distance increases, transportation costs, administrative boundaries, and the coverage of green finance networks all weaken policy effectiveness [28]. Based on this, we propose:

Hypothesis 3. *The promotional role of pilot free trade zones in corporate green transformation will generate positive spatial spillover effects on surrounding cities.*

3. Research Design

3.1. Sample Source

We select Chinese A-share listed firms over the period 2013–2024 as the research sample to investigate how the staggered launch of pilot free trade zones shapes corporate green transition. The phased rollout and regional heterogeneity inherent to pilot free trade zone policies create an ideal quasi-natural experiment setting, which facilitates the identification of the causal effect of institutional opening-up on corporate green transition. Firm-level financial, governance and operational indicators are mainly obtained from the CSMAR and Wind databases. Corporate green innovation metrics are compiled from listed firms' patent records and supporting databases, while firm ESG indicators come from mainstream ESG rating datasets. Regional economic, financial and environmental variables are primarily extracted from the China Urban Statistical Yearbook, China Regional Economic Statistical Yearbook, and public datasets released by the National Bureau of Statistics. Green finance indicators are matched according to regional green finance development conditions and local policy documents.

In terms of sample screening procedures, we first exclude firms operating within the financial and real estate industries. Second, we drop ST, *ST enterprises and entities suffering operational anomalies, and eliminate observations missing values on core variables. For all

continuous variables, we conduct winsorization at the 1st and 99th percentiles to mitigate the interference of outliers on regression estimates. This ultimately resulted in firm-year unbalanced panel data. We matched the firms' registered locations with the cities where the pilot free trade zones are located and determined the policy implementation time based on the year each batch of pilot free trade zones was officially established.

3.2. Model Specification

(1) Multi-period DID Model

Given that the pilot free trade zones were rolled out in phases across different geographic jurisdictions, this study employs a difference-in-differences (DID) framework to quantify the impact of these zones on firms' green transitions [29]. Considering that the research data include both firm and year dimensions, this paper adopts a two-way fixed-effects panel regression model, controlling for both firm and year fixed effects to reduce the interference of unobservable individual heterogeneity and common time shocks on the estimation results. The detailed model specification is as follows:

$$GreenTrans_{it} = \alpha + \beta FTZ_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

In the model, the dependent variable $GreenTrans_{it}$ represents the level of green transition for firm i in year t; the key independent variable FTZ_{it} takes the value 1 if a pilot free trade zone was established in the city where the firm is located in that year, and 0 otherwise; X_{it} represents firm-level control variables; The model includes firm-level fixed effects μ_i and year-level fixed effects λ_t, which capture, respectively, firm-specific characteristics that do not change over time and national-level time shocks; ε_{it} is the random error term.

The parameter β reflects the average treatment effect of establishing a pilot free trade zone on firms' green transition. If $\beta > 0$ and is significant, it indicates that the establishment of a pilot free trade zone promotes firms' green transition.

Given that this study employs a multi-period DID design, we further use event study methods to examine whether the treatment and control groups exhibited similar trends prior to policy implementation and to identify the dynamic changes in the policy effect:

$$GreenTrans_{it} = \alpha + \sum_{k \neq -1} \beta_k D_{it}^k + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

Here, D_{it}^k represents a dummy variable indicating the relative time of the city where the firm is located relative to the year the pilot free trade zone was established, with $k = -1$ serving as the base period. If β_k is generally not significant prior to policy implementation, this supports the parallel trends hypothesis.

(2) Mediation Mechanism Model for Green Finance

To examine whether green finance constitutes an important transmission channel through which free trade pilot zones influence firms' green transition, this paper further employs a mediation effect model. First, we examine the impact of the establishment of free trade pilot zones on the development of green finance:

$$GreenFinance_{it} = \alpha + \theta FTZ_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

Second, incorporate both green finance development and the free trade pilot zone variable into the corporate green transition model:

$$GreenTrans_{it} = \alpha + \beta FTZ_{it} + \delta GreenFinance_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

If θ is significant and the absolute value of the Free Trade Pilot Zone coefficient decreases after including the green finance variable, while δ is also significant, this indicates that green finance plays a mediating role in promoting corporate green transformation within the Free Trade Pilot Zone.

3.3. Variable Definitions

(1) Dependent Variable: Corporate Green Transition (GreenTrans)

Corporate green transition is the core dependent variable in this study. Drawing on existing research on corporate green innovation and green development performance [30,31], and considering the multidimensional nature of green transition, this study comprehensively measures the level of corporate green transformation across three dimensions: green technology innovation (GTI), environmental performance (EP), and ESG performance (ESG). First, green technology innovation (GTI) reflects the extent to which a company achieves greener production methods through technological progress. It can be measured by the number of green patent applications or granted patents, and further distinguishes between green invention patents and green utility model patents to identify differences in the quality of green innovation. Second, environmental performance (EP) reflects the extent to which a company's production and business operations contribute to environmental improvement; it can be measured using indicators such as pollutant emissions, carbon emission intensity, or resource and energy utilization efficiency. Together, these indicators reflect the effectiveness of a company's environmental management in areas such as pollution control, carbon emission reduction, and resource utilization. Finally, ESG performance (ESG) serves as a key supplementary indicator for green governance and sustainable operations. By integrating these three sub-dimension indicators (GTI, EP, and ESG), we can overcome the limitations of relying on a single indicator to comprehensively reflect a company's green transition and better identify the comprehensive impact of pilot free trade zones on enterprises' green development behaviors. The Enterprise Green Transition Index is calculated using the standardized entropy method:

$$GreenTrans_{it} = \sum_{j=1}^{m} w_j Z_{ijt} \tag{5}$$

Here, Z_{ijt} represents the standardized value of the jth green transition indicator, and w_j represents the weight of the corresponding indicator. The green transition indicator system for enterprises is shown in Table 1. For details on data sources, sample coverage, handling of missing values, and calculation of entropy weights for the indicators, see Appendix A.2.

(2) Key Explanatory Variable: Establishment of Pilot Free Trade Zones (FTZs)

The key explanatory variable in this paper is the policy on the establishment of pilot free trade zones. Drawing on existing research on the policy effects of China's pilot free trade zones [32], we construct dummy variables based on whether the city where the firm is registered is located within a pilot free trade zone and the year the policy was officially implemented:

$$FTZ_{it} = Treat_i \times Post_{it} \tag{6}$$

In this context, $Treat_i$ indicates whether the city where a firm is located falls within the coverage area of a pilot free trade zone; it takes the value 1 if the city is in a pilot area, and 0 otherwise. $Post_{it}$ represents a time-dependent dummy variable that varies depending on the timing of policy implementation. For pilot free trade zones established in phases, the policy implementation date is determined based on the actual year of approval for each region, thereby creating a multi-period DID treatment variable.

Table 1. Green Transition Indicator System for Enterprises.

Level 1 Dimension	Secondary Indicators	Metrics
Green Technology Innovation (GI)	Green Patent Applications	Logarithm of the number of green patent applications plus 1
	Green Invention Patents	Logarithm of the number of green invention patent applications plus 1
	Green Utility Model Patents	Logarithm of the number of green utility model patent applications plus 1
Environmental Performance (EP)	Pollution Emission Intensity	Pollutant emissions/Revenue
	Investment in Environmental Remediation	Environmental remediation expenditures/Revenue
	Energy Efficiency	Reciprocal of energy consumption per unit of output
Corporate Sustainability Performance (ESG)	ESG	ESG Composite Rating/Score

(3) Mediating Variable: Green Finance Development Policies (GreenFinance)

Green finance development policies are the mediating variable of primary focus in this study. They are used to examine whether pilot free trade zones, by encouraging local governments to improve the institutional framework for green finance and introduce supporting policies, thereby guide financial resources toward green projects and promote the green transformation of enterprises. Drawing on relevant research on the relationship between green finance policies and corporate green innovation [33,34]. Based on green finance policy documents issued by prefectural-level municipal governments and higher-level regulatory authorities, this study constructed a city-level green finance development policy intensity index covering three dimensions. Furthermore, the green finance development policy index is essentially a city-level variable; all enterprises within the same city share the same index value for a given year. In the empirical analysis, this study matches the city-year-level green finance index to firm-year observations based on the city of firm registration and the observation year, thereby enabling the inclusion of mediating variables in the firm-level regression framework. The three dimensions are constructed as follows:

(1) Policy quantity: the cumulative number of green finance-related policy documents issued by each prefectural-level city during the sample period; (2) Policy Level: Points are assigned based on the administrative level of the issuing authority—3 points for documents issued by provincial governments and departments, 2 points for those issued by municipal governments, and 1 point for those issued by municipal departments; (3) Policy Instruments: Policies are categorized into three types—market-based incentives, guidance and regulation, and capacity building—and counted separately to reflect the structural characteristics of policy instruments. Based on this, the entropy method is used to objectively weight the indicators across the three dimensions, thereby deriving a composite green finance development policy intensity index at the city-year level. According to the results of the entropy method, the weights for the three dimensions are as follows: 0.384 for the number of policies, 0.263 for the policy level, and 0.353 for policy instruments. A higher index value indicates that the green finance institutional framework provided by local governments is more comprehensive and that policy support is stronger. The indicator system for green finance development policies is shown in Table 2.

Table 2. Indicator System for Green Finance Development Policies.

Level 1 Dimensions	Secondary Indicators	Measurement Method	Weights
Number of Policies	Total Number of Policy Documents	Cumulative number of valid green finance policy documents applicable to cities as of the end of year t	0.384
Policy Level	Policy Strength	Calculate the weighted sum of applicable policies, with 3 points for provincial-level policies, 2 points for municipal government policies, and 1 point for municipal-level department policies	0.263
Policy Instruments	Tool Structure	Number of policy documents categorized as "Market Incentives," "Guidance and Regulation," and "Capacity Building" as of the end of year t	0.353

(4) Control Variables

To minimize the impact of differences in firm-specific characteristics on the estimation results, we further control for the following variables. Drawing on existing research on corporate green innovation, environmental performance, and the policy effects of pilot free trade zones [35–37], we select firm size, debt-to-asset ratio, profitability, firm growth, and equity concentration as control variables. (1) Firm size (Size) affects the ability to access resources, financing conditions, and investment in environmental governance; it is measured using the natural logarithm of total assets. (2) The debt-to-asset ratio (Lev) reflects the extent of a firm's debt financing and financing pressure; a higher leverage level may affect a firm's capacity for green investment, and it is measured as the ratio of total liabilities to total assets. (3) Profitability (ROA) determines a firm's internal capital accumulation and capacity for green investment; it is measured as the ratio of net income to total assets. (4) Firm growth (Growth) reflects a firm's operational expansion and development potential, which may influence innovation investment and willingness to transition toward sustainability; it is measured by the revenue growth rate. (5) Equity concentration (Top1) affects corporate governance efficiency and long-term investment decisions; it is measured by the largest shareholder's ownership percentage.

4. Empirical Results

4.1. Descriptive Statistics and Correlation Analysis

Table 3 presents the descriptive statistics for the key variables. The sample for this study covers Chinese A-share listed companies from 2013 to 2024, comprising 2862 firms from 157 cities; among these, 813 firms from 34 cities constitute the treatment group—firms located in cities subject to Free Trade Zone (FTZ) policy interventions. The entire sample consists of 32,146 firm-year observations. The mean of the firm green transition index (GreenTrans) was 0.312, with a standard deviation of 0.207; the minimum and maximum values were 0.021 and 0.896, respectively, indicating significant variation in the level of green transition across firms. The mean value of the Free Trade Pilot Zone policy variable (FTZ) is 0.284, indicating that approximately 28.4% of the sample observations are in the policy treatment group. The mean value of the green finance policy indicator (GreenFinance) is 0.342, with a standard deviation of 0.228, reflecting certain differences in the development levels of green finance policies across different regions. In terms of firm characteristics, variables such as firm size, capital structure, profitability, and growth potential all exhibit varying degrees of dispersion, indicating significant heterogeneity among the sample firms

in terms of operating conditions and resource endowments. Therefore, it is necessary to control for these firm characteristics in subsequent regression analyses.

Table 3. Descriptive Statistics for Main Variables (N = 32,146).

Variables	Definition	Mean	SD	Min	Max
GreenTrans	Corporate Green Transition Index	0.312	0.207	0.021	0.896
FTZ	Establishment of Pilot Free Trade Zones	0.284	0.451	0.000	1.000
GreenFinance	Policies for the Development of Green Finance	0.342	0.228	0.021	0.917
Size	Corporate Size	22.418	1.312	19.832	26.124
Lev	Debt-to-Asset Ratio	0.431	0.202	0.051	0.883
ROA	Profitability	0.042	0.056	−0.208	0.191
Growth	Corporate Growth Potential	0.152	0.318	−0.517	1.847
Top1	Concentration of Shareholding	0.342	0.148	0.085	0.719

To further examine the bivariate relationships among the variables, this paper presents the Pearson correlation matrix prior to the main regression analysis. The correlation analysis provides preliminary insights into the statistical relationships among free trade zone policies, green finance policies, and corporate green transformation. At the same time, the variance inflation factor (VIF) test is used to assess the degree of multicollinearity among the explanatory variables, thereby providing a basis for the subsequent regression analysis. The results in Table 4 show that the core explanatory variable, FTZ, is significantly positively correlated with the dependent variable, GreenTrans, at the 1% level, preliminarily indicating that the establishment of free trade zones helps enhance the level of corporate green transformation; the mediating variable, GreenFinance, is also significantly positively correlated with GreenTrans, suggesting that the development of green finance may positively empower corporate green transformation. Most firm-level control variables exhibit significant correlations with GreenTrans, confirming the necessity of including firm-level control variables in the regression analysis. In terms of correlation coefficients among the independent variables, the absolute values of the pairwise correlation coefficients for the vast majority of variables were below 0.5. Further VIF tests revealed that the maximum VIF value for all explanatory variables was 2.37, far below the critical value of 10, indicating that this study does not suffer from severe multicollinearity issues and that the model estimates are reliable.

Table 4. Pearson Correlation Matrix.

Variables	GreenTrans	FTZ	GreenFinance	Size	Lev	ROA	Growth	Top1
GreenTrans	1.000							
FTZ	0.142 ***	1.000						
GreenFinance	0.175 ***	0.413 ***	1.000					
Size	0.226 ***	0.128 ***	0.161 ***	1.000				
Lev	−0.083 ***	0.041 ***	0.052 ***	0.392 ***	1.000			
ROA	0.167 ***	0.025 ***	0.034 ***	0.071 ***	−0.364 ***	1.000		
Growth	0.054 ***	0.018 **	0.023 ***	0.047 ***	0.086 ***	0.281 ***	1.000	
Top1	0.031 ***	−0.024 ***	−0.037 ***	0.195 ***	0.062 ***	0.093 ***	0.014 *	1.000

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4.2. DID Baseline Regression

We estimate the benchmark regression with a multi-period DID model, incorporating firm and year two-way fixed effects and clustering standard errors at the firm level. Table 5 presents the estimation outcomes. Column (3) of Table 5 shows that after including covariates, the coefficient on the core explanatory variable, pilot free trade zone (FTZ) estab-

lishment, stands at 0.038 and is significantly positive at the 1% statistical level. In addition, the benchmark estimation results for the three sub-dimensions show that the coefficient for the establishment of pilot free trade zones on corporate green technological innovation is 0.031, which is significantly positive at the 1% significance level; the coefficient for environmental performance is 0.047, which is significantly positive at the 1% significance level; while the impact on improving ESG is relatively weaker, with a coefficient of 0.024, which is significantly positive at the 5% significance level. Overall, the coefficient for the environmental performance dimension is the largest, indicating that the promotional effect of FTZ policies on corporate green transformation is primarily driven by improvements in environmental performance and green technological innovation, rather than solely by changes in ESG ratings. This demonstrates that conditional on firms' time-invariant traits and annual macroeconomic shocks, FTZ establishment markedly raises corporate green transition levels. Accordingly, the institutional opening-up effects of pilot free trade zones extend beyond trade, investment and resource allocation, and create positive spillovers for firm green development. From an economic mechanism perspective, following the establishment of pilot free trade zones, the levels of marketization and institutionalization in the region have further improved, facilitating the flow of financial resources, technological factors, and green production factors [38]. On the one hand, institutional opening-up improves enterprises' access to external resources and reduces the information and transaction costs associated with green technology R & D, the upgrading of environmental protection equipment, and clean production retrofits. On the other hand, institutional innovations in pilot free trade zones may also encourage local governments to optimize their green development policy frameworks and guide financial institutions and social capital to pay greater attention to green projects and enterprises' environmental performance. Through the combined effects of these multiple channels, enterprises' investment in green innovation and their environmental governance practices are strengthened, thereby driving improvements in the level of green transformation.

Table 5. Baseline Regression Results.

Variables	(1) GreenTrans	(2) GreenTrans	(3) GreenTrans	(4) GreenTrans-GI	(5) GreenTrans-EP	(6) GreenTrans-ESG
FTZ	0.042 *** (8.40)	0.045 *** (7.50)	0.038 *** (7.60)	0.031 *** (6.52)	0.047 *** (5.84)	0.024 ** (2.31)
Size		0.031 *** (7.75)	0.025 ** (8.33)	0.033 *** (9.15)	0.021 *** (5.77)	0.026 *** (7.03)
Lev		−0.071 *** (−5.92)	−0.062 *** (−5.64)	−0.075 *** (−6.22)	−0.068 *** (−4.91)	−0.041 *** (−3.26)
ROA		0.203 *** (7.81)	0.185 *** (7.71)	0.162 *** (6.47)	0.214 *** (7.29)	0.188 *** (6.81)
Growth		0.014 ** (2.33)	0.012 ** (2.40)	0.015 ** (2.46)	0.011 * (1.83)	0.009 * (1.72)
Top1		0.053 *** (3.79)	0.048 *** (3.69)	0.051 *** (3.58)	0.044 ** (2.57)	0.032 ** (2.19)
Firm FE	Yes	No	Yes	Yes	Yes	Yes
Year FE	Yes	No	Yes	Yes	Yes	Yes
N	32,146	32,146	32,146	32,146	32,146	32,146
R^2	0.412	0.386	0.457	0.441	0.398	0.372

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

4.3. Parallel Trends Test and Treatment Effects on Heterogeneity

4.3.1. Parallel Trends Test

To verify the applicability of the multi-period DID model in this study and to examine the dynamic marginal effects of Free Trade Pilot Zone policies on corporate green transformation, we employed the event study method to construct a dynamic regression model

and conduct a parallel trends test, thereby avoiding estimation biases caused by pre-policy trend differences. The results of the parallel trends test are shown in Figure 1.

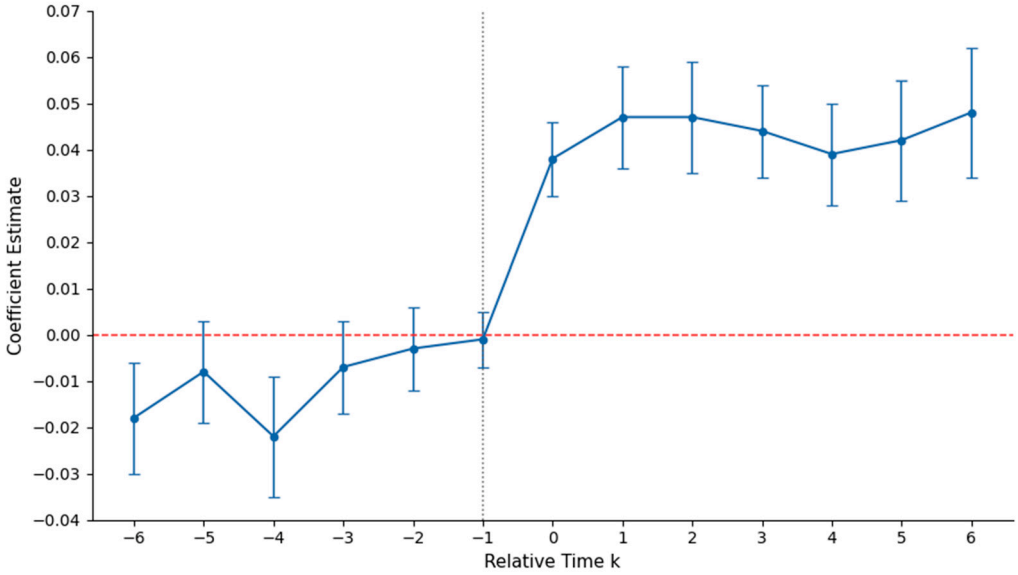


Figure 1. Results of the Parallel Trends Test.

Figure 1 shows the dynamic estimation results prior to policy implementation. During the period before the launch of the free trade pilot zone ($k < -1$), there were only slight fluctuations around zero. This pattern rules out the existence of any statistically significant pre-existing differences. In other words, enterprises located in pilot and non-pilot cities exhibited largely parallel green transition trajectories before FTZ policies took effect, without systematic divergence. Such evidence strongly supports the parallel trends assumption required for the difference-in-differences framework and validates our baseline regression estimates. Turning to post-policy dynamic effects, the policy coefficient becomes significantly positive starting from the implementation year ($k = 0$). This suggests that institutional opening-up dividends materialize promptly and lift corporate green transition levels right after policy rollout. From the first to the sixth period following policy implementation, the coefficient remained consistently and significantly positive, exhibiting an overall pattern of steady increase and gradual convergence. The reason for this is that in the early stages of the pilot free trade zones' establishment, the green business environment for enterprises was rapidly improved primarily through institutional liberalization and the facilitation of factor mobility; as the policy continued to be implemented, the regional green financial system was continuously improved, green regulatory mechanisms were continuously optimized, and social green investment continued to accumulate. The policy's empowering effects gradually deepened, continuously compelling and incentivizing enterprises to engage in green technological innovation, pollution control, and upgrades in green operations, thereby ensuring the long-term sustainability of the green transition effects [39].

4.3.2. Goodman-Bacon Decomposition and Robust Estimation of Heterogeneous Treatment Effects

Given that China's pilot free trade zones were established in batches, traditional two-way fixed-effects models may be subject to heterogeneity in treatment effects and the influence of inappropriate comparison groups. To enhance the reliability of causal identification, this paper further employs the Goodman-Bacon decomposition method to examine the comparison weights among different treatment-timing groups and their

contributions to the baseline estimation results. Building on this, this paper employs the group-by-time-averaged treatment effect estimation method proposed by Callaway and Sant'Anna (2021) [29] to re-examine the impact of the pilot free trade zones on corporate green transition. This method allows for heterogeneous treatment effects across different policy implementation batches and time periods, thereby avoiding biases that may arise from traditional two-way fixed-effects estimates.

The results of the Goodman-Bacon decomposition are shown in Table 6. The decomposition results indicate: First, the weight of the "never-treated group versus first-time-treated group" comparison accounts for 76.21%, with a corresponding within-group coefficient of 0.041; second, the weight of the "late-treated units as the control group versus early-treated units" comparison accounts for 23.79%, with this portion implying a partially negative weight and a corresponding within-group coefficient of 0.027. The overall weighting yields a benchmark TWFE coefficient of 0.038. The decomposition results indicate that valid comparisons are overwhelmingly dominant; the signs of the coefficients for both types of comparisons are consistent and both are significantly positive. No extreme cases of positive and negative values offsetting each other were observed. This preliminarily suggests that the direction of the benchmark TWFE estimate is of reference value, but the numerical value may still contain potential bias, which requires further confirmation through robust estimation.

Table 6. Goodman-Bacon decomposition results.

Comparison Groups	Weighting	Intra-Group Coefficient Contributions
Never-treated group vs. First-time-treated group	76.21%	0.041 ***
Late-treatment units as the control group vs. Early-treatment units	23.79%	0.027 **
TWFE Overall Weighting Coefficient	100%	0.038 ***

Note: *** and ** denote 1% and 5% significance levels, respectively.

Furthermore, this paper re-estimates the average treatment effect using the Callaway-Sant'Anna (CS) and Sun-Abraham (SA) heterogeneity-robust DID estimators [40,41]. Column (1) of Table 7 presents the baseline results using the traditional TWFE method; Column (2) shows the average treatment effect (ATT) estimated using the Callaway-Sant'Anna method; and Column (3) presents the results estimated using the Sun-Abraham method.

Table 7. Robust Estimation Results for Heterogeneous Treatment Effects.

Variables	(1) TWFE	(2) Callaway-Sant'Anna ATT	(3) Sun-Abraham ATT
FTZ	0.038 ***	0.033 ***	0.035 ***
	(7.60)	(6.71)	(6.94)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	32,146	32,146	32,146

Note: *** indicates a 1% significance level.

The average treatment effects (ATT) obtained from the two robust estimation methods are 0.033 and 0.035, respectively, both of which are significantly positive at the 1% level. Although these coefficients are slightly smaller than the TWFE baseline estimate of 0.038, their signs and significance levels remain highly consistent, demonstrating that the promotional effect of establishing pilot free trade zones on corporate green transformation is robust. The issue of negative weights arising from the mismatched treatment design does not alter the core conclusions of this paper. At the same time, this study re-estimates

the dynamic event study coefficients based on the CS and SA estimators. The dynamic coefficients for all periods prior to policy implementation are not significantly different from zero, supporting the parallel trends hypothesis; after policy implementation, the dynamic effects are significantly positive and gradually increase over time, with the dynamic pattern consistent with the overall trend observed in traditional TWFE event studies.

4.4. Sensitivity Analysis

4.4.1. Randomized Placebo Test

To exclude the concern that baseline estimates may stem from random noise or unobserved omitted variables, this paper implements a placebo test by constructing a randomly assigned fictitious treatment group. Concretely, we randomly draw a set of cities from the full city sample with the same quantity as real pilot cities to form a hypothetical treatment group. We further randomly allocate false FTZ implementation years to these selected cities, generate a simulated policy dummy variable, and rerun the baseline regression. This random sampling and estimation procedure is iterated 500 times, yielding 500 coefficient estimates and associated t-statistics for the fictitious policy shock.

The placebo results in Figure 2 indicate that the coefficients of these randomly assigned policy dummy variables roughly follow a normal distribution centered at zero, and nearly all estimates are not significant at the 10% significance level. In contrast, our true baseline coefficient of 0.038 lies in the right tail of this coefficient distribution. This evidence confirms that the positive effect of pilot free trade zones on corporate green transition cannot be explained by random chance or unobserved omitted variables, which verifies the robustness of our baseline findings.

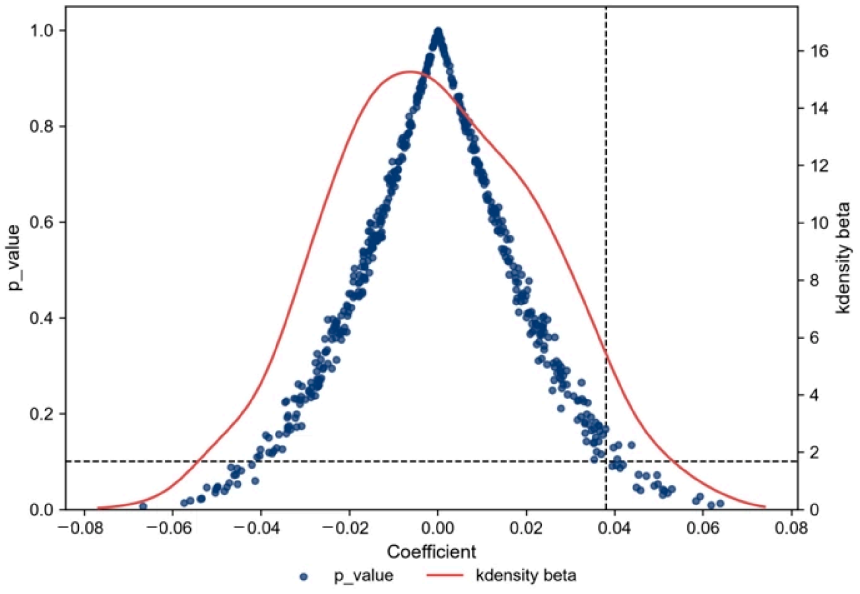


Figure 2. Results of the Placebo Test.

4.4.2. PSM-DID Estimation

Since the designation of pilot cities for free trade zones was not random, enterprises located in pilot and non-pilot zones may exhibit systematic differences in terms of firm size, operational characteristics, and developmental endowments. Such sample selection bias could contaminate the regression estimates. To mitigate this issue, this paper employs propensity score matching (PSM) for sample matching and uses the matched sample to re-estimate the multi-period DID model [42]. This paper selects firm size, return on total assets, debt-to-asset ratio, firm growth rate, and equity concentration as matching covariates.

Propensity scores are estimated using lagged covariates from the period prior to the policy shock to avoid the issue of covariates being distorted by the policy itself. This study employs a logit model to calculate the propensity scores for each firm, using the Epanechnikov kernel function with a bandwidth of 0.05. Through kernel matching, control group firms with propensity scores similar to those of the treatment group firms are matched, as shown in Table 8.

Table 8. Test for Covariate Balance (At the corporate level).

Covariates	Sample	Mean for the Treatment Group	Mean for the Control Group	Standardized Deviation (%)	Deviation Reduction Rate (%)
Size	Before matching	22.432	21.876	34.2	93.9
	After matching	22.395	22.361	2.1	
Lev	Before matching	0.468	0.513	27.5	91.2
	After matching	0.471	0.474	2.4	
ROA	Before matching	0.054	0.041	22.7	92.1
	After matching	0.052	0.051	1.8	
Growth	Before matching	0.186	0.142	25.1	93.6
	After matching	0.183	0.181	1.6	
Top1	Before matching	0.397	0.442	29.4	92.2
	After matching	0.395	0.392	2.3	

Table 8 reports the means, standardized deviations, and deviation reduction ratios for each covariate before and after matching. It can be seen that after matching, the standardized deviations of all covariates decreased significantly, all falling within 10 percent, with no systematic differences between the groups, thus meeting the balance requirements. To ensure the comparability of the two sample groups, this study applied a common support domain constraint, excluding observations whose propensity scores fell outside the common support interval; a total of 5254 observations were excluded.

It should be noted that the aforementioned tendency score matching only balanced the differences in characteristics between the treatment and control groups at the individual firm level; however, as a city-level policy shock, the selection of pilot cities for the Free Trade Zones is inherently highly selective. Judging from the list of China's approved Free Trade Zones, the selected cities are predominantly coastal port cities, provincial capitals, or regional trade hubs. These cities exhibit systematic differences from non-pilot cities in terms of port accessibility, industrial structure, foundations for opening up to the outside world, and the local institutional environment. If matching is based solely on firm-level characteristics, even if two firms are highly similar in terms of size, leverage, and profitability, differences between their respective cities along the aforementioned city-level dimensions may still persist in the sample, thereby posing a core identification threat.

To mitigate this issue, this paper—building upon firm-level nuclear matching—further collects and tests a series of city-level characteristics that may influence Free Trade Zone approval decisions, including: the city's level of economic development (lnGDP), port accessibility (lnPort), coastal port city status (PortCity), and administrative level (ProvCity). All of the above variables are drawn from the period immediately preceding the policy shock to avoid endogeneity arising from changes in city characteristics following policy implementation. Table 9 reports the between-group differences in the aforementioned city-level variables before and after matching.

Table 9. Covariate Balance Test (City Level).

Covariates	Sample	Mean for the Treatment Group	Mean for the Control Group	Standardized Deviation (%)	Deviation Reduction Rate (%)
lnGDP	Before matching	0.48	0.21	42.3	95.3
	After matching	0.46	0.45	2.0	
lnPort	Before matching	8.75	5.42	48.6	94.9
	After matching	8.60	8.56	2.5	
PortCity	Before matching	0.78	0.32	48.1	93.3
	After matching	0.75	0.73	3.2	
ProvCity	Before matching	0.65	0.22	45.7	93.9
	After matching	0.62	0.61	2.8	

The results in Table 9 show that, prior to matching, the cities in the treatment group had significantly higher levels of economic development and port accessibility than those in the control group, which is consistent with the Free Trade Zone selection criteria's emphasis on coastal ports, provincial capitals, and trade hubs. After double balancing for covariates at both the firm and city levels, the standardized deviations for all city characteristics fell within 10 percent. There were no longer any systematic differences between the treatment and control groups in terms of observable city characteristics prior to the intervention, thereby mitigating the impact of city-level selection bias on the estimation results.

Figure 3 displays the kernel density distributions of propensity scores before and after matching. The left-hand graph shows the propensity scores of the treatment and control groups before matching, revealing a clear difference between the two groups. The right-hand graph illustrates the distribution after matching; the propensity scores of the two groups show significant overlap, indicating satisfactory matching quality. Column (1) of Table 10 reports the PSM-DID regression results. The estimated coefficient for the Free Trade Zone (FTZ) is 0.035 and remains significantly positive at the 1% significance level; therefore, our core conclusion still holds.

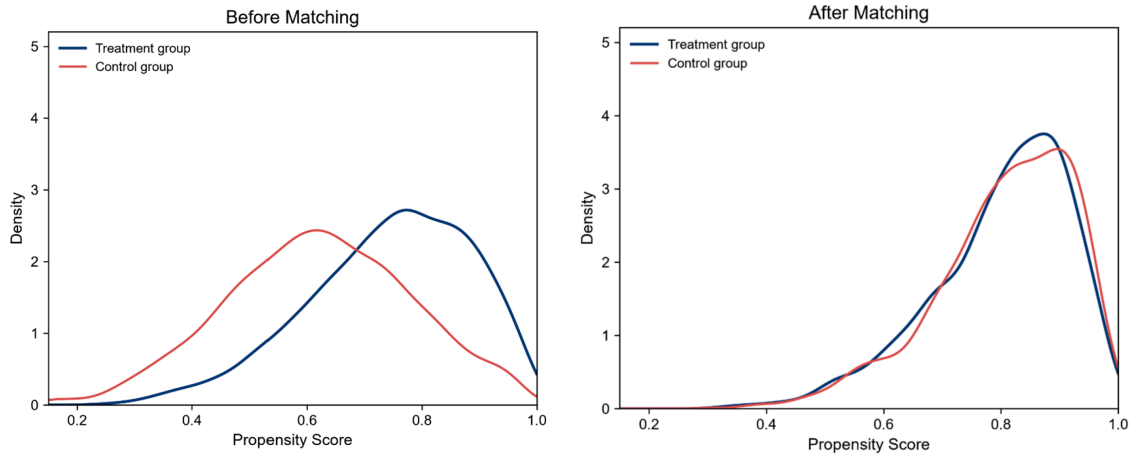


Figure 3. Matching Results for Corporate Preference Scores.

4.4.3. Replacing Core Variables

To avoid the impact of measurement bias on the empirical results, this study replaced the dependent variable and re-conducted the regression analysis. The indicator used to measure green technological innovation was replaced. Following standard practice in research on green innovation and environmental performance [43], the number of green

patents held by the firm was used in place of the number of applications, and the firm's green transition index was recalculated.

As shown in Column (2) of Table 10, after redefining the core research variables, the estimated coefficient for Free Trade Zones (FTZs) was 0.036 and remained statistically positive at the 1% significance level. Furthermore, the regression results for all control variables were highly consistent with the baseline results. These findings validate the core conclusion of this paper—that it is insensitive to variations in variable measurement methods—thereby further confirming the robustness of the research results.

4.4.4. Controlling for Concurrent Policy Interference

During the sample period, China simultaneously implemented multiple policies related to corporate green development, including pilot programs for green finance reform and innovation zones, carbon emissions trading pilots, and central environmental protection inspections. These policies may have simultaneously influenced firms' green transition, thereby masking the policy effects of the pilot free trade zones. To control for the interference caused by these concurrent policies, this study adopts the methodology from relevant research [44] by incorporating dummy variables for three types of policies (green finance pilot programs, carbon emissions trading pilot programs, and environmental protection inspections) into the baseline model and re-estimating the model after controlling for their effects on firms' green transition.

As shown in Column (3) of Table 10, after incorporating control variables for concurrent policies, the coefficient for the pilot free trade zones is 0.034 and remains statistically significant at the 1% level, while the coefficients and significance levels of the control variables remain largely unchanged. This evidence suggests that the promotional effect of free trade pilot zones on firms' green transition is a unique policy effect that cannot be attributed to other concurrently implemented green-related policies, further reinforcing the credibility of the baseline study's findings.

4.4.5. Adjusting the Estimation Specification

Given that free trade pilot zones constitute a city-level policy shock—where all firms within the same city share the same policy treatment status—firm-level clustered standard errors would overestimate the number of independent observation units, leading to biased statistical inferences. To address this, we conducted robustness tests across three mutually independent dimensions: (1) Adjusting the clustering level of standard errors from the firm level to the city level; changing the clustering level alters only the standard errors and t-statistics, without affecting the point estimates of the regression coefficients; (2) Excluding samples from municipalities directly under the central government to avoid interference from their unique administrative characteristics; (3) Using only balanced panel data regression to eliminate the effects of firm entry and exit present in unbalanced panel data. These three tests are mutually independent and are presented in columns (4), (5), and (6) of Table 10, respectively; the table also reports the number of clustering units corresponding to each column.

In Column (4) of Table 10, standard errors are clustered only at the city level; the point estimate for the FTZ coefficient is 0.038, unchanged from the baseline regression, and the t-statistic decreases to 4.83 but remains significant at the 1% level. Column (5) excludes samples from municipalities directly under the central government; the FTZ coefficient is 0.034 and is significantly positive. Column (6) is based on balanced panel regression; the FTZ coefficient is 0.040, which also passes the 1% significance test. The above results indicate that the core conclusions are not affected by the level of clustering of standard errors, specific samples, or panel structure, and the conclusions are robust.

Table 10. Regression Results of Robustness Tests.

Variables	(1) PSM-DID	(2) Replace DV	(3) Exclude Policies	(4) Clustering at the City Level	(5) Excluding Municipalities Directly Under the Central Government	(6) Balanced Panel
FTZ	0.035 *** (6.87)	0.036 *** (7.12)	0.034 *** (6.41)	0.038 *** (4.83)	0.034 *** (6.92)	0.040 *** (6.17)
Size	0.022 *** (7.46)	0.023 *** (7.79)	0.020 *** (7.11)	0.025 *** (4.97)	0.023 *** (7.41)	0.027 *** (7.05)
Lev	−0.056 *** (−5.03)	−0.058 *** (−5.30)	−0.054 *** (−4.77)	−0.062 *** (−3.81)	−0.057 *** (−5.18)	−0.068 *** (−5.24)
ROA	0.174 *** (7.08)	0.178 *** (7.31)	0.169 *** (6.74)	0.185 *** (4.62)	0.171 *** (7.04)	0.192 *** (6.88)
Growth	0.012 ** (2.16)	0.014 ** (2.29)	0.009 ** (1.98)	0.012 ** (1.96)	0.011 ** (2.14)	0.014 ** (2.21)
Top1	0.043 *** (3.27)	0.045 *** (3.46)	0.041 *** (3.04)	0.048 ** (2.52)	0.044 *** (3.31)	0.051 *** (3.44)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	26,892	32,146	32,146	32,146	27,018	21,374
R^2	0.448	0.452	0.460	0.457	0.449	0.471

Note: *** and ** indicate significance at the 1% and 5% levels, respectively.

4.5. Endogeneity Analysis

4.5.1. Instrumental Variables Method (2SLS)

To mitigate potential endogeneity issues associated with the establishment of pilot free trade zones, this paper uses an instrumental variable consisting of the interaction term between a city's road distance to the nearest major coastal port and the cumulative number of pilot free trade zones approved nationwide. This instrumental variable leverages the spatiotemporal variation arising from differences in cities' geographic locations and the phased expansion of pilot free trade zones at the national level to identify the relationship between policy implementation and corporate green transition. The validity of the instrumental variable requires satisfying both the correlation and exclusion constraints. Geographic location may influence the conditions under which cities participate in institutional opening, but the interaction term between port distance and the national policy expansion trend may also reflect differentiated development trends across regions in terms of trade liberalization, industrial structure, and environmental governance. Therefore, controlling only for firm and year fixed effects is insufficient to fully exclude the aforementioned potential effects [45,46].

Table 11 reports the results of the instrumental variable estimates. In column (2), the instrumental variable coefficient for the first stage is 0.31, significant at the 1% level, with a Kleibergen–Paap F-statistic of 89.36, indicating strong within-sample correlation for this instrumental variable. In column (3), the FTZ coefficient for the second stage is 0.035, significant at the 1% level, consistent in direction with the results of the baseline regression.

To further examine the validity of the exclusion of restrictions, this study supplements the analysis with a test of green transition trends prior to policy implementation and incorporates province-specific linear time trends into the two-stage regression to control for potential differences in long-term development trajectories across provinces. These tests aim to assess the sensitivity of the instrumental variable estimates to geographically correlated trends but cannot completely rule out other region-specific factors that vary over time. The results show that in Column (5), after incorporating province × year fixed effects, the coefficient decreases from 0.035 to 0.029. Both values remain significantly positive at

the 1% level; although the magnitude has decreased, the direction and significance of the policy effect remain unchanged. This indicates that coastal and inland enterprises did not exhibit divergent green transition trends prior to the policy, and the exclusion restriction hypothesis is not rejected based on the ex ante data. These findings confirm that, after effectively addressing potential endogeneity issues, the establishment of pilot free trade zones still plays a positive role in promoting the green transition of enterprises.

Table 11. Endogeneity Test Results.

Variables	(1) Benchmark Regression	(2) IV First	(3) IV Second	(4) One Issue Behind	(5) Provincial Trends IV
FTZ	0.038 *** (7.60)		0.035 *** (6.63)		
L.FTZ				0.036 *** (6.72)	
IV		0.31 *** (6.45)			0.029 *** (4.98)
Controls	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
K-P F statistic			89.36		
N	32,146	32,146	32,146	29,854	
R^2	0.457	0.408	0.451	0.449	

Note: *** indicates significance at the 1% level.

4.5.2. Lagged Explanatory Variables

Considering that the green transformation effects of pilot free trade zone policies may emerge with a time lag, and to alleviate potential reverse causality bias, this study incorporates the one-period lagged core explanatory variable (L.FTZ) into the regression model. As presented in Column (4) of Table 11, the coefficient of L.FTZ is 0.036 and significantly positive at the 1% statistical level. This outcome aligns with the baseline regression results, further verifying that the core research conclusions are not distorted by reverse causality and other potential endogeneity disturbances.

4.6. Mechanism Analysis

According to theoretical analysis, pilot free trade zones primarily influence corporate green behavior by improving the regional supply of green financial institutions and guiding green investment and financing; that is, green finance development policies play an intermediary role in this process. Building on this, green finance policies can further promote the green transition of enterprises through the following three channels: alleviating enterprises' financing constraints and attracting long-term institutional investors. This paper examines these mechanisms in turn.

4.6.1. Mediating Role of Green Finance Development Policies

To examine the potential transmission mechanisms through which the establishment of free trade zones influences corporate green transformation, this paper uses green finance development policies (GreenFinance) as a mediating variable and constructs a mediation model. Based on this, the statistical uncertainty of the indirect effects is assessed using the Bootstrap method.

Table 12 reports the basic regression results for the mediation test. Column (1) presents the results of the total effect regression, with the FTZ coefficient at 0.038, which is significantly positive at the 1% significance level. Column (2) uses green finance development policies (GreenFinance) as the dependent variable to test the impact of the establishment of

free trade zones on the mediating variable. The FTZ coefficient is 0.052, which is significantly positive at the 1% level, indicating that the establishment of free trade pilot zones can encourage local governments to improve the regional supply of green finance institutions and introduce supporting policies for green finance. Column (3) includes both FTZ and the mediating variable (GreenFinance); the coefficients for both variables are significantly positive at the 1% level, while the FTZ coefficient decreases from 0.038 to 0.029. It should be noted that GreenFinance primarily reflects the intensity of local green finance policy activities; the combined weight of the two indicators measuring the number of policy documents is 73.7%, which does not yet directly measure the actual scale of green financing. Therefore, the current results reflect more a statistical correlation between policy support and corporate green transformation than a strict causal relationship in the allocation of financing resources.

Table 12. Results of the Mediation Effect Test.

Variables	(1) GreenTrans	(2) GreenFinance	(3) GreenTrans
FTZ	0.038 *** (7.60)	0.052 *** (8.24)	0.029 *** (6.05)
GreenFinance			0.172 *** (7.38)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	32,146	32,146	32,146
R^2	0.457	0.412	0.463

Note: *** indicates significance at the 1% level.

To clearly present the results of the effect decomposition, this paper summarizes the total effect, direct effect, and indirect effect separately in Table 13, based on 5000 Bootstrap samples.

Table 13. Bootstrap Decomposition of the Mediating Effects of Green Finance Policies.

Effect Types	Effect Size	Proportion of Total Effect	Bootstrap 95% Confidence Interval
Total Effect	0.0380 ***	100%	[0.0284, 0.0476]
Direct Effect	0.0291 ***	76.6%	[0.0195, 0.0387]
Indirect Effect	0.0089 ***	23.4%	[0.0042, 0.0131]

Note: Bootstrap resampling was performed 5000 times; *** indicates significance at the 1% level.

As shown in Table 13, the total effect of FTZs on corporate green transformation is 0.0380, consisting of a direct effect of 0.0291 and an indirect effect of 0.0089. The indirect effect accounts for 23.4% of the total effect, with a 95% Bootstrap confidence interval of [0.0042, 0.0131]. Since the interval does not include 0, this indicates that green finance development policies exert a significant partial mediating effect. This suggests that Free Trade Zones not only directly promote corporate green transformation but also provide indirect support by optimizing the regional supply of green finance institutions and improving supporting green finance policies.

4.6.2. Testing the Transmission Channels

Having confirmed the intermediary role of green finance policies, this study further identifies their specific transmission channels at the micro level of firm behavior.

Table 14 presents the results of a two-stage regression analysis: the first stage examines the impact of the establishment of free trade zones (FTZs) on the variables in each channel; the second stage incorporates the channel variables into the baseline model and, while controlling for FTZs, tests the role of these variables in green transition, thereby identifying two micro-level transmission pathways.

Table 14. Results of the Channel Analysis.

Variables	(1) FC	(2) IO	(3) GreenTrans	(4) GreenTrans
FTZ	−0.043 *** (−6.89)	0.031 *** (5.94)	0.030 *** (5.82)	0.033 *** (6.41)
FC			−0.188 *** (−8.87)	
IOR				0.161 *** (6.57)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	32,146	32,146	32,146	32,146
R^2	0.441	0.405	0.465	0.461

Note: *** indicates significance at the 1% level.

(1) Alleviating financing constraints (FC). Green technology R&D and environmental protection investments are characterized by long cycles and slow returns; financing constraints are a key factor limiting firms' green transition. This study uses the SA index to measure the degree of firms' financing constraints and examines whether the establishment of Free Trade Zones (FTZs) alleviates these constraints through green finance policies, thereby promoting green transition [47]. The results for the first stage in Column (1) of Table 14 show that the coefficient for Free Trade Zones (FTZs) is −0.043, which is significantly negative at the 1% significance level, indicating that the establishment of free trade zones significantly alleviates firms' financing constraints. The results of the second-stage regression in Column (3) of Table 14 show that the coefficient for financing constraints (FC) is negative at the 1% significance level. This indicates that financing constraints exert a partial mediating effect: by leveraging regional green financial institutional innovations, FTZs broaden financing channels for enterprises' green projects, reduce financing costs, alleviate capital constraints on green investment, and ultimately empower the green transition.

(2) Attracting long-term institutional investors (IOR). Green finance policies rely on environmental disclosure and green rating systems to guide long-term capital toward corporate environmental performance. This study uses the proportion of shares held by institutional investors to measure the preferences of long-term capital and the extent of capital inflows [48]. In Column (3) of Table 14, the Free Trade Zone (FTZ) coefficient for the first phase is 0.031 and is significantly positive at the 1% significance level, indicating that the establishment of free trade zones significantly increased the proportion of shares held by institutional investors in firms. In Column (4), the IOR coefficient for the second phase is positive at the 1% significance level. This indicates that the improvement of green finance systems in free trade zones can attract long-term institutional capital, stabilize the supply of long-term funds to enterprises, and support their green transition.

4.7. Spatial Spillover Effects

To examine the cross-regional impacts of Free Trade Pilot Zone (FTZ) policies, this paper constructs a geospatial weighting matrix based on the reciprocals of spherical distances

between cities and uses it to calculate the weighted intensity of FTZ policies in neighboring cities (Neighbor_FTZ), while controlling for the policy effects of the firms' home cities [49]. After controlling for firm characteristics, firm fixed effects, and year fixed effects, we simultaneously include Neighbor_FTZ and FTZ in the regression model to examine the local effects of free trade pilot zone policies and their spatial correlations.

Column (1) of Table 15 reports the baseline regression results, while Column (2) further incorporates the Neighbor_FTZ variable. The results show that the coefficient for FTZ is 0.035, significant at the 1% level; the coefficient for Neighbor_FTZ is 0.021, significant at the 5% level. This indicates that Free Trade Pilot Zone policies are not only significantly associated with improvements in the level of green transition among enterprises in pilot cities, but that policy exposure in neighboring cities is also significantly and positively correlated with the green transition of local enterprises, providing empirical evidence for the potential spatial spillover effects of the policies.

Table 15. Results of the Spatial Spillover Effect Test.

Variables	(1) Benchmark Regression	(2) Spatial Spillover
FTZ	0.038 *** (7.60)	0.035 *** (7.02)
Neighbor_FTZ		0.021 ** (2.37)
Controls	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	32,146	32,146
R^2	0.457	0.459

Note: *** and ** indicate significance at the 1% and 5% levels, respectively.

Figure 4 further illustrates how spatial associations vary with geographic distance. As the distance between cities increases, the estimated coefficients generally show a downward trend, indicating that policy-related green transition effects exhibit a certain degree of spatial distance attenuation. This result is largely consistent with theoretical expectations regarding regional technology diffusion, industrial linkages, and factor flows [50].

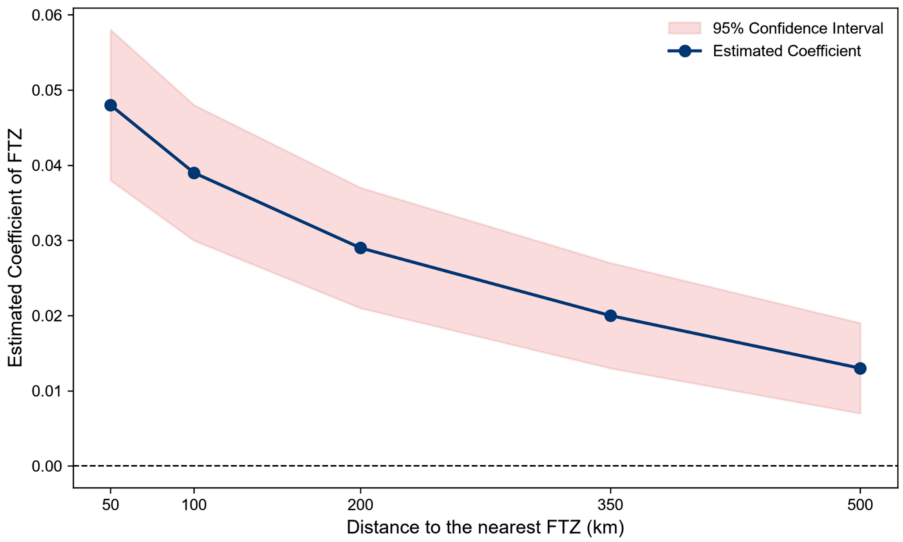


Figure 4. Spatial Spillover Decay by Distance.

Figure 4 illustrates how the policy effect varies with distance. It can be seen that within a short distance of 50 km from the pilot free trade zones, the free trade zone coefficient is approximately 0.048 and is statistically significant; as the distance increases, the estimated coefficient continues to decline, falling to about 0.02 when the distance exceeds 350 km, with the confidence interval widening significantly. This monotonically decreasing trend indicates that the driving effect of the pilot free trade zones on corporate green transformation is spatially uneven: enterprises located near the cities where the policy is implemented are better able to fully benefit from the environmental dividends brought about by institutional liberalization; conversely, enterprises in more distant regions face constraints such as factor mobility costs, technology diffusion barriers, and administrative boundaries, leading to a significant dilution of the policy dividends [50].

4.8. Heterogeneity Test

The benchmark results presented earlier reveal the average effect of the establishment of pilot free trade zones on corporate green transition; however, the policy impact may vary depending on differences in firms' pollution attributes and ownership characteristics. Therefore, we conduct a heterogeneity analysis based on two dimensions: industry pollution attributes and firm ownership.

4.8.1. Heterogeneity in Industry Pollution Attributes

Firms in highly polluting industries generate stronger environmental externalities, face stricter environmental regulations, and are subject to greater public pressure to adopt green practices; therefore, these firms may have greater potential for green transformation and higher policy sensitivity [51,52]. Based on the "Catalog of Industry Classification for Environmental Protection Audits of Listed Companies," this study categorizes the sample into highly polluting industries and non-highly polluting industries. Columns (1) and (2) of Table 16 present the results of the group-specific regressions. In the high-pollution industry group, the coefficient for the free trade zone is 0.052 and is significantly positive at the 1% significance level; whereas in the non-high-pollution industry group, the coefficient for the free trade zone is 0.024, significant only at the 5% significance level, and the coefficient is notably smaller. To identify the sources of industry heterogeneity, this paper further examines three dimensions: green technology innovation (GI), environmental performance (EP), and ESG. The results show that differences in policy effects are primarily concentrated in the environmental performance dimension, where the estimated coefficient for high-pollution industries is 0.068—significantly higher than the 0.026 for low-pollution industries—while the differences in the GI and ESG dimensions are relatively small. This suggests that the stronger response to green transition among high-pollution firms may primarily stem from their greater potential for improvement in environmental performance. The results of the between-group Wald test indicate a significant difference between the coefficients of the two groups ($z = 2.28$, $p = 0.023$). This suggests that the green transition effect of pilot free trade zones is stronger among enterprises in high-pollution industries. The reason lies in the fact that high-pollution enterprises have a stronger demand for environmental governance and are more responsive to green financing support; consequently, the green finance dividends resulting from institutional openness are more easily translated into emissions reduction investments and green innovation activities.

Table 16. Heterogeneity Test Results.

Variables	(1) High-Pollution Industries	(2) Non-High-Pollution Industries	(3) State-Owned Enterprises	(4) Privately Owned Enterprises
FTZ	0.052 ***	0.024 **	0.031 **	0.044 ***
	(7.13)	(2.43)	(2.51)	(6.76)

Table 16. *Cont.*

Variables	(1) High-Pollution Industries	(2) Non-High-Pollution Industries	(3) State-Owned Enterprises	(4) Privately Owned Enterprises
GI	0.024 *** (3.52)	0.019 ** (2.31)		
EP	0.068 *** (7.41)	0.026 ** (2.52)		
ESG	0.022 *** (2.89)	0.016 ** (2.08)		
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	11,842	20,304	13,786	18,360
R^2	0.472	0.431	0.438	0.461
Wald Test (z/*p*-value)	z = 2.28, $p = 0.023$		z = 0.93, $p = 0.352$	

Note: *** and ** indicate significance at the 1% and 5% levels, respectively.

4.8.2. Heterogeneity in Enterprise Ownership

State-owned enterprises (SOEs) and private enterprises exhibit systemic differences in terms of financing availability, access to policy resources, and risk-bearing capacity. Private enterprises typically face stricter financing constraints and are more sensitive to marginal improvements in financial support for green projects [52]. Therefore, we divided the sample into two groups—state-owned enterprises and private enterprises—based on the nature of their actual controllers. The regression results are shown in columns (3) and (4) of Table 16. The coefficient for the state-owned enterprise group is 0.031, which is significant at the 5% level; the coefficient for the private enterprise group is 0.044, which is a positive coefficient significant at the 1% level. Although the point estimate for the private enterprise group is higher, the Wald test between the two groups shows that the difference in coefficients is not statistically significant (z = 0.93, $p = 0.352$). This suggests that, based on the point estimates, the policies of the pilot free trade zones have a relatively greater promotional effect on the green transition of private enterprises; however, this difference between the two groups is not statistically significant.

5. Discussion

This study examines the impact of pilot free trade zones on corporate green transformation, focusing on the mediating role of green finance development policies, firm heterogeneity, and spatial spillover effects. The findings indicate that pilot free trade zones significantly promote corporate green transformation, suggesting that the policy benefits of institutional openness are not only reflected in trade growth and improved resource allocation efficiency but also in enhanced corporate environmental performance. This conclusion is consistent with the findings of Huang et al. (2025) [53] regarding the improvement of corporate green governance performance in FTZs and with those of Sun et al. (2025) [54] on how institutional openness promotes corporate green innovation. Yusufu and Lu (2024) [55] further provide relevant evidence from the perspective of corporate environmental, social, and governance (ESG) performance, indicating that institutional openness may influence corporate sustainability through multiple channels. However, Xu and Liu (2025) [56] point out that the promotional effects of pilot free trade zones on different types of environmental investments vary, indicating that institutional openness does not necessarily lead to comprehensive environmental improvements. Therefore, the green transformation effects of pilot free trade zones depend on whether institutional inno-

vations can be effectively translated into corporate green investments and environmental governance capabilities.

Green finance development policies play a partial mediating role between free trade pilot zones and corporate green transition, suggesting that the allocation of green financial resources may be a key channel through which institutional openness promotes corporate green development. However, the actual effects of green finance are not always positive. Liang et al. (2025) [57] argue that green finance helps curb corporate "greenwashing," while Huang et al. (2025) [58] and Hu et al. (2025) [59] found that green finance reforms may also induce strategic environmental disclosure. This suggests that while green finance policies alleviate financing constraints, they still need to strengthen environmental information disclosure and regulation to prevent enterprises from substituting substantive environmental improvements with merely formal green commitments.

The firm-level heterogeneity in the green transition effects of pilot free trade zones further reveals the uneven distribution of benefits from institutional liberalization policies. Pilot free trade zones have a more pronounced promotional effect on the green transition of highly polluting firms and private enterprises. This may be because highly polluting firms face greater pressure to address environmental governance, while private enterprises are more sensitive to improvements in the financing environment. It is worth noting that Yusufu and Lu (2024) [55] found that free trade pilot zones had a more pronounced promotional effect on the green transition of non-heavily polluting enterprises and state-owned enterprises, which differs from the heterogeneity findings in this study. This suggests that policy effects may be influenced by differences in the sample period, firm characteristics, and green transition indicators, further highlighting the necessity of conducting heterogeneity analyses.

Spatial spillover effects further reveal the regional transmission characteristics of green development benefits from free trade pilot zones. These zones can promote the green transition of enterprises in surrounding areas, and the positive spillover effects weaken as geographic distance increases. This aligns with the findings of Xu and Liu (2025) [56] regarding the spatial spillovers of free trade zone policies on green productivity. This may be attributed to the diffusion of green technologies, industrial linkages, and the demonstration effect of policies; however, barriers to cross-regional factor flows may also limit the dissemination of policy benefits. Therefore, regional cooperation in green finance and the exchange of green technologies should be strengthened to facilitate the diffusion of environmental benefits resulting from institutional openness to surrounding areas.

6. Conclusions

Based on a quasi-natural experiment involving the phased establishment of pilot free trade zones, this study constructs a multi-period difference-in-differences model to systematically examine the impact of pilot free trade zones on corporate green transition and its underlying mechanisms. The results indicate that the catalytic effect of pilot free trade zones on corporate green transition stems not only from direct incentives resulting from deregulation and the free flow of production factors, but also from their deeper-level impact in driving local governments to build green financial systems. In this process, alleviating financing constraints and attracting long-term capital constitute two mutually supportive and reinforcing transmission channels that together shape the microfoundations of corporate green transformation. The study also reveals that the environmental effects of pilot free trade zones are not uniformly distributed.

From a spatial perspective, although policy dividends radiate from pilot cities to surrounding areas, their effects diminish with increasing distance due to constraints imposed by the costs of factor mobility and the boundaries of technology diffusion; from the perspec-

tive of economic agent heterogeneity, policy effects are more pronounced among enterprises in high-pollution industries. Such enterprises face stronger environmental externalities and more severe financing constraints, and are therefore more sensitive to policy shocks from free trade zones. This implies that the green transition effects resulting from institutional liberalization will not materialize automatically; their extent depends largely on the absorption capacity of local financial markets and the enterprises' own endowments for transformation. This paper theoretically enriches research on the relationship among institutional liberalization, green finance, and corporate green transition, and practically offers policy insights for refining green finance policies, optimizing resource allocation, and promoting synergy between economic openness and environmental sustainability.

Based on the above conclusions, this paper proposes the following policy recommendations. First, further deepen institutional opening-up in pilot free trade zones and expand the replication and promotion of green finance reform and innovation experiences. Pilot free trade zones should continue to be granted greater autonomy in reforming areas such as green credit, green bonds, and environmental rights trading, to promote the nationwide adoption of green finance policies and fully unleash the green transition dividends of institutional opening-up [60,61]. Second, it is essential to optimize the policy transmission mechanism of green finance, with a key focus on easing the financing constraints of small and medium-sized enterprises (SMEs) and private firms. Given the more prominent policy effects on these enterprises, governments should further improve supporting systems including green re-lending, risk compensation mechanisms and information disclosure regulations. These improvements can reduce information asymmetry and transaction costs in green financing, thereby encouraging financial institutions to scale up credit support for green SMEs [62–64]. Third, strengthen cross-regional green coordinated development and fully leverage the spatial spillover effects of pilot free trade zones. Given that policy effects diminish with distance, efforts should be made to extend the green institutional experiences of pilot free trade zones to surrounding and inland regions through means such as exclave economies, industrial relocation, and regional green finance cooperation, thereby avoiding the uneven spatial distribution of policy benefits [65]. Fourth, integrate the development of pilot free trade zones with environmental regulations and industrial upgrading policies to create synergies. Enterprises in heavily polluting industries have significant room for green transformation. Within the framework of pilot free trade zones, efforts should be made to combine the elevation of environmental standards with green financial support, thereby creating a combined policy effect of market incentives and compliance pressures to guide enterprises in heavily polluting industries to accelerate their green transformation [66].

This paper still has the following limitations, which require further exploration in future research. First, due to limitations in data availability, this study's measurement of green finance development policies is primarily based on the number, hierarchical level, and instrumental dimensions of policy texts. Future research could incorporate microdata—such as the actual volume of green credit disbursements and the implementation status of green projects—to more accurately characterize the intensity of policy implementation. At the same time, this study employs a staggered multi-period DID estimation method. The staggered design estimates are subject to potential identification bias arising from heterogeneous treatment effects, and the reliability of cluster-level inferences depends on a limited number of clusters of treated cities. Second, this study primarily examines green transition at the firm level and does not further distinguish between differentiated transition pathways such as end-of-pipe treatment, clean production, and green product innovation. The mediation analysis suffers from a "post-treatment conditioning" issue: since the mediating variable is affected by the policy shock, conditioning the mediating variable on post-treatment states can lead to estimation bias, and the causal interpretation of the mediation path should

be interpreted with caution. Third, the spatial spillover analysis employs a geographic distance-weighted matrix; in the future, economic distance, technological distance, and industrial linkage weights could be introduced to optimize the network representation. Furthermore, the policy-induced spatial spillover effects identified in this study may cause contamination of the control group, violating the SUTVA assumptions and interfering with the DID identification framework. Fourth, the sample period of this study ends in 2024. As pilot free trade zones continue to expand and high-level openness platforms such as the RCEP and CAI advance, the interactive relationship between institutional openness and corporate green transformation remains in a state of dynamic evolution. Future research could extend the sample window to examine the long-term evolution of policy effects.

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Appendix A. Data Notes for the Corporate Green Transition Index

Appendix A.1. Data Sources and Coverage

To verify the availability of data for the seven indicators, Table A1 reports the data sources and sample coverage for each indicator. The three patent indicators in the Green Technology Innovation dimension are sourced from the patent search database of the China National Intellectual Property Administration and the CSMAR patent sub-database. In the Environmental Performance dimension, data for the three indicators—pollutant emission intensity, environmental remediation investment, and energy efficiency—are sourced from the environmental database of the China Research Data Service Platform (CNRDS), the Pollution Source Supervision Information Platform of the Institute of Public and Environmental Affairs (IPE), and the social responsibility reports of listed companies. Corporate ESG data is sourced from the Huazheng ESG Rating Database. The 32,146 firm-year observations ultimately included in the regression analysis constitute the complete sample following the completion of the indicator synthesis; missing values were uniformly handled during the synthesis process.

It should be noted that the three patent indicators in the green technology innovation dimension have a high coverage rate, ranging from 76% to 89%, with few missing values; in contrast, the proportion of investment in environmental governance (67.3%) and the pollution emission intensity ratio (68.5%) in the environmental performance dimension have significant missing values, and the ESG ratio (84.7%) also has a certain proportion of

missing values. For the missing observations mentioned above, this study uses industry- and year-level averages for interpolation.

Table A1. Data Sources and Coverage of Corporate Green Transition Indicators.

Level 1 Dimension	Secondary Indicators	Data Sources	Coverage (%)
Green Technology Innovation (GI)	Green Patent Applications	National Intellectual Property Administration Patent Database, CSMAR Patent Sub-database	89.2
	Green Invention Patents		82.6
	Green Utility Model Patents		76.4
Environmental Performance (EP)	Pollution Emission Intensity	CNRDS Environmental Database, IPE Pollution Source Monitoring Platform	68.5
	Investment in Environmental Remediation	CNRDS Environmental Database, Social Responsibility Reports of Listed Companies	67.3
	Energy Efficiency	CNRDS Environmental Database, Energy Statistics	71.8
Corporate Sustainability Performance (ESG)	ESG	CNRDS Environmental Database, IPE Pollution Source Monitoring Platform, Huazheng ESG Rating Database	84.7

Note: Coverage refers to the proportion of enterprise-years with non-missing observations for each indicator out of the total sample (32,146).

To examine the impact of the interpolation process on the baseline findings, this paper retains only those firm-year observations in the subsample where all seven indicators have actual observed values and re-estimates the baseline DID model. This complete subsample consists of 3761 observations, and the regression results are shown in Table A2.

Table A2. Baseline Regression for the Complete Observation Subsample with All Indicators.

Variable	(1) Full Sample (Baseline)	(2) Full Subsample
FTZ	0.038 *** (7.60)	0.036 *** (5.12)
Control Variable	Yes	Yes
Firm FE	Yes	Yes
Year FE	Yes	Yes
N	Yes	Yes
R^2	32,146	18,419

Note: *** indicates significance at the 1% level; values in parentheses are t-values.

The results in Table A2 show that, after excluding all observations containing interpolated values, the FTZ coefficient is 0.036, which remains significantly positive at the 1% level and is essentially consistent with the full-sample estimate of 0.038 in terms of both economic magnitude and statistical significance. This indicates that the interpolation of industry-year averages did not systematically distort the conclusions of the baseline regression, and that measurement bias in the green transition index has a limited impact on the core findings.

Appendix A.2. Missing Value Handling and Entropy Weighting

Before applying entropy weighting, this study handles missing values separately for each of the three sub-dimensions. The Green Technology Innovation sub-dimension had no missing values; in the Environmental Performance sub-dimension, for firms that did not disclose data on pollutant emissions, environmental protection expenditures, and energy consumption, publicly available data from the CNRDS and IPE platforms were used to fill in the gaps whenever possible, and any remaining missing observations were imputed using the average values for the same industry and year; in the ESG sub-dimension, missing observations were imputed using the average values for the same industry and year. The above processing was used solely for the construction of the composite index and did not affect the actual disclosure practices of non-disclosing firms. Subsequently, the completed indicators were standardized using the range method and objectively weighted using the entropy weighting method to obtain entropy weights for the seven indicators (see Table A3). The index was calculated as the weighted sum of the standardized indicators and their corresponding weights; a higher index value indicates a higher level of corporate green transformation.

Table A3. Entropy Weights for the Corporate Green Transformation Index.

Level 1 Dimension	Secondary Indicators	Entropy Weight	Total Sub-Dimension Weights
Green Technology Innovation (GI)	Green Patent Applications	0.158	0.421
	Green Invention Patents	0.142	
	Green Utility Model Patents	0.121	
Environmental Performance (EP)	Pollution Emission Intensity	0.152	0.436
	Investment in Environmental Remediation	0.138	
	Energy Efficiency	0.146	
Corporate Sustainability Performance (ESG)	ESG	0.143	0.143

Note: The entropy-weighted method objectively assigns weights based on the dispersion of the sample after standardizing each indicator by its range; the sum of the weights for the seven indicators equals 1.

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