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Enterprise Green Transition, Pollution Mitigation, and Financing Constraints

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Abstract

Amidst the deepening implementation of China's "Dual Carbon" national strategy, this study integrates the Natural Resource-Based View with financing constraint theory to investigate the pollution mitigation effects of corporate green transition. Utilizing textual analysis on panel data from heavily polluting A-share listed companies (2013-2022), we develop a multidimensional green transition index and employ fixed-effects regression models. Key findings reveal: (1) Corporate green transition demonstrates significant marginal improvement effects on pollution abatement, with enhanced efficacy observed in firms facing stringent environmental regulations; (2) Financing constraints exhibit substantial negative moderating effects on the green transition-pollution reduction nexus. Theoretically, this research advances micro-level understanding of environmental governance economics. Practically, it provides empirical support for optimizing transition finance instruments and calibrating environmental regulation intensity gradients.

Keywords

Enterprise Green Transition; Pollution Mitigation; Financing Constraints.

1. Introduction

Against the backdrop of accelerated global climate governance, environmental imperatives have evolved from consensus to concrete policy implementation. The IPCC Sixth Assessment Report reveals that industrial activities contribute 72% of global greenhouse gas emissions, elevating surface temperatures by 1.07°C above pre-industrial levels-approaching the critical 1.5°C threshold [1]. This environmental crisis is reshaping global governance frameworks, with World Bank (2023) data indicating that 89 nations have legislated carbon neutrality targets, positioning green development as a cornerstone of economic restructuring.

As the world's largest carbon emitter, China formally introduced its dual-carbon strategy in 2020, systematically deploying green transition pathways through successive Five-Year Plans. These initiatives emphasize advancing green technological innovation and facilitating low-carbon transformation in key industries-a policy orientation that not only aligns with high-quality development imperatives but also imposes stricter environmental governance standards on heavily polluting enterprises [2]. Under tightening ecological constraints, resolving the "high-input, low-efficiency" environmental paradox and achieving synergistic improvements in pollution reduction and economic returns present critical challenges for these enterprises. Current academic research exhibits theoretical gaps in explaining corporate emission reduction mechanisms. While technological determinism emphasizes the pollution-abating effects of clean technologies, it fails to account for environmental performance disparities under homogeneous technological conditions. Similarly, institutional theory focuses on regulatory pressures but inadequately integrates financial markets' capital allocation functions [3]. In reality, corporate green transformation constitutes a systemic engineering process encompassing technological innovation, institutional adaptation, and capital

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reconfiguration, involving multidimensional changes in managerial cognition, environmental investment decisions, and production process optimization [4]. Enterprises adopting cleaner production systems not only reduce emission intensity but also generate new profit streams through resource circularity, achieving dual environmental-economic dividends.

This study addresses two critical research gaps: First, by developing multidimensional green transformation indicators through big data text analysis of corporate annual reports, we transcend the limitations of conventional financial metrics in capturing strategic commitment and organizational change. Second, our identification of the negative correlation between financing constraint intensity and pollution abatement effectiveness provides theoretical foundations for resolving green financing dilemmas. Empirical findings from heavily polluting industries demonstrate that financial constraints significantly moderate the emission reduction effects of green transformation, with practical implications for optimizing green financial instruments and policy design.

2. Mechanism Analysis and Research Hypothesis

2.1. Corporate Green Transformation and Pollution Reduction

Corporate green transformation, as an innovative practice strategically guided by sustainable development theory, fundamentally involves reconstructing technological and managerial paradigms to establish a sustainable model that integrates green retrofitting across production processes and minimizes industrial emissions [5, 6]. Distinct from the unidimensional technological substitution in traditional industrial upgrades, green transformation enhances environmental performance and reduces pollution through the following pathways:

Green Technology Innovation: Serving as the core driver, it breaks path dependency on conventional technologies through R&D in clean production processes and low-carbon equipment upgrades. Accelerating the iteration of old and new technologies, combined with lifecycle assessment methods, optimizes production workflows and significantly reduces pollution intensity per unit output.

Circular Economy Integration: By establishing green supplier screening mechanisms and implementing closed-loop material management and waste valorization, this approach generates systemic emission reduction effects.

Comprehensive Governance System: Increased investment in clean technologies compels upgrades in pollution control systems, forming a full-chain emission reduction framework spanning “source prevention, process control, and end-of-pipe treatment.” The integration of environmental risk early-warning systems and real-time emission monitoring further reduces pollution incident [7]. As such, the following hypotheses are constructed.

Hypothesis 1.: The degree of corporate green transformation exhibits a negative correlation with pollution

2.2. Green Transformation, Pollution Mitigation, and Financing Constraints

External financing constraints critically influence corporate behavior, particularly in highly polluting industries. As Sun and Li (2023) demonstrate [8], financing constraints inhibit environmental performance during green transitions through three mechanisms:

Financing Accessibility: Green innovation projects face severe information asymmetry due to their high-risk, long-cycle, and uncertain-return characteristics [9]. This forces firms to rely on volatile internal financing, exposing them to cyclical cash flow shortages that disrupt R&D continuity and reduce innovation efficiency [10].

Cost Premiums: Environmental innovation projects bear 20-35% higher financing costs than conventional projects, driven by risk assessment premiums and compensation requirements from financial institutions. This cost escalation creates a “financing cost-risk exposure” spiral,

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crowding out R&D budgets and potentially triggering financial instability, which delays clean technology adoption and weakens end-of-pipe governance.

Resource Misallocation: Under acute financing constraints, managerial myopia incentivizes allocating limited capital to short-term profitable activities rather than environmental investments with positive externalities [11]. This prioritization exacerbates pollution emissions and undermines environmental performance. As such, the following hypotheses are constructed.

Hypothesis 2. Financing constraints negatively moderate the relationship between green transformation and pollution reduction, with stronger constraints weakening the marginal emission reduction effects of green initiatives.

3. Study Design

3.1. Data

This study focuses on A-share listed companies in 16 heavy-polluting industries (including thermal power, steel, cement, aluminum electrolysis, coal, metallurgy, chemicals, petrochemicals, building materials, papermaking, brewing, pharmaceuticals, fermentation, textiles, leather, and mining) from 2013 to 2022 [12]. After data cleaning and matching, the final dataset comprises an unbalanced panel of 2,612 firms with 18,287 firm-year observations. Table 1 reports descriptive statistics. Corporate green transition metrics were constructed through textual analysis of annual reports. Financial data were sourced from the CSMAR database, while environmental indicators were integrated from the *China Energy Statistical Yearbook* and the CNRDS platform.

3.2. Variable Definitions

3.2.1. Dependent Variable

Following Wu Qingyang [13] and grounded in the theory of environmental cost internalization, this study measures pollution emission intensity(PE) as the ratio of corporate pollution discharge fees to total operating revenue. Pollution discharge fees are calculated as:

$$PC_{i,t} = \sum_j^3 \tau_j \times G_{ij,t} + \sum_j^3 \tau_j \times L_{ij,t} + \sum_j^3 \tau_j \times S_{ij,t}. \tag{1}$$

$$PE_{i,t} = \frac{PC_{i,t}}{OR_{i,t}} \tag{2}$$

where τ_j represents the emission coefficients for air pollutants, water pollutants, and solid waste. Following the *Pollutant Discharge Fee Collection and Management Regulations (2003)*, $G_{ij,t}$, $L_{ij,t}$, $S_{ij,t}$ denote the official fee standards for corresponding pollutant types. A provincial-level penalty factor for excess emissions is introduced, implementing fee multipliers for enterprises exceeding regional average emission levels. By dividing the computed $PC_{i,t}$ by annual operating revenue $OR_{i,t}$, we obtain pollution emission intensity $PE_{i,t}$.This metric quantifies environmental externalities per economic output unit, with higher values indicating poorer environmental performance.

3.2.2. Core Explanatory Variables

Building on Zhou [14] and Loughran & McDonald's [15] text analysis methodology, we develop a multidimensional green transition index (GTR) using annual report disclosures. Conventional approaches relying on green patents or environmental investments inadequately capture strategic and managerial dimensions of transition, particularly in service industries. While composite indices constructed via entropy methods risk subjective weighting bias, textual

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analysis leverages mandatory disclosure formats to mitigate measurement errors and track dynamic strategic shifts.

Guided by policy documents including 'the *12th Five-Year Plan*' and *China Manufacturing 2025*[16-19], we establish five evaluation dimensions: green advocacy, strategic orientation, technological innovation, pollution control, monitoring systems[20]. Using natural language processing (NLP) techniques, we compile a specialized lexicon containing 113 keywords from standardized policy texts. We construct a green transformation term frequency index, then take the natural logarithm of the term frequency count plus one to quantify the degree of green transformation. Higher GTR values reflect more substantive green transition efforts.

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GTR	18287	5.8040	0.9654	2.1928	6.9414
Soe	18287	3.6081	0.7676	2.1034	5.3218
Ins	18287	0.3059	0.4608	0.0000	1.0000
Board	18287	41.9239	24.9107	0.0001	101.1401
Lev	18287	2.1119	0.1931	1.6094	2.6391
ROA	18287	0.4047	0.1879	0.0625	0.8534
SA	18287	0.0388	0.0604	-0.2193	0.2000

3.2.3. Control Variables

Following existing studies on the green transformation [21], five control variables, namely Financial leverage (*Lev)*, Ownership nature (*Soe)*, Profitability (*ROA*), Institutional ownership (*Ins*), Board size (*Board*) are selected to examine the factors that cannot be controlled for. All definitions of the variables are listed in Table 2.

3.3. Model Settings

To investigate the impact of corporate green transformation on pollution reduction, we establish the following baseline model:

$$PE_{it} = \theta + \sigma GTR_{it} + \gamma X_{i,t} + \lambda_t + \mu_i + \varepsilon_{it} \tag{3}$$

Where PE_{it} denotes the pollution emission reduction of firm i in year t, GTR_{it} represents the green transformation index of firm i in year t, and $X_{i,t}$ includes a set of control variables: ownership type, institutional ownership percentage, board size, financial leverage ratio, and profitability. To mitigate potential omitted variable bias and account for unobserved heterogeneity, we employ a two-way fixed effects model based on the Hausman test results. Here, λ_t captures year-specific fixed effects, μ_i denotes firm-specific fixed effects, and ε_{it} is the idiosyncratic error term.

To examine the moderating role of financing constraints, we extend the baseline model by introducing an interaction term:

$$PE_{it} = \theta + \sigma GTR_{it} + \alpha SA_{it} + \beta SA_{it} \times GTR_{it} + \gamma X_{i,t} + \lambda_t + \mu_i + \varepsilon_{it} \tag{4}$$

In this extended specification, SA_{it} measures the financing constraints faced by firm i in year t, and the coefficient β on the interaction term $SA_{it} \times GTR_{it}$ captures how financing constraints modulate the relationship between green transformation and pollution reduction.

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Table 2. variables definitions.

Variable name	Variable symbol	Variable definition
pollution emission intensity	*PE*	Pollution Discharge Fees / Total Operating Revenue
Green Transition	*GTR*	Ln(Frequency of Green Transition Keywords in Disclosures +1)
State Ownership	*Soe*	Dummy variable (1 for state-controlled firms, 0 otherwise)
Institutional Ownership	*Ins*	Total Shareholding Percentage by Institutional Investors
Board Size	*Board*	Ln(Number of Board Members)
Leverage Ratio	*Lev*	Total Liabilities / Total Assets
Return on Assets	*ROA*	Net Profit / Average Total Assets

4. Results and Discussion

4.1. Baseline Regression Results and Discussion

The benchmark regression results presented in Table 4-1 validate research hypothesis H1 through a three-tier verification system constructed via stepwise regression. Column (1), controlling solely for time and individual fixed effects, reveals a *GTR* coefficient of -0.039, indicating that a one-unit increase in green transition intensity reduces pollution emission intensity by 3.91%. Column (2) and (3) progressively incorporate governance structure variables and financial control variables respectively, with coefficients remaining negative and statistically significant at the 1% level. The stability of coefficients across three specifications and their statistical significance collectively suggest that corporate green transition may improve environmental performance through technological innovation, process optimization, and circular economy practices.

Table 3. variables definitions.

Variable	(1)	(2)	(3)
GTR	0.0391***	-0.0387***	-0.0388***
	(0.0147)	(0.0147)	(0.0147)
Soe	*GTR*	0.1126**	0.1160**
		(0.0540)	(0.0538)
Ins	*Soe*	-0.0019**	-0.0020**
		(0.0009)	(0.0009)
Board	*Ins*	0.0806	0.0823
		(0.0788)	(0.0789)
Lev			-0.1168
			(0.0878)
ROA			0.0331
			(0.1679)
Constant	5.9452***	5.8199***	5.8659***
	(0.0529)	(0.1744)	(0.1787)
Year FE	YES	YES	YES
Company FE	YES	YES	YES
Observations	18,287	18,287	18,287
Adjusted R^2	0.032	0.032	0.032

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

Control variables exhibit differentiated impacts: A 10-percentage-point increase in institutional investor ownership reduces pollution intensity by 0.20%, confirming the effectiveness of ESG monitoring mechanisms. Although financial leverage *(LEV*) fails statistical significance tests, its direction aligns with green credit incentive theory. State-owned enterprises (*SOE*) demonstrate emission reduction inhibitory effects, potentially attributable to delayed environmental technology upgrades caused by administrative inertia. The positive coefficient of board size (*Board*) reveals that organizational expansion may compromise environmental decision-making efficiency.

4.2. Robustness Test

To address potential endogeneity concerns arising from measurement bias, this study employs the entropy weight method framework proposed by Su and Sheng[19] to construct a Composite Pollutant Emission Index (*EIAP*) for robustness verification. Six core pollutants were selected based on data availability and environmental hazard coefficients: industrial wastewater, chemical oxygen demand, industrial waste gas, SO_2, soot, and dust. As shown in Column (1) of Table 4, the regression coefficient for green transformation remains stable at -0.0062 after replacing the dependent variable with EIAP. Specifically, a one-unit increase in green transformation intensity corresponds to a 0.62% reduction in the composite pollution index, thereby robustly confirming Hypothesis 1.

Considering the institutional shock effects induced by the implementation of China's Environmental Protection Tax Law, which expanded the tax base by 37.2% and increased tax rates by 28.5 percentage points compared to the previous pollution discharge fee system [22,23], we conducted additional tests by excluding samples from the 2018 policy transition period. The results presented in Column (2) demonstrate that the core explanatory variable maintains a statistically significant negative coefficient, confirming that our findings remain robust against structural interference from the fee-to-tax policy reform.

Table 4. Robustness test.

Variable	*EIAP*	*PE*
GTR	-0.0062**	-0.0499***
	(0.0025)	(0.0107)
Constant	1.4777***	5.9146***
	(0.0300)	(0.2004)
Controls	YES	YES
Year FE	YES	YES
Company FE	YES	YES
Observations	18,279	16,314
Adjusted R^2	0.510	0.034

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

4.3. Moderating Effect of Financing Constraints

Based on the verification requirements of Hypothesis H2, this study constructs an interaction term between financing constraints and green transition (*GTR×SA*) to examine the moderating effect. The regression results in Table 5 (column 2) show that the coefficient of the interaction term is -0.0836, supporting the hypothesis that financing constraints negatively moderate the pollution reduction effect of corporate green transition. Specifically, a one-standard-deviation increase in corporate financing constraints weakens the pollution reduction effect of green transition by approximately 14.6%. Financing constraints may constrain green transition effectiveness through two primary channels: the cash flow constraint effect and the risk premium effect. Given the characteristic environmental investments of requiring large upfront

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capital commitments and extended payback periods, heightened financing constraints exacerbate corporate liquidity pressures, resulting in insufficient investment in pollution control facility upgrades and clean technology R&D. Concurrently, intensified information asymmetry increases capital costs for green projects, significantly undermining corporate motivation for technological transformation.

Table 5. Moderating Effect of Financing Constraints.

Variable	(1)	(2)
GTR	-0.0388***	-0.3632**
	(0.0147)	(0.1816)
GTR×SA		-0.0836*
		(0.0466)
SA		0.4303*
		(0.2516)
Constant	5.8659***	7.5219***
	(0.1787)	(0.9801)
Controls	YES	YES
Year FE	YES	YES
Company FE	YES	YES
Observations	18,287	18,287
Adjusted R^2	0.032	0.032

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

4.4. Heterogeneity Results

Table 6. Heterogeneity results.

Variable	(1) ER_High	(2) ER_Low
GTR	-0.0335*	-0.0300
	(0.0184)	(0.0224)
Constant	5.9785***	5.9802***
	(0.2379)	(0.3005)
Controls	YES	YES
Year FE	YES	YES
Company FE	YES	YES
Observations	10,497	6,893
Adjusted R^2	0.034	0.060

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

Considering the institutional shock effects induced by the implemeTo explore the institutional boundary conditions of policy effects, this study conducted grouped tests based on environmental regulation intensity. Following Chen et al. (2023), we measured regional environmental regulation intensity using the ratio of industrial pollution control investment to secondary industry value added, then divided the sample into two subgroups through median grouping: strong regulatory constraint regions (ER_High) and weak regulatory constraint regions (ER_Low) [24]. The regression results in Table 6 demonstrate that environmental regulation intensity exerts significant moderating effects on pollution reduction through green transition. In strong regulation regions, the green transition coefficient shows statistically significant negative values, indicating that each unit improvement in green transition reduces

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pollution emission intensity by 3.35%. This aligns with the “innovation compensation effect” in environmental regulation theory, where stringent emission standards and monitoring systems compel enterprises to transcend end-of-pipe treatment limitations and internalize pollution control costs through clean technology innovation. In weak regulation regions, the coefficient of the explanatory variable fails to achieve statistical significance, revealing that inadequate environmental enforcement may induce “compliance inertia”. Specifically, under weak regulatory pressure, enterprises tend to maintain traditional production modes rather than proactively invest in green technologies.

5. Conclusion and Implications

This study systematically investigates the impact mechanisms of green transition behaviors in heavily polluting enterprises on pollution reduction by constructing a multi-dimensional green transition measurement system based on text analysis. The core findings are as follows: Green transition behaviors of heavily polluting enterprises exhibit a statistically significant enhancement effect on pollution reduction, a conclusion that remains robust after replacing core dependent variables and excluding samples from policy pilot regions. Financing constraints impose a significant inhibitory effect on corporate emission reduction, while environmental regulations demonstrate notable policy synergy effects, validating the theoretical expectation of the Porter Hypothesis that appropriately designed environmental regulations can stimulate innovation compensation effects.

Some potentially valuable policy implications based on the above findings are as follows.: (1) Establish a full-cycle green transition support system. Government authorities should implement differentiated support for enterprises at varying transformation stages-providing special green technology R&D subsidies to start-ups (e.g., clean production equipment procurement) and graduated emission trading incentives to mature enterprises (e.g., circular economy projects)-while strengthening mechanisms to link environmental performance to financial resource allocation. (2) Innovate green financial risk mitigation instruments. Financial institutions are advised to develop “environmental-performance-linked green credit” products by integrating corporate ESG ratings and carbon footprint verification results into credit evaluation models. Dynamic adjustments to green credit interest subsidy rates could enable hierarchical management of financing constraints, thereby addressing the “green premium” challenge [25]. (3) Build a coordinated transformation mechanism integrating “hard capabilities and soft cultural factors.” Enterprises should intensify R&D investment to advance clean production processes and end-of-pipe treatment technologies. A three-dimensional management system encompassing green supply chain management, environmental accounting systems, and employee green training programs should be prioritized.

This study has limitations: (1) The green transition metrics currently exclude supply chain collaboration indicators. Future research could incorporate input-output tables to construct industry-level transition indices. (2) The economic effects of corporate green transition and its synergies-particularly the dynamic equilibrium mechanisms among carbon reduction, pollution mitigation, and efficiency enhancement-require further exploration.

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