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Does Green Technology Innovation Mitigate or Amplify the Financial Impact of Environmental Regulation? Evidence from Highly Regulated Industries in China

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Abstract

This study examines the effect of environmental regulation on corporate financial performance and investigates whether green technology innovation moderates this relationship. Using an unbalanced panel of Chinese A-share listed firms in highly regulated industries from 2016 to 2024, we employ firm and year fixed-effects models with standard errors clustered at the firm level. The results show that environmental regulation has a significantly negative effect on

return on assets, suggesting that compliance costs and resource constraints dominate potential innovation compensation effects in the short term. Green technology innovation is positively associated with financial performance; however, its interaction with environmental regulation is significantly negative, indicating that green technology innovation may amplify the short-term financial burden of environmental regulation. Further heterogeneity analysis shows that this negative effect is mainly concentrated among large firms. The results remain robust after replacing ROA with ROE, excluding observations from 2020, and conducting additional endogeneity checks. This study contributes to the literature by showing that green technology innovation does not necessarily buffer regulatory pressure in the short term, but may instead intensify firms' financial burden when compliance and innovation costs overlap.

Keywords: environmental regulation, green technology innovation, financial performance, return on assets

1. Introduction

In recent years, as China has advanced its green development strategy and "dual carbon" goals, the intensity of environmental regulation has steadily increased. Institutional arrangements such as environmental inspections, pollution control investment, emission constraints, and green development assessments have progressively reshaped firms' production methods, resource allocation, and business decisions. In highly regulated industries—including coal mining, petroleum extraction, chemical manufacturing, metallurgy, and electric power—firms are directly exposed to regulatory pressure and must bear the costs of pollution control, equipment upgrading, and compliance management, as well as the pressure of green transformation and technological upgrading. Prior studies have shown that environmental regulation, climate policy uncertainty, and macroeconomic fluctuations can significantly affect corporate decision-making and financial risk exposure (D'Orazio, 2025; Huang, 2023; Sun et al., 2024). Therefore, under the combined pressures of green transformation and external uncertainty, how environmental regulation affects the financial performance of firms in highly regulated industries remains an important question.

Regarding the relationship between environmental regulation and corporate performance, the existing literature provides two main explanations. The compliance cost hypothesis argues that environmental regulation increases firms' expenditures on pollution control, emission reduction, and compliance management, thereby crowding out resources for R&D, marketing, and routine operations and ultimately reducing profitability. In contrast, the Porter Hypothesis suggests that well-designed and effectively enforced environmental regulation can encourage firms to engage in green technology innovation and process restructuring, thereby improving long-term performance through technological compensation effects (Du et al., 2021; Zhou & Wang, 2022). However, prior research also shows that the performance effects of environmental regulation are not uniform, but depend on the institutional environment, corporate resource endowments, financing constraints, and risk tolerance (Wang & Wang, 2024; Bao et al., 2024). For firms in highly regulated industries, where regulatory pressure is stronger and transition costs are higher, environmental regulation is more likely to compress

financial performance in the short term.

Green technology innovation is generally regarded as an important means for firms to respond to environmental regulatory pressure. Existing studies suggest that green technology innovation can help firms reduce compliance costs and enhance long-term competitiveness through energy-saving and emission-reduction technologies, green process transformation, and resource allocation optimization (Zhang et al., 2022; Zhou et al., 2024). However, green technology innovation does not necessarily translate into immediate financial returns. Studies have shown that economic and climate policy uncertainty may suppress corporate green innovation activities and influence long-term decisions through financing constraints, risk expectations, and investment payback uncertainty (Cui et al., 2023; Attílio, 2025). Consequently, under intensifying environmental regulation, firms may simultaneously face compliance costs and green innovation inputs, making it difficult for green technology innovation to fully generate financial returns in the short run.

Furthermore, green technology innovation may not simply serve as a "buffering mechanism" between environmental regulation and corporate financial performance. On the one hand, green technology innovation helps firms restructure production processes, improve resource efficiency, and strengthen their capacity to adapt to green transformation requirements. On the other hand, it is characterized by substantial capital investment, long R&D cycles, and uncertain returns, which may increase firms' cost burden in the short term. Prior research also shows that innovation and organizational resilience can improve long-term firm performance, but their effects are often conditioned by external environments and differences in firm capabilities (Garrido-Moreno et al., 2024). Thus, in highly regulated industries, green technology innovation may not always mitigate the negative impact of environmental regulation on financial performance. Instead, it may amplify the short-term profit compression effect of environmental regulation through increased input costs and resource reallocation pressures.

Based on the above analysis, this study uses a sample of Chinese A-share listed firms in highly regulated industries from 2016 to 2024, covering coal mining, petroleum and natural gas extraction, metal ore mining, petroleum processing, chemical manufacturing, chemical fiber, non-metallic mineral products, ferrous metal smelting, non-ferrous metal smelting, and electricity and gas supply. We employ a two-way fixed-effects model to examine the impact of environmental regulation on corporate financial performance and further investigate the moderating role of green technology innovation. This study makes three main contributions. First, by focusing on highly regulated industries, it provides empirical evidence on corporate financial performance under the background of green transformation. Second, by examining green technology innovation from a moderating perspective, it differs from studies that treat green technology innovation mainly as a mechanism for improving regulatory performance. Third, it proposes and tests the short-term cost amplification effect of green technology innovation. Under strong environmental regulation, green technology innovation may not immediately alleviate firms' financial pressure, but may instead reinforce the negative impact

of environmental regulation on short-term financial performance through input costs, compliance pressure, and resource reallocation.

2. Literature Review and Research Hypotheses

2.1 Environmental Regulation and Corporate Financial Performance

Environmental regulation affects corporate financial performance through its influence on cost structure, investment decisions, and production efficiency. According to the compliance cost hypothesis, environmental regulation requires firms to increase expenditures on pollution treatment facilities, environmental equipment upgrades, emission monitoring, and environmental management. These expenditures are often difficult to convert into revenue in the short term and may therefore suppress corporate return on assets. For firms facing tighter capital constraints, weaker pollution control infrastructure, or greater green transformation pressure, the cost burden imposed by environmental regulation is more likely to crowd out operating resources and weaken short-term profitability. Prior research also shows that firms' perceptions of environmental regulation costs are shaped by regulatory complexity, enforcement intensity, and institutional differences, leading firms to adopt different response strategies (Lah & Kotnik, 2025). Therefore, the impact of environmental regulation on corporate financial performance is not uniform, but depends on the institutional environment and industry characteristics in which firms operate.

Meanwhile, the Porter Hypothesis suggests that well-designed and effectively enforced environmental regulation may improve corporate performance through innovation compensation effects. Moderate and stable environmental regulation can encourage firms to pursue green technology innovation, optimize production processes, and improve resource utilization efficiency, thereby offsetting part of the compliance costs over the long run (Song et al., 2022; Wu & Lin, 2022). In the Chinese context, environmental regulation has been found to affect green total factor productivity through channels such as technical efficiency improvement, technological progress, and technology gap convergence (Cheng & Kong, 2022). Moreover, market-based environmental regulation, particularly carbon emission trading schemes, may enhance both economic and environmental performance by incentivizing green technology innovation and management improvement (Luan et al., 2025; Li et al., 2025).

However, the realization of innovation compensation effects usually requires a longer time horizon and stronger organizational capabilities, and may not be sufficient to offset compliance costs in the short term. Existing studies indicate that the effect of environmental regulation on firm performance is highly context-dependent, with its direction and magnitude jointly shaped by the type of regulatory instrument, industry characteristics, macroeconomic uncertainty, and firm-level resource endowments (Rigamonti et al., 2024). In addition, some firms may respond to regulatory pressure through symbolic behaviors, such as environmental information disclosure, rather than substantive green investment, which may weaken the actual performance-enhancing effect of environmental regulation (Tang et al., 2023). Environmental regulation may also affect financial outcomes indirectly by influencing corporate accounting

behavior and earnings management practices (Fu et al., 2023). Therefore, in highly regulated industries, when the immediate costs imposed by environmental regulation exceed the benefits of technological compensation, its effect on corporate financial performance is more likely to be negative.

Based on the above analysis, we propose the following hypothesis:

H1: Environmental regulation has a significantly negative effect on corporate financial performance.

2.2 The Moderating Role of Green Technology Innovation

Green technology innovation reflects firms' accumulated capabilities in green technologies, green processes, and cleaner production. As sustainability issues become increasingly embedded in corporate strategic decision-making, green technology innovation is no longer merely a technological output, but also an important manifestation of firms' resource integration, process restructuring, and capability renewal under environmental constraints. From a dynamic capabilities perspective, innovation capability is not the result of a one-time investment, but a capability system through which firms continuously identify opportunities, integrate resources, and reconfigure organizational processes in uncertain environments (Kafouros et al., 2022; Ferraro et al., 2024; Li et al., 2023). Compared with general technological innovation, green technology innovation faces stricter institutional oversight, higher technological uncertainty, and more complex stakeholder pressures, and therefore relies more heavily on firms' internal capability systems (Fan et al., 2023; Sahoo & Yadav, 2022).

In general, green technology innovation helps firms improve resource utilization efficiency, reduce energy consumption, optimize production processes, and enhance their green market image, thereby potentially improving financial performance. Existing studies show that green dynamic capabilities can help firms identify green opportunities, absorb environment-related knowledge, and reconfigure resource allocation, thereby fostering green innovation capabilities and improving sustainable performance (Yousaf, 2021; Ali et al., 2023; Bucheli et al., 2024). Green absorptive capacity and green knowledge management are also important foundations for transforming external environmental pressure into green innovation solutions (Akhtar et al., 2024; Makhloufi, 2024). Accordingly, from a long-term perspective, green technology innovation may serve as an important pathway for firms to respond to environmental regulatory pressure and strengthen competitive advantages.

However, green technology innovation also involves substantial upfront investment. Firms need to invest R&D funds, recruit specialized talent, upgrade production equipment, and bear the uncertainties associated with technological failure and market conversion. This problem becomes more pronounced when environmental regulation is stringent, as firms may simultaneously face the dual resource burden of compliance investment and innovation investment. If green innovation outcomes have not yet been fully converted into production efficiency, cost savings, and market returns, green technology innovation may increase firms' cost burden in the short run. Related studies also show that the performance effects of green

innovation capability are not unconditional, but depend on firms' capability base, external environment, and technology commercialization conditions (Mubeen et al., 2024). Although emerging capabilities such as digital technology and artificial intelligence may strengthen firms' green innovation capacity, their value realization also depends on organizational learning and resource integration processes (Yu et al., 2022; Gama & Magistretti, 2025; Gao et al., 2025; Abdelfattah et al., 2025).

Therefore, under strong environmental regulatory pressure, green technology innovation may not immediately buffer the negative impact of environmental regulation on financial performance. For firms in highly regulated industries, green technology innovation may generate additional R&D expenditure, equipment upgrading costs, and production process adjustment costs in the short term, thereby reinforcing the inhibitory effect of environmental regulation on corporate financial performance. In other words, green technology innovation may have long-term value, but its short-term financial returns are often characterized by lag and uncertainty. When firms simultaneously face stringent regulatory pressure and green innovation investment pressure, green technology innovation may amplify the cost effects of environmental regulation in the short run.

Based on the above analysis, we propose the following hypothesis:

H2: Green technology innovation negatively moderates the effect of environmental regulation on corporate financial performance.

3. Data, Variables, and Model Specification

3.1 Data Sources and Sample Construction

This study uses Chinese A-share listed firms in highly regulated industries from 2016 to 2024 as the research sample and constructs an unbalanced firm–year panel dataset. Following the literature on environmental regulation and heavily polluting industries, we retain firms in coal mining, petroleum and natural gas extraction, metal ore mining, petroleum processing, chemical manufacturing, chemical fiber, non-metallic mineral products, ferrous metal smelting, non-ferrous metal smelting, and electricity and gas supply, which are industries most directly affected by environmental regulation. Corporate financial and governance data are mainly obtained from the CSMAR and WIND databases. The environmental regulation indicator is constructed from provincial-level environmental governance statistics, while the green technology innovation indicator is identified and compiled using corporate green patent information. Specifically, we retain firms with industry codes B06, B07, B08, B09, C25, C26, C28, C30, C31, C32, D44, and D45.

During the sample screening process, we exclude ST and *ST firms as well as observations with missing key variables. To mitigate the influence of extreme values, all continuous variables are winsorized at the 1st and 99th percentiles. After these screening and processing steps, the descriptive statistics sample contains 5,596 firm–year observations. After further controlling for firm and year fixed effects and excluding observations with missing regression

variables, the effective sample for the baseline regressions consists of 5,534 firm–year observations.

3.2 Variable Definitions

The dependent variable is corporate financial performance, measured by return on assets (ROA), which is calculated as the ratio of net income to total assets. The key independent variable is environmental regulation (ER), measured as the ratio of completed investment in industrial pollution control to industrial value added at the provincial level, following the existing literature. This provincial-level indicator is matched to firm-year observations based on each firm's registered location and year. The moderating variable is green technology innovation (GTI), which is identified using the World Intellectual Property Organization (WIPO) green patent classification list and measured as ln(number of green patents + 1).

Following related studies on environmental regulation, ESG, and corporate financial performance (Dagestani et al., 2023; Handoyo & Anas, 2024), we include a set of firm-level control variables: firm size (Size), operating cash flow (Cashflow), revenue growth rate (Growth), the largest shareholder's ownership proportion (Top1), firm age (FirmAge), and a state-owned enterprise dummy (SOE). These variables control for differences in firm characteristics, governance structure, and operating conditions that may affect financial performance.

3.3 Model Specification

To examine the impact of environmental regulation on corporate financial performance, we specify the following two-way fixed-effects model:

$$ROAit = \alpha + \beta 1 ERit + \gamma Controlsit + \mu i + \lambda t + \varepsilon it \qquad (1)$$

where ROA denotes the financial performance of firm i in year t, ER denotes the intensity of environmental regulation, Controlsit represents control variables, μi captures firm fixed effects, λt captures year fixed effects, and εit is the error term. Standard errors are clustered at the firm level.

To further test the moderating role of green technology innovation, we augment Model (1) with the interaction term between ER and GTI:

$$ROAit = \alpha + \beta 1 ERit + \beta 2 GTIit + \beta 3 ERit \times GTIit + \gamma Controlsit + \mu i + \lambda t + \varepsilon it \qquad (2)$$

where $\beta 3$ is the moderating effect coefficient of interest. A significant $\beta 3$ indicates that green technology innovation alters the marginal effect of environmental regulation on corporate financial performance.

4. Empirical Results

4.1 Descriptive Statistics, Correlation Analysis, and Multicollinearity Tests

Table 1 reports the descriptive statistics of the main variables. The mean of ROA is 0.040 with

a standard deviation of 0.073, indicating moderate variation in sample firms' profitability. The mean of ER is 0.162 with a standard deviation of 0.146, suggesting notable differences in the intensity of environmental regulation across regions. The control variables—firm size, cash flow, growth, ownership concentration, and firm age—exhibit sufficient sample variation, providing a solid foundation for subsequent regression analysis.

Table 1. Descriptive Statistics

	Obs	Mean	Std. Dev.	Min	Max
ROA	5596	0.040	0.073	−0.894	0.953
ER	5596	0.162	0.146	0.006	0.646
Size	5596	22.759	1.426	19.885	26.359
Cashflow	5596	0.061	0.063	−0.156	0.240
Growth	5596	0.147	0.359	−0.593	2.055
Top1	5596	0.344	0.149	0.081	0.732
FirmAge	5596	3.096	0.268	1.946	4.304
SOE	5596	0.418	0.493	0.000	1.000
GTI	5596	0.497	0.874	0.000	3.912

Table 2 reports the pairwise correlation coefficients among the main variables. ROA is significantly positively correlated with Cashflow, Growth, and Top1, and significantly negatively correlated with FirmAge and SOE. The correlation coefficient between ER and ROA is negative but statistically insignificant, indicating that the bivariate relationship is insufficient to reveal the true effect of environmental regulation on financial performance, necessitating further control for firm fixed effects, year fixed effects, and other firm-level characteristics.

Table 2. Correlation Matrix

	ROA	ER	Size	Cashflow	Growth	Top1	FirmAge	SOE	GTI
ROA	1								
ER	−0.020	1							
Size	0.030**	0.036***	1						
Cashflow	0.487***	0.012	0.153***	1					
Growth	0.339***	0.056***	0.012	0.065***	1				
Top1	0.060***	0.069***	0.309***	0.105***	0.006	1			
FirmAge	−0.116***	−0.158***	0.145***	−0.013	−0.116***	−0.072***	1		
SOE	−0.087***	0.089***	0.443***	0.062***	−0.060***	0.343***	0.203***	1	
GTI	0.051***	−0.019	0.392***	0.131***	−0.015	0.170***	−0.016	0.220***	1

Note. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3 reports the multicollinearity test results. The VIF values of all explanatory variables are well below 10, with the highest being only 1.48, confirming the absence of serious multicollinearity and indicating that the variable specification is statistically appropriate.

Table 3. Multicollinearity Test (VIF)

Variable	VIF	1/VIF
ER	1.05	0.95
Size	1.48	0.68
Cashflow	1.04	0.96
Growth	1.02	0.98
Top1	1.21	0.82
FirmAge	1.13	0.88
SOE	1.40	0.72
GTI	1.21	0.83

4.2 Baseline Regression Results

Table 4 reports the baseline regression results for the effect of environmental regulation on corporate financial performance. Column (1) includes firm and year fixed effects only, while Column (2) further adds firm-level control variables. The coefficients of ER are −0.032 and −0.030, respectively, both significant at the 1% level, indicating that stronger environmental regulation significantly reduces corporate ROA.

Taking Column (2) as an example, holding other variables constant, a one-unit increase in environmental regulation is associated with an average decrease of 0.030 points in ROA. Given that the standard deviation of ER is 0.146, a one-standard-deviation increase in environmental regulation corresponds to an approximately 0.44-percentage-point decline in ROA. Relative to the sample mean of ROA, which is 0.040, this effect is economically meaningful. These results support H1, suggesting that in highly regulated industries, the compliance costs, governance expenditures, and operational constraints imposed by environmental regulation outweigh potential innovation compensation benefits in the short term.

Table 4. Baseline Regression Results

	ROA (1)	ROA (2)
ER	−0.032***	−0.030***
	(0.011)	(0.009)
Size		0.009**
		(0.004)
Cashflow		0.399***
		(0.028)
Growth		0.054***
		(0.005)
Top1		0.002
		(0.021)
FirmAge		−0.079**
		(0.036)
SOE		−0.004
		(0.008)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	5,534	5,534
Adj. R-squared	0.361	0.512
F-statistic	9.232	38.570

*Note. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

4.3 The Moderating Effect of Green Technology Innovation

Table 5 further examines the moderating role of green technology innovation. The results in Column (2) show that the coefficient of GTI is 0.003 and significant at the 10% level, suggesting that green technology innovation may contribute to corporate financial performance. Meanwhile, the coefficient of the interaction term ER×GTI is −0.011 and significant at the 10% level, indicating that green technology innovation changes the marginal effect of environmental regulation on financial performance.

Specifically, the marginal effect of environmental regulation on ROA is −0.025 − 0.011×GTI. This means that as the level of green technology innovation increases, the negative effect of environmental regulation on ROA becomes stronger. This finding suggests that although green technology innovation may have long-term value, it may also occupy corporate resources together with environmental compliance investment in the short term, thereby amplifying the cost pressure imposed by environmental regulation. Given that the interaction term is significant at the 10% level, this moderating effect should be interpreted with caution.

Table 5. The Moderating Effect of Green Technology Innovation

	ROA (1)	**ROA (2)**
ER	−0.030***	−0.025**
	(0.009)	(0.010)
Size	0.009**	0.009**
	(0.004)	(0.004)
Cashflow	0.399***	0.399***
	(0.028)	(0.028)
Growth	0.054***	0.054***
	(0.005)	(0.005)
Top1	0.002	0.002
	(0.021)	(0.021)
FirmAge	−0.079**	−0.079**
	(0.036)	(0.036)
SOE	−0.004	−0.003
	(0.008)	(0.008)
GTI		0.003*
		(0.002)
ER×GTI		−0.011*
		(0.006)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	5,534	5,534
Adj. R-squared	0.512	0.512
F-statistic	38.570	31.397

*Note. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

4.4 Robustness Tests

Table 6 reports the robustness tests from two perspectives. First, we replace ROA with ROE as an alternative measure of corporate financial performance. As shown in Columns (1) and (2), the coefficient of ER remains negative, and the baseline effect is statistically significant. After

adding the interaction term, the coefficient of ER×GTI remains negative and significant at the 10% level, providing additional but relatively weak evidence for the moderating role of green technology innovation.

Second, we exclude observations from the COVID-19 shock year of 2020. The results in Columns (3) and (4) show that the coefficient of ER remains significantly negative, while the interaction term ER×GTI remains negative and significant at the 10% level. Overall, these results indicate that the adverse effect of environmental regulation on corporate financial performance is robust to alternative performance measurement and sample adjustment. The negative moderating effect of green technology innovation is also directionally consistent, although it should be interpreted cautiously because its statistical significance is relatively weak.

Table 6. Robustness Tests

	ROE (1)	ROE (2)	Excl. 2020 (3)	Excl. 2020 (4)
ER	-0.046**	-0.035	-0.028***	-0.022**
	(0.020)	(0.022)	(0.009)	(0.010)
GTI		0.007*		0.004**
		(0.004)		(0.002)
ER×GTI		-0.021*		-0.012*
		(0.012)		(0.007)
Size	0.035***	0.035***	0.006	0.006
	(0.010)	(0.010)	(0.005)	(0.005)
Cashflow	0.642***	0.641***	0.403***	0.403***
	(0.046)	(0.046)	(0.028)	(0.028)
Growth	0.081***	0.081***	0.056***	0.056***
	(0.007)	(0.007)	(0.005)	(0.005)
Top1	0.011	0.011	0.008	0.008
	(0.042)	(0.042)	(0.023)	(0.023)
FirmAge	-0.075	-0.076	-0.081**	-0.081**
	(0.075)	(0.076)	(0.037)	(0.037)
SOE	-0.015	-0.015	-0.007	-0.007
	(0.020)	(0.021)	(0.009)	(0.009)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	5527	5527	4946	4946
Adj. R-squared	0.457	0.457	0.527	0.527
F-statistic	54.515	44.295	38.121	31.034

*Note. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

4.5 Additional Endogeneity Check

To partially address potential endogeneity concerns, particularly reverse causality and the persistence of firm financial performance, we conduct additional tests. First, we use the one-period lagged environmental regulation variable to examine whether prior regulatory pressure continues to affect current corporate financial performance. Since current ROA is unlikely to affect prior-period environmental regulation, this test helps mitigate concerns about contemporaneous reverse causality. Second, we include lagged ROA in the model to control for the persistence of firm financial performance over time.

Table 7. Endogeneity Checks

	(1) Lagged ER	(2) Dynamic Model
L.ER	-0.023**	
	(0.009)	
ER		-0.022**
		(0.009)
L.ROA		0.232***
		(0.041)
Size	0.014***	0.006
	(0.005)	(0.005)
Cashflow	0.386***	0.344***
	(0.030)	(0.028)
Growth	0.052***	0.058***
	(0.005)	(0.005)
Top1	-0.009	-0.007
	(0.024)	(0.019)
FirmAge	-0.097**	-0.071*
	(0.046)	(0.038)
SOE	-0.003	-0.003
	(0.009)	(0.008)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	4615	4615
Adj. R-squared	0.526	0.554
F-statistic	33.060	38.619

*Note. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

As shown in Table 7, the coefficient of L.ER in Column (1) is −0.023 and statistically significant at the 5% level, indicating that environmental regulation in the previous period continues to have a negative effect on current ROA. In Column (2), after controlling for lagged ROA, the coefficient of ER remains negative and statistically significant at the 5% level. The coefficient of L.ROA is significantly positive, suggesting strong persistence in corporate financial performance over time. These findings provide additional evidence that the negative effect of environmental regulation on corporate financial performance is not mainly driven by contemporaneous reverse causality or performance persistence. Nevertheless, these tests only partially alleviate potential endogeneity concerns, and the causal interpretation of the results should still be made with caution.

4.6 Heterogeneity Analysis: Firm Size

To explore heterogeneity in the effect of environmental regulation across firms of different sizes, we divide the full sample into small and large firms based on the annual median of firm size (Size). The subsample regression results are reported in Table 8.

For small firms, the coefficient of ER is −0.005 and statistically insignificant, indicating that

environmental regulation does not exert a discernible effect on the financial performance of smaller firms during the sample period. In contrast, for large firms, the coefficient of ER is −0.028 and significant at the 1% level, suggesting that the negative effect of environmental regulation on ROA is concentrated among larger firms. This cross-subsample contrast reveals a clear size-dependent asymmetry in the financial consequences of environmental regulation.

This heterogeneous pattern may be explained by several factors. First, large firms in highly regulated industries are typically the primary targets of environmental enforcement because of their higher emission volumes, greater regulatory visibility, and more extensive reporting obligations. Provincial regulators are more likely to prioritize the monitoring and inspection of large-scale polluters, thereby imposing stricter compliance requirements and larger absolute compliance expenditures on these firms (Lah & Kotnik, 2025). Second, large firms generally operate more complex and capital-intensive production systems, often involving multiple production lines, subsidiaries, and geographic locations. As a result, they need to invest more heavily in pollution control equipment, emission reduction technologies, and environmental management systems. Their greater organizational rigidity may also slow their adjustment to tightening regulatory requirements, extending the period during which compliance costs weigh on profitability. Third, the resource reallocation effect induced by environmental regulation is likely to be stronger among large firms, as diverting capital from productive investment to environmental compliance represents a larger absolute opportunity cost for firms with extensive asset bases.

By contrast, smaller firms may face relatively lighter regulatory pressure. Their lower emission volumes and smaller operational footprints reduce their visibility to regulators. In addition, their cost structures are often more flexible, allowing them to adjust production processes and resource allocation more quickly in response to regulatory changes. Small firms may also benefit from regulatory thresholds or de facto enforcement leniency that exempt them from the most costly compliance obligations. Consequently, environmental regulation does not impose a statistically significant financial burden on small firms in this sample.

The subsample results also reveal several patterns in the control variables. Cashflow is positive and significant in both subsamples, but its coefficient is larger for large firms, suggesting that internal cash generation is a more important determinant of profitability for firms with larger fixed-cost bases. Growth is also positive and significant in both subsamples, with a slightly larger coefficient for small firms, indicating that growth opportunities may be more important for smaller firms still expanding their market presence. FirmAge is negative and marginally significant only for small firms, suggesting that older small firms may face organizational inertia or declining growth prospects. Finally, the SOE dummy is negative and marginally significant only for large firms, consistent with the view that state ownership may weaken profit maximization incentives in large enterprises through bureaucratic constraints and policy-driven objectives.

Overall, the heterogeneity analysis shows that the adverse financial impact of environmental regulation is not evenly distributed across firm sizes. The negative effect is mainly driven by

large firms, which bear disproportionate compliance burdens because of their regulatory visibility, operational complexity, and asset-intensive production structures. These findings complement the baseline results and indicate that firm size is an important boundary condition shaping the financial consequences of environmental regulation in highly regulated industries.

Table 8. Heterogeneity Analysis: Firm Size

	(1) Small Firms	(2) Large Firms
ER	−0.005	−0.028***
	(0.018)	(0.009)
Cashflow	0.328***	0.426***
	(0.038)	(0.040)
Growth	0.062***	0.049***
	(0.008)	(0.005)
Top1	0.051	−0.025
	(0.045)	(0.024)
FirmAge	−0.099*	0.037
	(0.058)	(0.038)
SOE	0.012	−0.018*
	(0.013)	(0.010)
Firm FE	Yes	Yes
Year FE	Yes	Yes
Observations	2,722	2,754
Adj. R-squared	0.504	0.576

*Note. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

5. Conclusions and Implications

Using data from Chinese A-share listed firms in highly regulated industries from 2016 to 2024, this study employs a two-way fixed-effects model with firm and year fixed effects to examine the impact of environmental regulation on corporate financial performance and the moderating role of green technology innovation. The findings are as follows. First, environmental regulation significantly reduces corporate ROA, indicating that compliance costs and resource constraints are pronounced during the sample period. Second, green technology innovation itself is positively associated with corporate financial performance, but its interaction with environmental regulation is significantly negative, suggesting that green technology innovation may reinforce the inhibitory effect of environmental regulation on financial performance in the short term. Third, the main results remain robust after replacing ROA with ROE, excluding observations from 2020, and conducting additional endogeneity checks using lagged environmental regulation and lagged ROA. Fourth, the heterogeneity analysis shows that the negative effect of environmental regulation is concentrated among large firms, while small firms are not significantly affected, highlighting firm size as an important boundary condition.

These findings have several policy and managerial implications. For policymakers, environmental regulation should balance regulatory stringency with incentive compatibility. While strengthening environmental governance requirements, governments should reduce firms' green transformation costs through green finance, tax incentives, and R&D subsidies to

avoid excessive short-term pressure on corporate profitability. Given the disproportionate impact on large firms, targeted support mechanisms for large enterprises in highly regulated industries may be particularly important. For firms, green technology innovation should not remain at the level of patent quantity or symbolic input. Instead, greater attention should be paid to the commercialization of innovation outcomes, process efficiency improvement, and cost control. Only when green innovation is effectively transformed into production efficiency and market competitiveness can firms better coordinate green development with financial performance under tightening environmental regulation.

This study has several limitations. First, although this study uses ROA and ROE to measure corporate financial performance, future research may further incorporate market-based indicators, such as Tobin's Q or stock market performance, to examine long-term valuation effects. Second, green technology innovation is measured primarily by green patents, which does not fully capture patent quality, commercialization value, or the heterogeneous effects of green invention patents and green utility model patents. Third, the environmental regulation indicator is measured at the provincial level and may not fully capture firm-specific regulatory exposure. Future research may use more refined regulatory measures or firm-level environmental enforcement data. Fourth, future studies may further explore heterogeneity across industry pollution intensity, ownership structure, and regional institutional environments to provide a more comprehensive understanding of the economic consequences of environmental regulation and green technology innovation.

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Author contributions

Xiaolong Ma was responsible for data collection, data analysis, and drafting the manuscript. Haslindar Ibrahim provided supervision and guidance on the research direction and study design. Huiran Lin contributed to revising, editing, and polishing the manuscript. All authors read and approved the final manuscript.

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