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New "Environmental Protection Law" and Enterprise Technological Innovation

-- Based on Evidence from Listed Companies in Heavily Polluting Industries

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Abstract

The revised Environmental Protection Law, effective January 1, 2015, was enacted to drive sustainable economic growth and facilitate the green transformation of heavily polluting enterprises. This study examines the law's impact on technological innovation within these enterprises and explores the underlying mechanisms. Using data from companies listed on the Shanghai and Shenzhen A-share markets between 2012 and 2019, a difference-in-differences (DID) model is employed to test the hypotheses. Findings show that the law significantly boosts the innovation capabilities of heavily polluting enterprises, with the most substantial effects observed in eastern regions, older companies, those with lower market concentration, and higher corporate governance levels. Further analysis reveals that the new Law compels heavily polluting enterprises to pursue technological innovation primarily by increasing financing constraints.

Keywords

New Environmental Law; Heavy Polluters Enterprise; Technology Innovation.

1. Introduction

The Fifth Plenary Session of the 19th CPC Central Committee underscored the importance of innovation in China's modernization. Despite growing recognition of innovation among Chinese enterprises, there remains a significant gap between their technological capabilities and global leaders. Therefore, enhancing technological innovation is crucial not only for boosting international competitiveness but also for achieving scientific and technological self-reliance. With the deepening of market-oriented and industrial reforms, China's economy has grown rapidly, averaging an annual GDP increase of 9.4% from 1978 to 2019. However, this growth has also intensified ecological and environmental issues. The first Environmental Protection Law, introduced in 1989, failed to shift the focus from economic development to environmental protection. Government officials often prioritized economic performance over environmental standards, leading to severe environmental degradation. The 2022 Global Environmental Performance Index, jointly released by Yale University and other institutions, ranked China 160th out of 180 countries, highlighting the need for a balance between economic growth and ecological protection. The 2015 revision of the Law aimed to address these issues by clarifying legal responsibilities for environmental supervision and pollution control. Known as the "strictest environmental protection law in history," it imposes significant constraints to promote the development of China's green economy and set new standards for economic entities.

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In the context of rapid economic growth, the outdated model of "pollution first, treatment later" is no longer effective for pollution control. Instead, enterprises are now focusing on technological innovation in the production process to manage pollution more effectively (Siegel, 2009). Despite some progress, Chinese enterprises still face significant limitations in their technological innovation, making it crucial to study its impact on the behavior of heavily polluting industries.

Lin and Polenske (1995) examined factors influencing energy consumption in China from 1981 to 1987, concluding that technological advancements were key to energy conservation. Similarly, Garbaccio et al. (1999) found that technological progress was the primary driver of reduced energy intensity in China between 1987 and 1992. Innovations in products and processes, particularly in heavily polluting industries like pharmaceuticals and steel, have been shown to improve energy consumption (Yin et al., 2019). Technological innovation is now recognized as a vital approach for conserving energy and reducing emissions (Jänicke, 2012; Zhang et al., 2017), as it decreases energy waste and promotes sustainable development in enterprises.

The introduction of the new Law has generated significant academic debate regarding its impact on corporate emission reduction behaviors. According to Porter's hypothesis, environmental regulation can compel companies to enhance green innovation and engage in pollution control (Porter and Linde, 1995). As environmental regulations tighten, enterprises view compliance as a strategic necessity. Polluting companies have increased their investments in environmental protection and green innovation to improve production processes and lower emissions (Liu et al., 2021; Wang et al., 2020). Conversely, classical economic theory suggests that such regulations internalize the costs of pollution, increasing expenses for polluting firms and creating a 'crowding out effect' on production and innovation. The new Law has exacerbated resource constraints for heavily polluting enterprises, limiting their capacity to invest in green innovation (Li and Wang, 2019). Consequently, these firms may reduce production to lower emissions (Cui and Jiang, 2019). Excessive regulatory pressure could also lead to decreased output and potential plant relocations (Shen and Zhou, 2017; Chen et al., 2018).

Given the emphasis on enhancing independent innovation and green transformation highlighted in the 20th National Congress of the Communist Party of China, it is crucial to examine the impact of the "Environmental Protection Law" enacted on January 1, 2015, on the technological innovation of heavily polluting enterprises. Will the law motivate these enterprises to bolster technological innovation to meet environmental standards? Or will stringent environmental regulations drive them to relocate to areas with more lenient environmental requirements, thus hindering the improvement of independent technological innovation?

This study examines Shanghai and Shenzhen A-share listed companies from 2012 to 2019, using the difference-in-differences method. The heavily polluting enterprises are designated as the treatment group, while other enterprises serve as the control group. The research empirically investigates the impact of the new Law on technological innovation among heavily polluting enterprises and explores the mechanisms under different financing constraints. Additionally, the study analyzes the heterogeneity of the law's impact across various market concentrations, regions, and enterprise ages.

The potential contributions of this paper include evaluating the policy effects of the new Law from a micro perspective, thereby expanding the research scope of environmental regulation impacts on enterprises. It also offers theoretical support and empirical evidence for China's goal of achieving coordinated ecological and economic development under the 'double carbon' target.

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The structure of this paper includes: the literature review and research hypothesis in the second part, the research design in the third part, the empirical result analysis in the fourth part, and the conclusion in the fifth part.

2. Literature Review and Research Hypothesis

2.1. Environmental Regulation and Enterprise Technological Innovation

Research on the impact of environmental regulation on technological innovation can be categorized into three main areas.

Firstly, environmental regulations designed according to the 'Porter hypothesis' can drive enterprises to engage in R&D innovation. Empirical studies by Sen (2015) indicate that pollution taxes, used as a measure of environmental regulation, not only reduce pollution but also enhance technological innovation in enterprises. Zhang et al. (2011), using China's provincial panel data, found that investment-driven environmental regulation positively influences enterprise technological innovation. Guo et al. (2017) validated this using structural equation modeling, showing significant promotion of technological innovation by environmental regulations. Pan et al. (2019) explored the relationship between environmental regulation, energy efficiency, and technological innovation through the SVAR model, finding that market-based environmental regulation fosters technological innovation, whereas command-based regulation does not. Jiang Yingbing and Cui Guanghui (2019) highlighted that environmental regulation boosts investment in environmental protection from an industrial policy perspective. Jing Weimin and Zhang Lu (2014) demonstrated that effective environmental regulation enhances innovation in cleaner production technologies, aligning with the Porter hypothesis by increasing enterprise enthusiasm for environmental governance. Furthermore, Wang et al. (2017) studied Dongguan City's environmental protection policies and concluded that environmental regulation significantly improves environmental governance in enterprises. Tao et al. (2020) found that environmental regulation is crucial for promoting high-quality economic development. Strengthening environmental governance within enterprises is essential, as it directly correlates with enhanced technological innovation.To enhance environmental governance efficiency, companies must apply their technological innovation capabilities to actual production, which necessitates a focus on technological innovation outputs. Wang Xiaoqi et al. (2020) noted that the new law can induce a 'Porter effect,' compelling enterprises to innovate through environmental governance. Additionally, despite strategic decision-making processes, the new environmental protection law continues to drive enterprise innovation and development (Li and Huang, 2021). Thus, environmental regulation not only encourages enterprises to manage environmental protection but also enhances their technological innovation capabilities.

Another perspective, the 'follow cost' hypothesis, suggests that environmental regulation compels enterprises to invest more in environmental protection, raising their compliance costs. This, in turn, can crowd out innovative resources and hinder technological advancement (Gray and Shadbegian, 2003). Wagner (2007) similarly argued that such regulation can stifle innovation outputs. Research by Chintrakarn (2008) indicates that environmental regulation can impede improvements in corporate technical efficiency. Chen et al. (2018) examined water pollution control under the "Eleventh Five-Year Plan," finding that regulation did not boost investment in environmental protection among heavily polluting enterprises but instead led them to relocate to areas with less stringent requirements. The hypothesis that regulation drives technological progress holds true only when new technologies enhance production efficiency (Roy and Das, 2011). From a microeconomic standpoint, the 'Porter Hypothesis based on intellectual capital' asserts that environmental rules must foster capital accumulation in corporate knowledge to spur innovation (Ziesemer, 2013). Thus, the effectiveness of Laws is

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not guaranteed, as companies might prioritize other invisible profits over technological innovation, which policies may not address. Moreover, the cost of 'environmental compensation' under regulatory constraints can lead to a 'crowding-out effect' on enterprise innovation. This aligns with the pollution haven and cost hypotheses, suggesting that if production costs are significantly higher under stringent regulation, enterprises might relocate to regions with weaker regulations to boost profits. Consequently, environmental constraints could limit technological investment (Wang and Yin, 2015), adversely affecting innovation output

Beyond the two aforementioned perspectives, some studies indicate a nonlinear relationship between environmental regulation and technological innovation. Mishra and Smyth (2011) analyzed panel data from 34 Chinese industries, concluding that command-based environmental regulation impacts regional technological innovation in a U-shaped manner. Li et al. (2020) found that in heavily polluted environments, the impact is inverted U-shaped, while in lightly polluted environments, it is U-shaped. Both Liu et al. (2018) and Li et al. (2020) support the existence of this U-shaped relationship.

To ensure the effective implementation of the new Law, the Ministry of Environmental Protection introduced four measures: daily punishment, seizure, restriction of production, and information disclosure. These measures have driven adaptive innovation in enterprises across various dimensions, including governance and social responsibility, demonstrating increased state-imposed restrictions and penalties for polluting companies. Furthermore, the revised law incorporates public prosecution and public interest litigation, enhancing the stringency of environmental protection. The law sets more specific requirements for different departments and provides clear implementation guidelines (Yang et al., 2015). Additionally, it offers incentives for enterprises excelling in pollution control, addressing aspects like taxation, pricing, and finance, thereby fostering further development and encouraging technological innovation. Thus, the new Law is both mandatory and incentivizing.

Based on this analysis, the research hypothesis is proposed:

H1A: The new Law has a positive incentive effect on enterprise technological innovation.

H1B: The new Law has a reverse crowding out effect on enterprise technological innovation.

2.2. Environmental Regulation and External Financing Difficulty

The new Law will intensify penalties for environmental violations, leading to increased business risks and a higher likelihood of financial distress. Consequently, investors may demand a higher risk premium, exacerbating the external financing difficulties faced by enterprises (Gao et al., 2021). Additionally, bank credit remains the primary financing source for Chinese enterprises. Due to the new law, some heavily polluting enterprises may struggle to repay loans on time as their financial situation deteriorates, prompting banks to reduce credit availability. Studies indicate that increased external environmental regulation pressure and internal environmental protection investment needs will prompt polluting enterprises to adjust their credit resource mix in response to changes in the external financing environment (Xu, 2022). When these enterprises encounter significant financing challenges, they tend to allocate fewer resources to green innovation activities, focusing instead on improving innovation efficiency and technological upgrading. Thus, heightened external financing difficulties will push enterprises to optimize resource allocation and redirect resources towards green innovation and technological advancements.

Based on this analysis, the research hypothesis is proposed:

H2: The implementation of the new Law increases the financing difficulty of heavily polluting enterprises, compelling them to optimize resource allocation and promote technological innovation.

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3. Research Design

3.1. Data Description

This paper examines the patent data of China's heavily polluting industries from 2012 to 2019, along with corresponding enterprise-level economic data. The data on technological innovation capability and patents, as well as the basic and financial information of other listed companies, are sourced from the China Patent database, CSMAR database, and WIND database. The data processing steps include: (1) Excluding listed companies under special treatment (ST, *ST, etc.) during the observation period; (2) Removing companies with missing data; (3) Excluding samples of companies with an asset-liability ratio greater than 1. To mitigate the impact of extreme values on the analysis, the major continuous variables are winsorized at the 1% and 99% quantiles. This resulted in a total of 14,094 samples.

3.2. Indicator Construction

Table 1. Description of variables

Variable names and meanings	Symbols	Way to define
Enterprise innovation	LnCit	Total number of new patent citations per year +1, logarithm
Whether it is a heavy polluter	Treat	Dummy variable, if the enterprise is a heavy polluter, the value is 1, otherwise it is 0
New Environmental Protection Law	Post	Dummy variables, bounded by the implementation of the new Environmental Protection Law in 2015, are 0 before implementation and 1 after implementation
Enterprise scale	Size	Ln(Total assets)
Asset-liability ratio	Lev	Total liabilities/total assets
Nature of equity	Soe	Dummy variable, 1 for state-owned enterprises and 0 for non-state-owned enterprises
Cash flow ratio	Cashflow	Net cash flow from operating activities/operating income ∗100%
Ownership concentration	Top10	Shares held by the top 10 shareholders
Board size	Board	Ln(Number of corporate boards)
Percentage of independent directors	Indep	Percentage of independent directors on the board
Two roles in one	Dual	Dummy variable, 1 if there is chairman and CEO, 0 if not
Enterprise growth	Growth	Operating income growth rate
Profitability	ROE	Net return on assets
Research and development investment	Lnrds	R&D investment/operating income

Explained variable: Technological innovation is measured using the natural logarithm of the total number of new patent citations per year plus 1 (LnCit). While a higher number of patent applications indicates stronger innovation capability to some extent, it does not fully capture the quality of innovation. The number of patents cited provides a better reflection of patent quality, industry recognition, and sustainable value (Chen et al., 2020).

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Explanatory variable: 'New environmental protection law'. The analysis is based on the implementation of the new Law in 2015. Samples are selected according to the event year, comparing data before and after the implementation. The value is set to 0 for 2012-2014 and to 1 for 2015-2019.

Control variables: This study selects control variables from institutional environment dimensions, corporate governance, financial status, and enterprise size, setting a dummy variable for the year. ① Enterprise scale: Enterprise scale is regarded as a crucial factor affecting innovation (Bu et al., 2020), with R&D investment in larger enterprises being more stable. The logarithm of total assets at the year's end represents enterprise scale.②Asset-liability ratio: represented by "total liabilities/total assets"; ③ the nature of equity; ④Corporate governance: varies by board size, independent director proportion, senior executive characteristics, and education backgrounds, indirectly influencing innovation through decision-making efficiency; ⑤ Enterprise age: measured by the number of establishment years, indicating that older enterprises may have a stronger innovation tendency; ⑥ Current assets ratio: defined as "total current assets/total assets." Both asset-liability and current assets ratios measure solvency, with higher ratings facilitating technological innovation financing; ⑦Profitability: measured by net return on assets, reflecting enterprise profitability.

Detailed descriptions and statistics for each major variable are presented in Table 1.

3.3. Measurement Model

This study uses the 2015 implementation of the new Law as a quasi-natural experiment to assess its impact on the technological innovation of heavily polluting enterprises through a difference-in-differences method. The total number of patent citations for these enterprises post-2015 serves as the treatment group, while the total number of patent citations from 2012 to 2015 forms the control group. The policy's effect on enterprise technological innovation is evaluated using this framework. The metrological model is designed as follows:

$$LnCit_{it} = \beta_0 + \beta_1 Treat_i \times Post_t + \rho Control_{it} + \gamma_i + \alpha_t + \varepsilon_{it} \quad (1)$$

In this study, $LnCit_{it}$ represents enterprise technological innovation. $Treat_i$ indicates whether the variable is a heavy polluter, with a value of 1 if it is, and 0 otherwise. Post is a dummy variable for the implementation of the new Law, assigned 0 before 2015 and 1 afterward. Control variables include enterprise size ($Size_{it}$), enterprise age (Age_{it}), asset-liability ratio (Lev_{it}), cashflow ratio ($Cashflow_{it}$), equity nature (Soe_{it}), net profit rate on assets (ROE_{it}), and R&D investment ($Lnrds_{it}$), etc.

The focus is on the coefficient β_1 before the interaction term. A significantly positive estimated value indicates that the new Law significantly promotes technological innovation in heavily polluting enterprises. To account for industry differences, regional economic development levels, and dynamic economic changes, the model includes industry fixed effects (γ_i) and year fixed effects (α_t). ε_{it} represents a random disturbance term.

4. Analysis of Empirical Results

4.1. Descriptive Statistics

The descriptive statistical results of the main variables in Table 2 reveal that the standard error of technological innovation among heavy polluting enterprises is 1.538. This indicates significant heterogeneity in technological innovation within this group, with a relatively unbalanced distribution of innovation achievements. The mean value of Treat is 0.244, suggesting that heavily polluting industries constitute a notable portion of the entire industry

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and face considerable challenges in pollution control. Other variables fall within the normal range.

Table 2. Descriptive statistics of main variables

variable	N	mean	sd	min	max
LnCit	14094	3.066	1.538	0	7.402
treat	14094	0.244	0.430	0	1
Post	14094	0.721	0.448	0	1
Size	14094	22.27	1.234	19.57	26.39
Lev	14094	0.418	0.196	0.0350	0.927
ROE	14094	0.0570	0.131	0.962	0.397
Cashflow	14094	0.0470	0.0640	0.199	0.256
Growth	14094	0.170	0.398	0.582	3.894
Board	14094	2.127	0.197	1.609	2.708
Indep	14094	0.376	0.0540	0.313	0.600
Dual	14094	0.277	0.447	0	1
Top10	14094	0.572	0.146	0.217	0.907
SOE	14094	0.324	0.468	0	1
Age	14094	18.44	5.299	5	35
Lnrds	14094	0.980	1.263	3.912	3.274

4.2. Parallel Trend Test

Meeting the parallel trend hypothesis is essential for establishing the differential model. This means that before the implementation of the new Law, unobserved factors cause the experimental and control groups to follow the same change trend. However, post-implementation, the two sample groups exhibit different change trends. Only with the parallel trend hypothesis can the policy effect be accurately estimated. To test the prior parallel trend and any time-lag effects of policies, this study uses the research framework of Li et al. (2016) to analyze the dynamic effects of the new Law policies via the event study method. Specifically, the DID in equation (1) is replaced with a dummy variable for the years before and after the policy's implementation, while the dependent variable remains unchanged. The formula is as follows:

$$LnCit_{it} = \beta_0 + \prod_{n\geq -3}^{4} D_n \beta_n + \rho Control_{it} + \gamma_i + \alpha_t + \varepsilon_{it} \quad (2)$$

Where D_0 is the dumb variable of the year when the new Law was implemented, *n* negative number indicates *n* years before the implementation of the new Law, and positive number indicates n years after the implementation of the new Law. Figure 1 reports the regression coefficients corresponding to the estimated parameters$\{\beta_{-3}、\ \beta_{-2}、\ \ldots\beta_3、\ \beta_4\}$. It can be seen from FIG 1 that in 2015 and before, the estimated coefficient before the cross-fertilization term was not significant and contained zero value in the 95% confidence interval, indicating that the change trend of the treatment group and the control group was consistent without significant difference before the implementation of the policy. At the same time, due to the time-lag effect of the policy, the estimated coefficient in the year when the policy was implemented was also not significant. However, after the implementation of the policy, the estimated coefficient began to be significantly positive in 2016, and then the policy effect continued until 2019. Thus, the sample passes the parallel trend test required for DID. It also provides prima facie evidence for hypothesis H1A.

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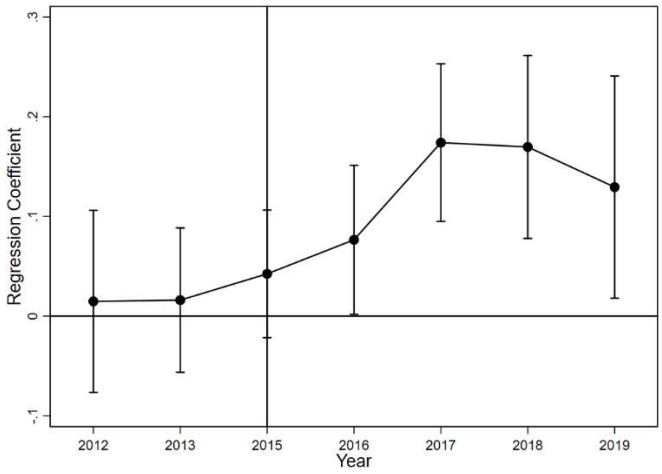

Fig. 1 Parallel trend test

4.3. Results of Empirical Test

Table 3. Benchmark regression results

	LnCit				
	(1)	(2)	(3)	(4)	(5)
Treat × Post	0.463***	0.358***	0.101***	0.360***	0.101***
	(15.18)	(11.51)	(2.98)	(11.57)	(2.96)
Size		0.558***	0.453***	0.570***	0.460***
		(16.95)	(14.24)	(17.20)	(14.34)
Lev		-0.144	0.109	-0.156	0.102
		(-1.42)	(1.13)	(-1.58)	(1.08)
ROE		0.112*	0.105*	0.110*	0.106*
		(1.72)	(1.74)	(1.70)	(1.75)
Growth		0.013	-0.052***	0.007	-0.058***
		(0.79)	(-3.27)	(0.42)	(-3.60)
Indep		-0.069	0.176	-0.058	0.193
		(-0.25)	(0.68)	(-0.21)	(0.76)
Board		-0.031	0.106	-0.027	0.108
		(-0.33)	(1.21)	(-0.29)	(1.23)
Top10		-0.968***	-0.732***	-0.929***	-0.694***
		(-6.44)	(-5.03)	(-6.21)	(-4.80)
Cashflow		-0.104	0.304**	-0.101	0.298**
		(-0.82)	(2.57)	(-0.80)	(2.54)
Dual		0.023	0.023	0.024	0.025
		(0.82)	(0.87)	(0.85)	(0.93)
SOE		-0.107	0.022	-0.093	0.038
		(-1.43)	(0.33)	(-1.25)	(0.56)
Age		-0.036***	-0.486*	-0.035***	-0.482*
		(-6.04)	(-1.86)	(-6.01)	(-1.84)
lnrds		0.114***	0.130***	0.106***	0.121***
		(5.40)	(6.27)	(5.00)	(5.85)
Constant	2.988***	-8.139***	-0.412	-8.525***	-0.629
	(579.93)	(-11.56)	(-0.11)	(-11.16)	(-0.16)
Year	NO	NO	Yes	NO	Yes
Ind	NO	NO	NO	Yes	Yes
N	14094	14094	14094	14094	14094
R^2	0.030	0.140	0.282	0.145	0.287

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This section evaluates the impact of the new Law on the technological innovation output of heavily polluting enterprises. Initially, equation (1) is estimated, with the results presented in Table 3. Column (1) shows the regression for the interaction terms of Treat and Post, while column (2) includes additional control variables. Column (3) and column (4) account for the year effect and industry effect respectively, and column (5) controls for both effects. The results reveal a positive relationship between the new Law and technological innovation output. The interaction term is significantly positive at the 1% level, indicating that the law significantly promotes technological innovation in heavily polluting enterprises. This may be because the law encourages these enterprises to address technical problems and enhance environmental protection standards. Consequently, pollution is reduced through technological innovation, and the enterprises' innovation capabilities are significantly improved. Even after pollution levels drop, these enterprises continue to focus on technological development to boost economic efficiency and environmental standards. Thus, the benchmark regression results confirm that the new Law positively incentivizes technological innovation in enterprises, supporting the verification of H1.

4.4. Robustness Test

4.4.1. Placebo Test

In the placebo test, the pseudo-policy occurrence time and the pseudo-treatment group and the control group were randomly generated to construct the pseudo-cross term, which was repeated 500 times. FIG 2 shows the estimated coefficient and probability density of the placebo test, where the distribution of the estimated coefficient is centered on 0, and the estimated coefficient (0.101) in the benchmark regression is much higher than 0, which supports the credibility of the conclusion.

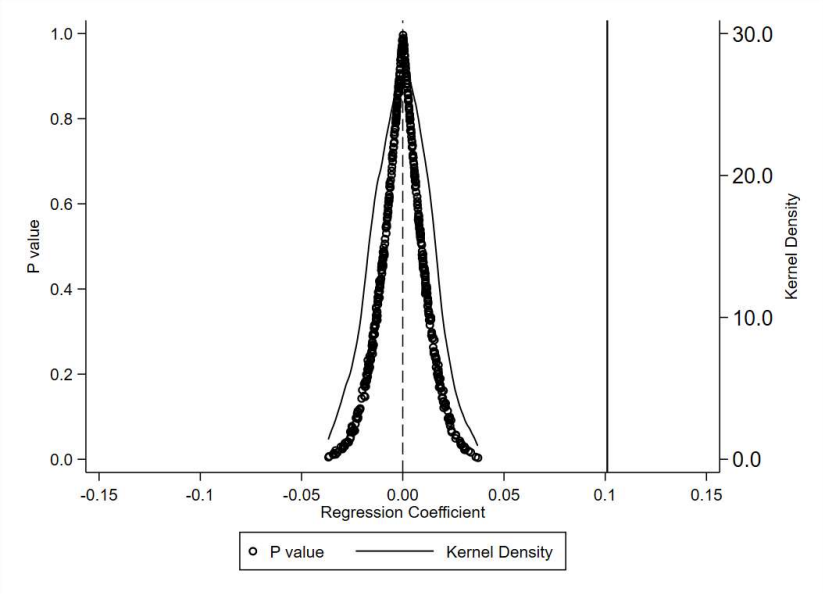

Fig. 2 Placebo test

The circle represents the estimated coefficient of the placebo test and the probability density, the curve is the kernel density fitting line, and the solid line represents the true coefficient estimate, which is the result shown in column (5) of Table 3.

4.4.2. Virtual Policy Time Points

To eliminate the interference of other policies on the regression results, this study follows Chen et al. (2015) and assumes the implementation times of the new Law as 2013 and 2019.

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Regression is performed on model (1) using samples from 2012-2014 (pre-implementation) and 2016-2019 (post-implementation). The results are presented in columns (1) and (2) of Table 4, showing that the study's conclusions are robust.

4.4.3. Change the Sample Period

This study uses the 2012-2019 interval for regression analysis. For robustness, model (1) is re-tested in two ways: First, the Law, passed by the Standing Committee of the National People's Congress in April 2014 and officially implemented in 2015, excludes samples from 2014 and 2015 from the regression. The results are shown in column (3) of Table 4. Secondly, the study accounts for the Green Credit Guidelines released in 2012, the State Council's 2013 Notice on the Action Plan for the Prevention and Control of Air Pollution, and the 2019 Soil Pollution Prevention and Control Law. To exclude the combined effects of these policies, only data from 2013 to 2017 are used in the regression. The results in column (4) of Table 4 confirm the robustness of the study's conclusions.

Table 4. Regression results of robustness test

	Virtual policy time points		Change sample interval	
	(1)	(2)	(3)	(4)
Treat×Post	0.050	0.034	0.147***	0.116***
	(0.043)	(0.043)	(0.046)	(0.045)
Control variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Constant	-0.601	-0.549	-2.871	-0.201
	(3.868)	(3.873)	(4.565)	(3.457)
N	14094.000	14094.000	10920.000	5085.000
Adj-R^2	0.285	0.284	0.308	0.409

4.5. Heterogeneity Analysis

4.5.1. Heterogeneity of Market Concentration

Whether the new Law can "back" the green innovation of heavy polluting enterprises is closely related to the market structure of the industry in which it is located. According to the research paradigm of "Market structure-Firm Behavior Performance" (SCP), enterprises in oligopolistic market structure can make price decisions and obtain super profits by virtue of their market power (Ding et al. 2010). As a result, enterprises in high-concentration markets have more funds to make up for the costs brought by the Law. Firms with lower market concentration have less price advantage and less negotiating power. The increased cost of pollution will not only have an impact on corporate performance, but also bring litigation risk. At this point, companies will tend to shift from passive payment of fines to proactive environmental governance. According to the resource-based view, in order to obtain profit space under the high pollution cost or avoid litigation risk, enterprises will reduce environmental pollution or improve resource utilization by means of technological innovation, thus forming long-term competitiveness and producing "compensation effect" on technological innovation cost. It is expected that the implementation of the new Law will have a more significant effect on the technological innovation of heavy polluting enterprises in low-concentration markets compared to high-concentration markets. To verify this, a group test was conducted based on industry concentration levels (HHI), distinguishing between above-average and below-average concentration. The results in columns (1) and (2) of Table 5 show that the law significantly promotes green innovation in heavy polluting enterprises in low-concentration markets but

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not in high-concentration ones. This indicates that the new Law effectively boosts technological innovation in heavy polluting enterprises within low-concentration markets.

4.5.2. Analysis of Regional Heterogeneity

There are clear differences in the marketization process and development levels between the eastern and the central and western regions. The eastern region, compared to the central and western regions, boasts higher economic development and relatively higher innovation and technology development. When the new Law increases pressure on enterprises to protect the environment, heavy polluting enterprises in the eastern region, unlike those in the western region, are more motivated and capable of technological innovation to maintain vested interests, thus improving resource utilization and reducing pollution. In this study, the samples are divided into eastern and central and western regions for subgroup testing based on the provinces where the enterprises are registered. The results of columns (3) and (4) of Table 5 show that the interaction term is significantly positive for enterprises in the eastern region, but not significant for those in the central and western regions. This verifies the effectiveness of the new Law on the technological innovation of heavily polluting enterprises in the eastern region.

4.5.3. Age Heterogeneity of Enterprises

Enterprise age often represents the maturity of the enterprise, and the higher the maturity of the enterprise, the stronger the awareness of technological innovation. Therefore, in the face of strict regulations, enterprises of different ages show different coping methods and capabilities. Because the life cycle and growth stage of enterprises are in different periods, these factors will directly affect the compliance cost of enterprises, and then affect the R&D investment of enterprises. Therefore, it is necessary to analyze the heterogeneity of the influence of the new Law on enterprises' age. As can be seen from column (5) of Table 4, after the implementation of the new Law, the impact of the new Law on the technological innovation of older enterprises is significantly positive at the 5% level, while the impact coefficient on the technological innovation of younger enterprises is not significant. This indicates that the promoting effect on older enterprises is more obvious, while the promoting effect on younger enterprises is not significant or the promoting effect has not yet appeared.

4.5.4. Heterogeneity of Corporate Internal Governance Level

From the perspective of enterprises, the root cause of technological innovation is market demand and profit maximization, and the progress of technological innovation activities depends on the corporate governance structure and model. Corporate governance and technological innovation are synchronized and interact. Different governance models have different impacts on technological innovation, and different governance levels make enterprises differ greatly in their sensitivity to market demand and input to technological innovation activities. Corporate governance, through institutional arrangements and constraints, has a profound impact on technological innovation decisions of enterprises. With different governance levels, there are significant differences in the incentives and constraints of firms' innovation input. From the conceptual and theoretical analysis of corporate governance and technological innovation, market demand and technological development affect the external governance environment of enterprises, thus affecting the transformation of corporate governance mode and promoting the emphasis and investment in technological innovation activities. In addition, there is also a significant correlation between internal governance and technological innovation, such as equity structure, board of directors system, board of supervisors system and executive incentive mechanism. Therefore, with reference to the practice of Lin Shu (2023), this paper selects 9 indicators including property right nature, executive compensation, executive shareholding ratio, independent director ratio, board size, institutional shareholding ratio, equity balance degree, dual role integration, and shareholding ratio of the largest shareholder, and constructs corporate governance index (CGI) with

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principal component analysis method. The first principal component obtained from the principal component analysis method is used as a comprehensive index reflecting the level of corporate governance. The higher the score, the better the level of corporate governance, and therefore the more significant the role of enterprise technological innovation. It can be seen from columns (7) and (8) in Table 5.

Table 5. Heterogeneity analysis

	(1)	(2)	(3)	(4)
	High market concentration	Low market concentration	Eastern	Midwest
Treat×Post	0.093	0.111***	0.110**	0.066
	(0.070)	(0.040)	(0.044)	(0.059)
Control variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
cons	-1.971	6.996	-1.721	3.054*
	(3.512)	(4.313)	(4.389)	(1.715)
N	4960.000	9134.000	9819.000	3691.000
Adj-R^2	0.232	0.322	0.290	0.295

Continuation of table 5

	(5)	(6)	(7)	(8)
	Older enterprise	Younger enterprise	High level of corporate governance	Low level of corporate governance
Treat×Post	0.126**	0.058	0.111**	0.074
	(0.061)	(0.045)	(0.044)	(0.056)
Control variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Cons	-7.770***	-7.094***	-1.227	-0.833
	(1.251)	(0.911)	(9.921)	(2.355)
N	6808.000	6252.000	7661.000	6433.000
Adj-R^2	0.253	0.375	0.270	0.299

5. Mechanism Analysis

Based on the above analysis, the new Law requires heavy polluting enterprises to enhance resource use efficiency and improve pollution reduction and emission reduction technologies. This results in higher transformation costs in production and operation, increased operational risks, and escalating financing difficulties. Environmental investment, characterized by high risk, long cycles, and large capital consumption (Tang et al., 2013), makes it challenging for heavy polluting enterprises to balance technological innovation and normal production without external financial support (Chen et al., 2021). Financing constraints significantly influence enterprises' choices of emission reduction methods. The study uses the SA index to examine how the new Law affects the external financing difficulties of heavy polluting enterprises. In Table 5, the interaction term in column (1) and (3) is significantly positive, indicating that financing constraints have intensified post-implementation. In column (2), the SA coefficient and the interaction term are significantly positive, showing that the new Law compels heavy polluting enterprises to innovate technologically by increasing external financing difficulties.

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Table 6. Mechanism analysis

	(1)	(2)	(3)
	LnCit	SA_index	LnCit
Treat×Post	0.101***	0.009***	0.095***
	(0.034)	(0.003)	(0.034)
SA_index			0.584**
			(0.265)
Control variables	Yes	Yes	Yes
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes
Cons	-0.629	-2.422***	0.786
	(3.864)	(0.615)	(3.716)
N	14094.000	14094.000	14094.000
Adj-R^2	0.285	0.856	0.286

6. Conclusion and Implications

This paper examines the new Law as a natural experiment to assess its micro-policy effect on technological innovation. The findings indicate that the law enhances technological innovation in heavy polluting enterprises, consistent with Porter's hypothesis. Moderate environmental regulation stimulates technological innovation and provides significant positive incentives. This conclusion holds after robustness tests including placebo tests, virtual policy time points, and sample adjustments, demonstrating that environmental regulation supports high-quality economic development. The heterogeneity analysis reveals that the law's incentive effect on technological innovation is significant mainly in the eastern region, where market concentration is low, enterprises are older, and corporate governance is strong. This study enriches research on technological innovation by evaluating the law's impact from a micro perspective, testing the effects of policies and regulations, and combining macro-innovation mechanisms with market operations. The findings provide valuable insights for China in forming relevant policies and regulations. The empirical evidence on technological innovation in heavy polluting enterprises offers reference points for policy formulation and supports the development of green finance.

Based on the research conclusions of this paper and the development status at home and abroad, the following policy suggestions are put forward: First, Enhance the willingness of heavy polluting enterprises to disclose sustainable development information, improve their environmental awareness, and stimulate the motivation for independent research and development. The government should also strengthen supervision, enforce relevant laws and regulations, and promote technological progress in these enterprises through guidance and constraints; Second, Address regional and age-related differences in enterprise development by implementing targeted environmental management. The "government-market-society" coordination mechanism should be leveraged to support the innovative development of heavy polluting enterprises in constructing ecological civilization; Third, the "suitability" of environmental regulations should be taken into account when implementing them. According to the characteristics of local resource endowment, the government should analyze the driving force for supporting the technological innovation output of local heavy polluting enterprises, and formulate innovation incentive policies suitable for the development of local enterprises from the actual development situation, so that it can become a powerful starting point for promoting development; Fourth, Emphasize the importance of innovative development, particularly green development. Enterprises should increase investment in innovation and

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improve environmental protection efforts, improve resource utilization efficiency and achieve sustainable development by strengthening technology research and development.

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