The Impact of Carbon Trading Policies on Technological Innovation in Chemical Enterprises

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Abstract. As a pivotal market-based environmental instrument,carbon trading policy plays a significant role in driving the green transformation of the chemical industry.Grounded in New Institutional Economics,the Porter Hypothesis,and Decoupling Theory,this study utilizes a multi-period difference-in-differences(DID)model and panel data from 308 listed chemical firms(2009–2023)to evaluate the policy's causal effect on technological innovation.The results indicate that the policy raises the overall level of technological innovation by 13.5%on average;however,this effect is entirely driven by non-state-owned enterprises(non-SOEs),with no significant impact observed in state-owned firms(SOEs).Further mechanism analysis reveals that non-SOEs respond to the policy mainly through cost constraints and market incentives,whereas SOEs tend to rely on purchasing quotas,which suppresses their innovation motivation.Moreover,the increase in institutional shareholding is identified as a key channel through which the policy spurs innovation in non-SOEs.The application of computational methods in this study also enhances the accuracy and robustness of the empirical evaluation.Based on these findings,policy recommendations are proposed,including optimizing quota allocation mechanisms,linking emission-innovation performance with subsidy incentives for SOEs,and establishing technology sharing platforms to support non-SOEs.

Keywords: Carbon Trading Policy, Chemical Enterprises, Multi-period Difference-in-Differences, Technological Innovation

1 Introduction

The chemical industry,a major driver of China's economic growth since the reform and opening-up, is also characterized by high pollution and high emissions. These have contributed to severe environmental challenges over the past two decades, including persistent smog and frequent extreme weather events. For instance, in 2013, the average PM2.5 concentration in the Beijing-Tianjin-Hebei region reached 106 μg/m³—far exceeding the WHO standard of 10 μg/m³—with 71 of 74 key Chinese cities failing to meet air quality standards, posing serious public health risks. This has

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called into question the sustainability of the extensive economic growth model previously pursued.Globally, many countries have faced similar environmental issues. The European Union launched the EU Emissions Trading System (EU ETS) in 2005, inspiring other nations to adopt carbon trading mechanisms. In response, China initiated pilot carbon trading policies in 2013, 2014, and 2016, and further committed to its "dual carbon" goals in 2020.

China's carbon trading policy and "dual carbon" goals compel chemical enterprises to innovate, forcing a choice between technological upgrades to cut emissions or increased costs to buy quotas. This pressure, coupled with the national shift toward high-quality economic growth, makes innovation vital for the industry's green, high-end transition and sustained contribution to the economy.

2 Literature Review

While literature on carbon trading has matured,covering market models[1],green innovation impacts[23],and policy optimization[4],a significant gap remains in micro-level,industry-specific mechanism analysis.Most studies operate at a macro level,lacking evidence from specific high-pollution sectors like the chemical industry.This study contributes by:(1)integrating emissions rights and decoupling theories to extend beyond the Porter Hypothesis;(2)providing micro-level evidence from the chemical industry;and(3)identifying institutional shareholding as a core transmission mechanism through a multi-period DID model.

3 Theoretical Mechanisms and Research Design

3.1 Theoretical Mechanisms

Drawing on New Institutional Economics,Porter Hypothesis,and Decoupling Theory,we posit that carbon trading policy promotes innovation through market mechanisms and financial incentives[5].However,ownership heterogeneity is expected due to Lin's(2004)"SOE efficiency paradox"[6],where SOEs may rely on quota purchases rather than innovation.Furthermore,the policy may spur innovation by attracting ESG-focused institutional investors[7].This leads to three testable hypotheses:

H1:Carbon trading policies promote technological innovation in chemical enterprises.

H2:The effect is stronger for non-SOEs than SOEs.

H3:The policy works through increasing institutional shareholding.

3.2 Research Design

3.2.1 Variable Selection.

Explained variable:Technological innovation of chemical enterprises(Lnp). Indicators for measuring corporate technological innovation mainly include the number of patent applications,the number of patent authorizations,and R&D investment.Considering data availability and missing data in some years,this paper refers to the method of Li Yuhua et al.(2024)and measures the technological innovation of listed chemical enterprises by taking the logarithm of(the number of patent applications+1).To enhance computational accuracy,we applied a logarithmic transformation algorithm to normalize the patent data,which is expressed as:

$$\mathrm{Lnp} = \ln(\mathrm{Patene\ Applications} + 1)$$

The core explanatory variable is DID.Enterprises in pilot regions constitute the treatment group,where DID is coded 0 before policy implementation and 1 from the implementation period onward.Enterprises outside these regions form the control group,for which DID is consistently set to 0.

Control variables Include enterprise size(Size),measured as the logarithm of total assets in 100 million yuan;asset-liability ratio(Lev),defined as total liabilities divided by total assets;return on assets(ROA),calculated as net profit to total assets;enterprise growth(Growth),measured by operating income growth rate;and enterprise age(Age),defined as years since establishment.

3.2.2 Model Construction.

The multi-period Difference-in-Differences(DID)method can avoid potential concurrent trends of confounding treatment effects,making research results more accurate.It can more precisely reflect the heterogeneous impacts of policies on different individuals at different time points and provide more robust and reliable findings.Therefore,the multi-period DID method can effectively evaluate the effects of a certain policy implemented in different periods.In China,the pilot regions for the carbon trading policy were Beijing,Shanghai,Guangdong,and Tianjin in 2013;Hubei and Chongqing in 2014;and Fujian and Sichuan in 2016.This paper adopts the multi-period DID method to study the impact of carbon trading policies on the technological innovation of chemical enterprises and constructs the following multi-period DID model:

$$\mathrm{Lnp}_{it}=\beta_0+\beta_1\mathrm{DID}_{it}+\alpha X_{it} + \gamma_i+\theta_t+\varepsilon_{it} \tag{1}$$

Among them,i represents a chemical enterprise,t represents the year,Lnp_{it}denotes the technological innovation of the chemical enterprise,DID is the policy dummy variable,X_{it}stands for control variables,$\gamma_i$and$\theta_t$represent the individual fixed effect and time fixed effect respectively,and$\varepsilon_{it}$is the error term of the model.The estimation is performed using matrix-based computational routines optimized for large panel datasets.

3.2.3 Data Sources.

This paper selects data from 308 listed chemical enterprises from 2009 to 2023. Patent data is sourced from MarkData, and control variables are from the CSMAR Database. We employ automated data cleaning and imputation algorithms to handle missing values using linear interpolation. To eliminate the impact of extreme values, we apply a Winsorization algorithm at the 1% and 99% levels, implemented via Python-based data preprocessing pipelines.

4 Empirical Results and Analysis

4.1 Baseline Regression

The estimation results from the multi-period DID model are presented in Table 1. Across all specifications—without controls or fixed effects (Column 1), with controls only (Column 2), with fixed effects only (Column 3), and with both controls and fixed effects (Column 4)—the coefficient of the DID variable remains significantly positive, confirming the robustness of the core finding. This indicates that carbon trading policies incentivize chemical enterprises to proactively invest in technological innovation to mitigate compliance costs and enhance competitiveness, thereby validating Hypothesis 1. Economically, these policies raise the average level of technological innovation in chemical enterprises by 13.5%.

4.2 Parallel Trend Test

To ensure the validity of the multi-period DID model, a parallel trend test was conducted. This test examines whether the treatment and control groups exhibited similar trends in technological innovation before the policy intervention.

Given the staggered implementation of the carbon trading policy across pilot regions, the test was performed using an event-study approach. To mitigate multicollinearity, the period immediately preceding the policy was omitted. Data from five or more years prior to implementation were consolidated into a single pre-period, while data from seven or more years after were grouped into a single post-period.The results, shown in Fig. 1, indicate that the estimated coefficients for the pre-treatment periods were statistically insignificant, confirming parallel pre-trends. Significant coefficients emerged in the policy implementation period and several subsequent periods, demonstrating a treatment effect and validating the use of the multi-period DID model.

Table 1. Baseline Regression Results

Variable	(1) Lnp	(2) Lnp	(3) Lnp	(4) Lnp
DID	0.816***	0.333***	0.144**	0.135*
	(0.0655)	(0.0665)	(0.0730)	(0.0729)
Size		0.0690**		-0.0379
		(0.0270)		(0.0312)
Lev		0.193**		0.341***
		(0.0790)		(0.0830)
ROA		-0.178		-0.0608

		(0.142)		(0.149)
Growth		0.0124		0.00150
		(0.0162)		(0.0168)
Age		0.0588***		0.0344
		(0.00459)		(0.0329)
Constant	1.469***	-0.936*	0.788***	1.204*
	(0.0526)	(0.524)	(0.0555)	(0.691)
Control Variable	No	Yes	No	Yes
Individual Fixed Effect	No	Yes	Yes	Yes
Time Fixed Effect	No	No	Yes	Yes
Observations	4620	4620	4620	4620
R-squared			0.154	0.159
Number	308	308	308	308

Note: Values in parentheses represent robust standard errors;***,**,and*indicate significance levels of 1%,5%,and 10%respectively.The same notation applies to subsequent tables.

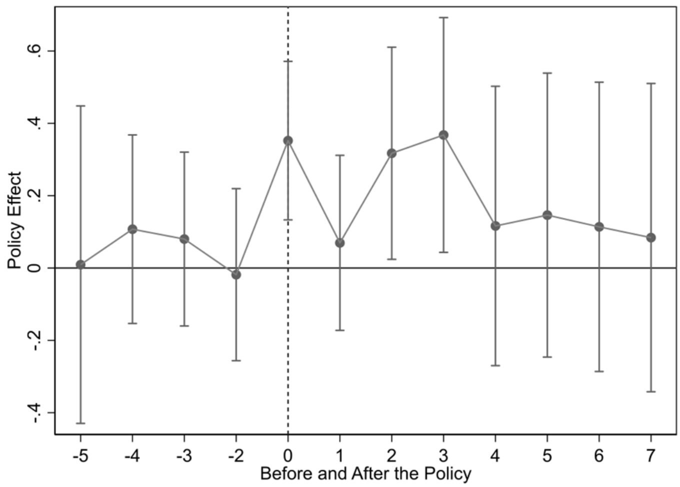

Fig. 1. Parallel Trend Test

4.3 Robustness Tests

4.3.1 Placebo Test.

To rule out the influence of unobservable events, this paper conducts a placebo test using a computational simulation approach—randomly assigning policy implementation times and pilot regions. The kernel density estimation of t-values is performed via a Monte Carlo-style resampling algorithm, and the results, as shown in Fig. 2, confirm the robustness of the baseline findings.

4.3.2 Winsorization.

To avoid the impact of outliers on the regression results of this study,all continuous variables were subjected to Winsorization at the 1%and 99%levels before conducting the baseline regression.For the rigor of the results,an additional Winsorization was performed on the continuous variables at the 5%and 95%levels.The regression results are presented in Table 2, where the coefficients remain significantly positive,further validating Hypothesis 1.

4.3.3 Excluding the Impact of Major Events.

To rule out the impact of the COVID-19 pandemic—a major event—on the regression results,this study follows the approach of Chen Lin et al.(2024)by excluding data from 2020 in the regression analysis.The regression results are presented in Table 3, where the coefficients remain significantly positive.This indicates that the carbon trading policy exerts a positive promotional effect on the technological innovation level of chemical enterprises,further validating Hypothesis 1.

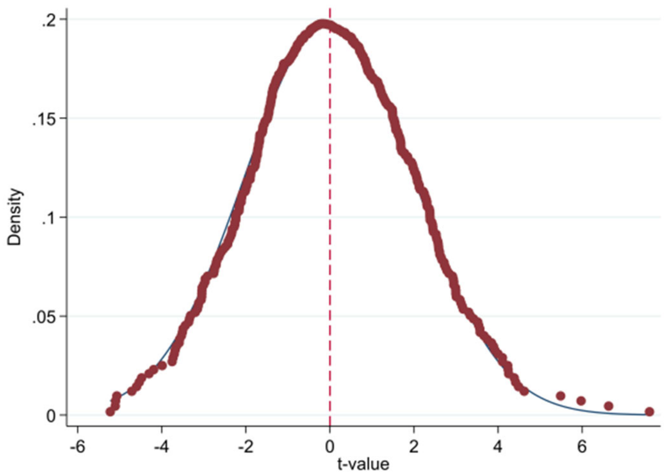

Fig. 2. Placebo Test

Table 2. Regression Results of Continuous Variables with Winsorization at the 5% and 95% Levels

Variable	(1) Lnp	(2) Lnp	(3) Lnp	(4) Lnp
DID	0.799***	0.341***	0.145**	0.125*
	(0.0640)	(0.0652)	(0.0716)	(0.0716)
Size		0.0852***		-0.0428
		(0.0316)		(0.0374)
Lev		0.204*		0.413***
		(0.104)		(0.111)

ROA		-0.497**		-0.341*
		(0.196)		(0.207)
Growth		0.0295		0.00846
		(0.0276)		(0.0287)
Age		0.0567***		-0.0275
		(0.00475)		(0.0178)
Constant	1.452***	-1.249**	0.785***	1.904**
	(0.0506)	(0.616)	(0.0545)	(0.765)
Observations	4620	4620	4620	4620
R-squared			0.153	0.158
Number of id	308	308	308	308

Table 3. Regression Results with 2020 Data Excluded

Variable	(1) Lnp	(2) Lnp	(3) Lnp	(4) Lnp
DID	0.819***	0.357***	0.169**	0.161**
	(0.0665)	(0.0676)	(0.0741)	(0.0740)
Size		0.0796***		-0.0288
		(0.0275)		(0.0321)
Lev		0.161**		0.306***
		(0.0810)		(0.0857)
ROA		-0.222		-0.110
		(0.146)		(0.155)
Growth		0.00706		-0.00423
		(0.0167)		(0.0174)
Age		0.0559***		0.0426
		(0.00468)		(0.0337)
Constant	1.442***	-1.116**	0.788***	0.952
	(0.0524)	(0.534)	(0.0553)	(0.711)
Control Variable	No	Yes	No	Yes
Individual Fixed Effect	No	No	Yes	Yes
Time Fixed Effect	No	No	Yes	Yes
Observations	4312	4312	4312	4312
R-squared			0.154	0.158
Number of id	308	308	308	308

4.4 Heterogeneity Analysis

To assess the heterogeneous effects of the carbon trading policy by ownership type, this study divides the sample into state-owned enterprises (SOEs) and non-SOEs. Regression results from the multi-period DID model (Table 4) show a significantly positive coefficient for non-SOEs, indicating the policy effectively stimulated their technological innovation, likely to avoid the cost of purchasing carbon allowances. In contrast, the coefficient is significantly negative for SOEs, suggesting the policy may have suppressed their innovation, possibly because they rely on government financial support to buy allowances, reducing innovation incentives. These findings confirm Hypothesis 2.

4.5 Mechanism Test: Institutional Shareholding Ratio

The carbon trading policy attracts ESG-oriented institutional investors by creating emission reduction pressure. These investors promote corporate innovation by increasing R&D investment and improving governance to reduce managerial short-termism. As shown in Table 5, the policy significantly increases institutional shareholding in non-SOEs, consistent with previous findings that institutional ownership promotes innovation in non-SOEs but may hinder it in SOEs (Wen and Feng, 2012). This mechanism explains the heterogeneous effects: the policy boosts innovation in non-SOEs through increased institutional ownership, while its negligible impact on SOEs' institutional shareholding results in no significant innovative response, thus confirming Hypothesis 3.

Table 4. Heterogeneity Analysis Results

Enterprise Nature	(1) SOEs	(2) Non-SOEs	(3) SOEs	(4) Non-SOEs
DID	-0.376**	-0.344**	0.293***	0.276***
	(0.147)	(0.148)	(0.0840)	(0.0842)
Size		0.0985*		-0.0903**
		(0.0596)		(0.0369)
Lev		0.554***		0.254***
		(0.182)		(0.0967)
ROA		-0.216		0.0714
		(0.363)		(0.166)
Growth		-0.0657**		0.0206
		(0.0327)		(0.0197)
Age		0.0190		0.0319
		(0.0537)		(0.0415)
Constant	0.940***	-1.608	0.734***	2.270***
	(0.106)	(1.367)	(0.0649)	(0.807)
Control Variable	No	Yes	No	Yes
Individual Fixed Effect	Yes	Yes	Yes	Yes
Time Fixed Effect	Yes	Yes	Yes	Yes
Observations	1215	1215	3405	3405
R-squared	0.109	0.130	0.178	0.181
Number of id	81	81	227	227

Table 5. Mechanism of the Impact on Institutional Shareholding Ratio

Institutional Shareholding Ratio	(1) Full Sample	(2) SOEs	(3) Non-SOEs
DID	0.0303***	-0.00358	0.0525***
	(0.0109)	(0.0168)	(0.0146)
Size	0.0684***	0.0744***	0.0641***
	(0.00532)	(0.00852)	(0.00705)
Lev	-0.178***	-0.207***	-0.145***
	(0.0214)	(0.0376)	(0.0277)
ROA	0.146***	-0.0306	0.213***
	(0.0454)	(0.0766)	(0.0576)
Growth	0.0225***	0.0183*	0.0260***
	(0.00622)	(0.00952)	(0.00826)
Age	-0.00548*	-0.00978**	0.00140
	(0.00287)	(0.00414)	(0.00419)
Constant	-0.899***	-0.803***	-0.984***
	(0.111)	(0.183)	(0.144)
Observations	2610	856	1754
R-squared	0.119	0.156	0.128
Number of id	308	81	227

5 Conclusions and Recommendations

5.1 Conclusions

Supporting China's"dual carbon"objectives requires emission reduction through innovation in the chemical industry.This study,utilizing a multi-period DID model,demonstrates that the carbon trading policy boosts technological innovation by 13.5%on average.This aggregate effect,however,masks significant heterogeneity:it is entirely driven by non-state-owned enterprises,while state-owned firms show no significant response.Mechanism analysis indicates the policy works by attracting institutional investors,which promotes innovation in non-SOEs.The application of computational methods,such as data preprocessing algorithms and econometric software,underpins the robustness of these results. Looking ahead, the integration of machine learning techniques to forecast carbon price volatility and optimize dynamic quota allocation presents a promising avenue for enhancing market efficiency. Furthermore, future research should strive to incorporate a broader set of variables, such as inter-regional market linkages, supply chain pressures, and evolving consumer preferences for green products, to build a more holistic understanding of the innovation dynamics within the carbon-constrained chemical sector.

5.2 Suggestions

To advance China's carbon market,a multi-faceted approach is essential.Regulators should focus on enhancing market pricing,stability,and transparency,potentially through the adoption of blockchain and AI for dynamic quota management.Concurrently,the allocation of allowances within the chemical industry must be refined to prioritize fairness and efficiency.

For state-owned enterprises(SOEs),a fundamental shift from policy dependency to innovation-led growth is critical.This entails increasing R&D investment,integrating innovation into performance evaluations,and attracting high-tech talent.Regulators can incentivize this shift by linking carbon allowance allocation directly to R&D input and innovation outcomes.

Non-state-owned chemical enterprises should leverage their market agility to establish a virtuous cycle where emission reduction lowers costs and creates value.This can be achieved by investing in carbon-reduction technologies,engaging in surplus allowance trading,and boosting innovation capacity through digital transformation.Government-supported technology sharing platforms can further reduce R&D costs and foster industry-wide collaboration.

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