Mathematical Modeling and Algorithm Application
ISSN: 3006-0842 | Vol. 6, No. 3, 2025

A Study on the Impact Pathways and Heterogeneous Effects of Carbon Pricing on Corporate Green Transformation Based on the Multi-Period Double Difference Method

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Abstract: Using a multi-period difference-in-differences approach and a sample of Chinese A-share listed companies from 2009 to 2020, this study systematically examines the transmission channels and heterogeneous effects of carbon pricing on corporate green transformation. Findings reveal that rising carbon prices significantly accelerate corporate green transformation through a "mandatory" mechanism, with this effect being more pronounced in state-owned enterprises and high-carbon emission industries. Mechanism tests indicate that carbon pricing indirectly drives transformation via three pathways: incentivizing green innovation, alleviating financing constraints, and enhancing environmental information transparency. This study offers innovation and significance in the following dimensions: Theoretically, it extends the "Porter Hypothesis" to market-based environmental regulation, revealing the micro-incentive logic of carbon pricing. Methodologically, it constructs a multi-period DID model with interaction terms for intensity variables to enhance causal identification precision. Policy-wise, it provides empirical evidence for designing differentiated carbon markets and supporting green initiatives in private enterprises, offering valuable insights for achieving China's dual carbon goals.

Keywords: Carbon pricing, Green transformation, Difference-in-differences.

1. Introduction

1.1. Background

Global warming caused by greenhouse gas emissions presents a worldwide challenge. As a responsible major power, China has solemnly pledged to achieve carbon peak by 2030 and carbon neutrality by 2060. The establishment of the national carbon emissions trading market signifies China's gradual transition toward market-based environmental governance driven by economic incentives. Within this framework, carbon pricing is no longer an "external cost" but a critical factor influencing corporate profitability and strategic decisions. Theoretically, fluctuations in carbon prices should compel enterprises to increase investments in process optimization and technological innovation to counteract rising carbon costs. This aligns with the "Porter Hypothesis," which posits that moderate environmental regulation can stimulate corporate innovation, enhancing overall competitiveness and green performance. However, current research on how carbon prices indirectly influence corporate ESG performance through internal incentive mechanisms remains insufficient. Specifically, the identification of causal relationships, transmission pathways, and boundary conditions at the micro-firm level has not been systematically explored. Therefore, this study addresses the core questions: How can we identify the causal relationship between rising carbon prices and the degree of corporate green transformation? Does this driving effect exhibit heterogeneity based on firm ownership structure and carbon emission intensity? And through which internal mechanisms—green innovation, financing constraint mitigation, or environmental disclosure—does this effect transmit? To address these questions, this paper utilizes a sample of A-share listed companies from 2009 to 2020. Employing a Difference-in-Differences framework and introducing carbon price as a treatment intensity variable, we construct a regression model incorporating the Treat×Post×Price interaction term to identify the causal effects and heterogeneity of carbon pricing on corporate green transformation. Subsequently, parallel trend tests and multiple robustness checks ensure the model's applicability and the reliability of the results. Finally, Heckman's two-step method is employed for mechanism testing to explore the underlying mechanisms through which carbon prices influence corporate green transformation. The research methodology employed in this study effectively controls for unobservable fixed factors and common temporal trends, thereby isolating the "net effect" of carbon pricing policies. This approach enables a more reliable identification of causal relationships between policy interventions and outcomes. By establishing an experimental group and a control group, and comparing their differences in green transition performance before and after policy implementation, the study provides robust evidence for the incentive effects of carbon pricing.

1.2. Theory and Literature Review

1.2.1. Factors Influencing Corporate Green Transformation

Corporate green transformation refers to a development model guided by sustainable development principles, driven by green growth and development concepts, and centered on green innovation. It aims to achieve the dual objectives of energy conservation, emission reduction, and efficiency improvement while pursuing a win-win outcome that benefits both environmental and economic outcomes[1].

Factors influencing corporate green transformation encompass both external and internal elements. External

factors primarily involve environmental regulations, with extensive research examining corporate green transformation from the perspective of government oversight. To prevent pollution and curb environmental degradation, governments have intensified environmental monitoring and enacted stringent regulations. Stakeholders such as consumers, competitors, and investors drive corporate green transformation by influencing product sales and creating competitive advantages[2]. Internal factors primarily impact green transformation through capital flows; for instance, equity pledging by controlling shareholders may reduce a company's willingness and capacity for green transformation[3]. Conversely, expanded corporate investment and green technological innovation can enhance green transformation outcomes through economies of scale and competitive effects[4].

1.2.2. Research on Carbon Trading Mechanisms

As a quintessential market-based instrument for internalizing pollution costs, carbon emissions trading serves as a crucial institutional design for driving corporate green transformation. Existing literature indicates that China's carbon market exhibits a dual nature of market mechanisms coexisting with administrative intervention. While carbon prices and market liquidity possess incentive effects, they remain significantly influenced by policy regulation[5]. Hu Jun et al. utilized carbon trading pilot programs as quasi-natural experiments, finding they significantly enhanced the total factor productivity of emission-controlled enterprises, though no discernible spillover effects emerged[6]. Other research indicates the carbon market exhibits pronounced economies of scale, where market expansion boosts emission reduction efficiency while synergistically reducing other pollutant emissions[7].

Regarding carbon pricing mechanisms, some studies using CGE models assessed macroeconomic impacts, concluding that excessively high carbon prices effectively reduce carbon intensity and energy intensity but negatively affect output in the short term[8]. While such literature has expanded understanding of carbon markets' macroeconomic performance, systematic research remains scarce at the micro level—particularly regarding how firms adjust green strategies in response to carbon price signals.

In summary, academic studies have revealed the economic effects of ESG ratings through financial performance and financing costs, and have conducted in-depth analyses of carbon trading's macro-level impacts. However, insufficient research exists on how carbon prices indirectly influence corporate ESG performance through internal incentive mechanisms (e.g., R&D investment). Therefore, this paper proposes to use carbon prices as the starting point, introducing corporate R&D investment as an intermediary variable to examine its impact pathway on ESG performance. It aims to reveal the synergistic effects between external policy tools and internal corporate governance, providing insights for refining carbon market policies and the green finance system.

2. Research Design

2.1. Sample Selection and Data Sources

Considering that China's carbon emission rights trading policy was implemented between 2013 and 2014, this study focuses on A-share listed companies from 2009 to 2020. The relevant data mainly include carbon prices of various carbon markets (manually collated from carbon market information), financial data of listed companies (sourced from the CSMAR database), and ESG scores (sourced from the Wind database). To ensure data validity, the following samples are excluded: ① ST, *ST, and PT stock samples; ② samples of companies in the financial and insurance industries; ③ samples with missing data. After the above processing, a panel dataset consisting of 42,694 observations from listed companies over 12 years is obtained, with descriptive statistics shown in the following table 1:

Table 1 Descriptive Statistics Results

Variable Type	Variable Name	Indicator Meaning	Observations	Mean	Standard Deviation	Minimum	Maximum
Dependent Variable	Escore	Corporate green transformation (ESG score)	42,694	1.925	1.138	1	9
Independent Variables	treat	1 if the company is within the carbon emission pilot area, otherwise 0	42,694	0.395	0.489	0	1
	price	Carbon price	8,124	40.100	19.930	2.748	89.560
	post	1 if the fiscal year is later than the implementation time of the carbon trading policy, otherwise 0	42,694	0.604	0.489	0	1
	treat_post	Interaction term of treat and post	42,694	0.238	0.426	0	1
	treat_post_price	Interaction term of treat, post, and price	8,124	35.950	23.410	0	89.560
Control Variables	age	Company age	42,694	16.790	6.145	0	70
	roa	Return on assets	42,694	0.047	0.076	-2.834	0.974
	level	Leverage ratio	42,694	0.386	0.209	0.007	1.957
	tobinsq	Tobin's Q	42,644	1.530	4.241	0	715.900
	largest_holder	Largest shareholder's shareholding ratio	42,644	25.890	20.220	0	99
	institutional_holder	Institutional investor's shareholding ratio	42,644	32.850	29.090	0	101.100

Due to the lagged effect of the carbon emission rights trading policy and the fact that the first transactions of carbon markets such as Beijing and Shenzhen all occurred at the end of the year, this study refers to existing research and takes the second year after the policy implementation as the shock point of the quasi-natural experiment. In addition, considering the lag and stickiness of ESG scores, this study lags the ESG scores by another year to better explain the time lag and transmission effect in the policy implementation process.

2.2. Model Specification and Variable Explanation

To identify the causal impact of the carbon trading policy on corporate green transformation, this study first constructs a benchmark regression model based on the Difference-in-Differences (DID) framework. Subsequently, carbon price is introduced as a treatment intensity variable, and the model is further extended to a multi-period DID model and a mechanism test model to explore the path through which carbon prices promote corporate green transformation by improving information disclosure transparency. Based on this, the benchmark regression model of this study is:

$$\mathrm{Escore}_{i,t+1} = \alpha_0 + \alpha_1 \mathrm{treat}_i \times \mathrm{post}_t \times \mathrm{price}_{i,t} + \alpha_2 \mathrm{treat}_i + \alpha_3 \mathrm{post}_t + \alpha_4 \mathrm{price}_{i,t} + \sum \mathrm{Control}_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

Different from previous studies that only focus on the impact of carbon emission rights trading on green transformation, this study adds the interaction term of carbon price to the traditional DID experiment, taking A-share listed companies as the research object to explore the impact of carbon price levels on the degree of their green transformation.

Where subscripts i and t represent the company and year, respectively. The dependent variable Escore is the ESG score of the company in year $t+1$. Treat is a dummy variable for the treatment group, taking the value of 1 if the company is within the carbon emission pilot area (8 provinces and cities including Beijing and Shenzhen), otherwise 0. Post

is a time dummy variable, taking the value of 1 if the fiscal year is later than the implementation time of the carbon trading policy, otherwise 0. $Treat \cdot Post \cdot Price$ is the key variable in the regression model, which truly measures the effect of the experimental group affected by carbon trading and carbon prices. Control is a combination of control variables. To minimize errors caused by omitted variables, this study selects company age, return on assets, leverage ratio, Tobin's Q, largest shareholder's shareholding ratio, and institutional shareholding ratio as control variables. μ_i is the company fixed effect, λ_t is the year fixed effect, and $\varepsilon_{i,t}$ is the random error term.

3. Empirical Results Analysis

3.1. Benchmark Regression

The benchmark regression results of the impact of carbon emission rights trading on corporate green transformation are shown in Table 2. In columns (1) and (2), the core explanatory variable is treat_post , while in the other columns, treat_post_price is used to represent the combined effect of carbon price shock and policy implementation. Regressions (1) and (3) do not introduce control variables, only comparing the green transformation differences between pilot and non-pilot areas after the implementation of the carbon trading policy; columns (3) to (6) introduce control variables, columns (5) and (6) introduce two levels of fixed effects, and cluster by company.

Table 2 Benchmark Regression Results

Variables	(1) M1: Base	(2) M2: +Controls	(3) M3: Alt Spec	(4) M4: Full	(5) M5: +Ind FE	(6) M6: +Ind×Year FE
treat	-0.180*** (0.033)	-0.213*** (0.033)	-0.159*** (0.0131)	-0.159*** (0.0130)	-0.148*** (0.0320)	-0.147*** (0.0324)
post	0.076*** (0.016)	0.029 (0.018)	0.0899*** (0.0120)	0.114*** (0.0128)	0.0908*** (0.0173)	-
treat_post	0.072*** (0.024)	0.074*** (0.023)	-	-	-	-
treat_post_price	-	-	0.00131*** (0.000387)	0.00152*** (0.000385)	0.00184*** (0.000678)	0.00172** (0.000718)
Control Variables	No	Yes	No	Yes	Yes	Yes
Industry Fixed Effects	No	No	No	No	Yes	No
Industry × Year Fixed Effects	No	No	No	No	No	Yes
Obs.	42,694	42,644	42,694	42,644	42,644	42,637
R^2	0.006	0.051	0.006	0.021	0.044	0.065

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

Specifically, in column (1), the coefficient of treat_post is 0.072, which is significant at the 1% significance level, indicating that the implementation of the carbon emission rights trading policy has significantly promoted the green transformation of enterprises in pilot areas. In column (2), after adding control variables, the result remains robust, with the coefficient of treat_post being 0.074, still significant at the 1% significance level, indicating that the policy impact is not driven by differences in enterprise size, profitability, corporate governance, etc. In columns (3) to (6), treat_post_price is used to represent the interactive impact of the carbon price mechanism and policy implementation. This variable is positive in all models and significant at the 1% significance level (e.g., the coefficient in column (4) is 0.002, significance level 1%), which further verifies that a higher carbon price has a positive incentive effect on corporate green transformation in the context of policy implementation.

In addition, after introducing industry fixed effects in column (5), the treat_post_price variable is still positive and significant, indicating that the role of carbon prices in promoting green transformation is not caused by industry selection bias; after further introducing industry × year fixed effects in column (6), the result remains robust, controlling for the dual impact of industry heterogeneity and time trends, and enhancing the identification power. Due to space limitations, this study does not list the regression results of control variables one by one, but it is certain that even with the introduction of control variables, the carbon emission rights trading policy and its formed carbon price mechanism have a clear positive effect on significantly improving the level of corporate green transformation, and this impact still exists after controlling for various robustness tests and fixed effects, indicating that the policy implementation has achieved significant results.

3.2. Parallel Trend Test

To verify the applicability of the Difference-in-Differences method, this study first conducts a prerequisite test for the treatment effect, namely the parallel trend assumption. Specifically, in the samples of high-carbon emission industries and low-carbon emission industries, the trends of the dependent variable (lagged one-year E score) of the

experimental group and the control group over time are observed to analyze whether there are significant differences in the trends between the treatment group and the control group in each year before the policy implementation: the parallel trend test of the high-carbon emission industry sample and the parallel trend test of the low-carbon emission industry sample is shown in Figure 1.

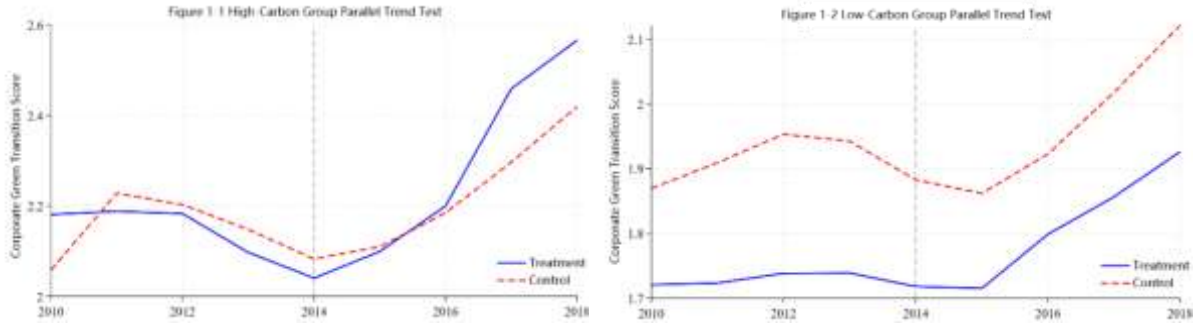

Figure 1 Parallel trend test for high-carbon industries

The regression results show that in high-carbon emission industries, the change trends of green transformation scores of the treatment group and the control group in each year before the policy implementation are basically consistent, indicating that they have similar trends before treatment, and the parallel trend assumption holds; this provides an effective prerequisite guarantee for the subsequent use of the Difference-in-Differences (DID) method to identify the causal impact of carbon price shocks on corporate green transformation behavior.

Furthermore, after the policy implementation, the green transformation scores of enterprises in the treatment group have increased significantly, and the gap with the control group has expanded year by year, indicating that the carbon price mechanism may have played a significant role in promoting the green transformation of high-carbon emission industries. This finding initially supports the policy effect hypothesis of "high-carbon pressure forcing green transformation".

In contrast, the trends of green scores between the treatment group and the control group in low-carbon emission industries before the policy are inconsistent, indicating that they do not meet the parallel trend assumption. Therefore, for this subsample, the identification power of the DID method is at risk of bias, and the interpretation of results needs to be cautious. Subsequent empirical analysis will focus on high-carbon emission industries to ensure the credibility of the estimation results.

3.3. Robustness Tests

To verify the robustness of the benchmark model, this study conducts robustness tests in the Table 3 : ① Placebo tests: randomly advance the time of the carbon emission rights trading pilot (column 1) and randomly assign the pilot provinces and cities of carbon emission rights trading (column 2) without changing other variables; ② Replace the dependent variable: replace ESG-rated companies with Bloomberg (column 3) to avoid differences caused by a single rating agency; ③ Change the clustering method: re-cluster by industry (column 4); ④ Conduct 1% winsorization on the data to avoid the impact of extreme values on the regression results (column 5).

Table 3 Robustness Test Results

Variables	(1) Time Placebo	(2) Space Placebo	(3) Bloomberg ESG	(4) Cluster: Industry	(5) Trimming
Explanatory Variable	treat_fake_post	fake_treat_post	treat_post_price	treat_post_price	treat_post_price
Coefficient of Key Variable	0.0251 (0.0263)	-0.078** (0.0352)	0.0042*** (0.0013)	0.0017** (0.00087)	0.0017*** (0.000647)
Control Variables	Yes	Yes	Yes	Yes	Yes
Industry × Year Fixed Effects	No	No	Yes	Yes	Yes
Obs.	42,644	42,644	11,697	42,637	38,724
R^2	0.0207	0.0182	0.1024	0.0649	0.072
Significance Mark	n.s. (p=0.339)	** (p<0.05)	*** (p<0.01)	** (p<0.05)	*** (p<0.01)

It is not difficult to see that in column 1, the regression result coefficient is not significant when using the fake policy time for regression analysis; although the coefficient in column 2 is significant, the sign is inconsistent with the

benchmark regression; the significance and signs of the regression result coefficients in the other columns are consistent with the benchmark regression results, supporting the robustness of the benchmark regression results.

3.4. Heterogeneity Analysis

3.4.1. Heterogeneity Analysis Based on Enterprise Ownership

Enterprises of different ownership natures have significant differences in management systems and development responsibilities, which are factors that need to be considered in the process of corporate green transformation. Therefore, according to enterprise ownership, listed companies are divided into: ① state-owned enterprises and ② non-state-owned enterprises, and regression is performed on model (1). The regression results are shown in columns (1) and (2) of Table 4. Comparing the coefficients and their significance of the regression, it can be seen that the coefficient of state-owned enterprises is significant, while that of private enterprises is not. The reason for this result is: state-owned enterprises usually have more abundant resources and sufficient cash flow, thus promoting green transformation with the help of policy implementation. In contrast, private enterprises have a relatively limited response to carbon price pressure. Firstly, private enterprises generally face problems such as narrow financing channels and tight cash flow, lacking sufficient resources to cope with the large-scale investment required for green transformation. Secondly, due to the lack of voice in the policy-making process, private enterprises are often at a disadvantage in obtaining government support such as green subsidies and green credit, making it difficult to fully utilize policy dividends. In addition, some private enterprises lack awareness of the long-term benefits of green transformation and have concerns about the stability of policy implementation, making them more inclined to maintain the existing production model, resulting in insufficient motivation for green transformation. Therefore, even if the carbon price rises to bring cost pressure, private enterprises may be more inclined to cope by cutting costs and delaying investment rather than taking the initiative to carry out green upgrading.

3.4.2. Heterogeneity Analysis Based on Carbon Emission Intensity

Taking A-share listed companies in the eight high-carbon emission industries that have been or will be included in the national carbon market as mentioned in the "Notice of the General Office of the National Development and Reform Commission on Earnestly Doing a Good Job in the Key Work for the Launch of the National Carbon Emission Rights Trading Market" in 2016 as the distinction standard, this study distinguishes power, steel, cement, non-ferrous metals, petrochemical, papermaking, building materials, chemical, and aviation industries from other industries, and performs regression on model (1) respectively. The regression results are shown in columns (3) and (4) of Table 4. It is found that the coefficients of both industries are significant, while the coefficient of high-carbon emission industries is higher and that of low-carbon emission industries is significantly lower. This can be understood as: due to their high energy consumption and high emission intensity in the production process, high-carbon emission industries face more direct and significant cost pressure when the carbon price rises, thus having stronger emission reduction incentives and transformation motivation. Under the role of the carbon market mechanism, these industries are more inclined to increase investment in green technologies and optimize energy structures to achieve green transformation goals. In contrast, low-carbon emission industries themselves have low emission intensity, and the impact of carbon prices on their cost structure is small. Therefore, the transmission effect of carbon price signals is relatively limited, and their green transformation relies more on the enterprise's own strategy or other institutional incentives. Therefore, the marginal incentive effect of carbon prices is more significant in high-carbon emission industries, showing the heterogeneous impact of "carbon price-driven" in different industries.

Table 4 Heterogeneity Analysis Results

Variables	(1) State-owned Enterprises: Ownership Nature	(2) Private Enterprises: Ownership Nature	(3) High-carbon Emission Industries: Carbon Emission Level	(4) Low-carbon Emission Industries: Carbon Emission Level
post_treat_price	0.00422*** (0.00122)	-0.000568 (0.000853)	0.00562*** (0.00129)	0.00140*** (0.000410)
Ind × Year FE	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes
Obs.	12,792	29,836	6,744	35,893
R^2	0.111	0.069	0.077	0.067

3.5. Mechanism Research

Next, this study conducts mechanism tests using the Heckman two-step method from three aspects: green innovation, financing constraint mitigation, and environmental information disclosure, to explore the internal mechanism through which carbon prices affect corporate green transformation. The regression results are shown in Table 5.

Table 5 Mechanism Research Results

Variables	(1) e_score_lead: Green Transformation	(2) patent_count: Mechanism 1 (Green Innovation)	(3) e_score_lead: Green Transformation	(4) fc: Mechanism 2 (Financing Constraint)	(5) e_score_lead: Green Transformation	(6) transparency_score: Mechanism 3 (Information Disclosure)
post_treat_price	-	0.115*** (0.0396)	-	-0.000599*** (0.000151)	-	0.00536*** (0.000271)
patent_count	0.00294*** (0.00103)	-	-	-	-	-
fc	-	-	-0.779*** (0.0634)	-	-	-
transparency_score	-	-	-	-	0.0450*** (0.0056)	-
Control Variables	Yes	Yes	Yes	Yes	No	No
Ind × Year FE	Yes	Yes	Yes	Yes	No	No
Obs.	42,637	42,637	30,510	30,510	42,644	42,644
R^2	0.067	0.069	0.107	0.573	0.017	0.236

3.5.1. Green Innovation Mechanism

Theoretically, as a mechanism for external cost internalization, the rise of carbon prices will increase the marginal carbon emission cost of enterprises, thereby enhancing their demand for green technologies and low-carbon processes. This process is consistent with the "Porter Hypothesis" that is, moderate environmental regulation can stimulate innovation incentives, improve resource allocation efficiency and enterprise performance. Under the carbon trading system, enterprises facing carbon price pressure are more inclined to replace carbon emissions with green innovation to optimize the long-term cost structure.

To verify this mechanism, this study constructs a regression model with the number of corporate green patent applications as the mediating variable. The results in columns (1) and (2) of the table show that the impact of the interaction term on the green innovation variable is significantly positive, and the carbon price coefficient in the main regression after controlling for green innovation decreases significantly, indicating that green innovation plays a partial mediating role in the process of carbon prices promoting corporate green transformation.

3.5.2. Financing Constraint Mechanism

Enterprises usually face obstacles of large initial investment and long return cycles in the process of green transformation, and financing constraints may become a major resistance to their green investment behavior. However, the price signal transmitted by the carbon market mechanism can serve as a market-oriented measure of the enterprise's environmental governance capacity, thereby improving its reputation and credit rating in the financial market[9]. On the one hand, the rise of carbon prices forces enterprises to improve their ESG performance to obtain green financial tools and policy support; on the other hand, investors and financial institutions are more inclined to invest in enterprises with excellent environmental performance and strong policy response capabilities, thereby reducing their financing costs.

This study uses the FC index to measure the degree of corporate financing constraints. The results in columns (3) and (4) of the table show that the rise of carbon prices significantly alleviates corporate financing constraints, and after controlling for this variable, the carbon price coefficient in the main regression decreases, indicating that this mechanism path has statistical significance and explanatory power.

3.5.3. Information Disclosure Mechanism

As a policy system based on quota and trading rules, the effective operation of the carbon market relies on the openness and transparency of corporate carbon emission data. The formation process of carbon prices intensifies the social supervision and institutional constraints faced by enterprises, forcing them to improve the level of environmental information disclosure to respond to the attention of regulators, investors, and the public. At the same time, the disclosure of environmental information helps alleviate the problem of information asymmetry in the capital market, improve the credibility of corporate ESG performance and the efficiency of capital flow.

Therefore, information disclosure is not only a strategy for enterprises to cope with carbon price pressure but also a prerequisite for promoting the upgrading of corporate green strategies. This study conducts mechanism tests with the environmental information transparency of listed companies as the mediating variable. The results are shown in columns (5) and (6) of the table. There is a significant positive correlation between carbon prices and transparency scores, verifying the existence of this mechanism path. Furthermore, since the improvement of information disclosure level helps enterprises obtain green credit and reduce external financing costs, this mechanism is complementary to the

aforementioned financing constraint mechanism, forming an indirect path through which carbon prices affect corporate green transformation.

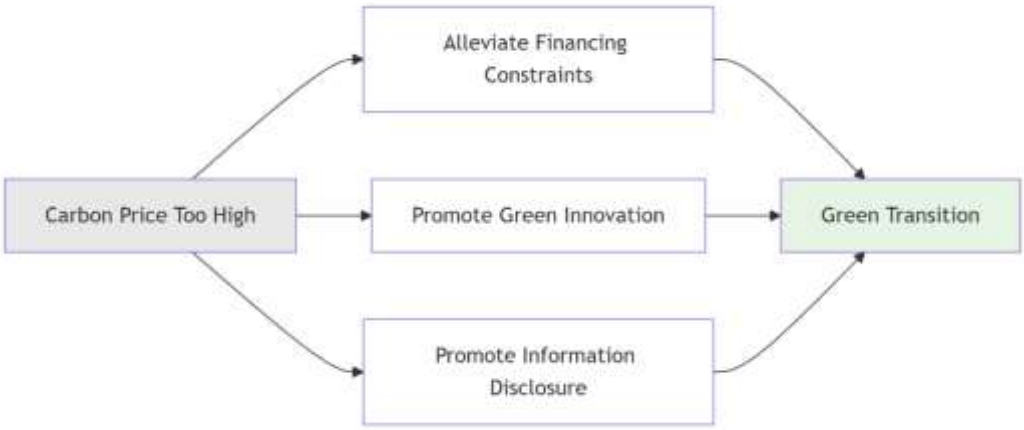

Figure 2 Mediating mechanism analysis

The figure 2 shows three mediating paths through which carbon prices promote corporate green transformation: green innovation, financing constraint mitigation, and information disclosure.

4. Conclusions

This study systematically examines the "enforcement" mechanism of rising carbon prices on corporate green transformation using a multi-period difference-in-differences model, based on China's carbon emissions trading policy implemented since 2013. Robust benchmark regression results indicate that higher carbon prices significantly accelerate green transformation among enterprises in pilot regions, with stronger incentives at elevated price levels. This effectively validates the applicability of the "Porter Hypothesis" within market-based environmental regulation frameworks.

Further analysis reveals significant heterogeneity in the carbon price's driving effects. Regarding ownership structure, state-owned enterprises (SOEs) respond more actively to carbon pricing due to their resource endowment advantages and stronger policy responsiveness. In contrast, private enterprises exhibit relatively slower transformation pace, influenced by financing constraints and risk preferences. At the industry level, high-carbon emitting enterprises face direct cost pressures, resulting in significantly stronger green transformation motivation compared to low-carbon industries. This demonstrates the "differentiated incentive" characteristic of carbon pricing.

Mechanism tests indicate that carbon pricing primarily drives green transformation through three indirect pathways: First, it strengthens incentives for green innovation, promoting R&D and adoption of low-carbon technologies. Second, it alleviates corporate financing constraints by improving access to external capital. Third, it enhances environmental information transparency, strengthening external oversight and trust. These pathways collectively form the intrinsic transmission mechanism through which carbon pricing influences corporate behavior.

Based on these findings, this study proposes three policy implications: First, gradually raise carbon price levels and enhance the effectiveness of price signals by reasonably tightening quota supply and expanding industry coverage to unleash the incentive role of carbon pricing in green transformation. Second, improve supporting policies to address the limited resources of private enterprises by alleviating their financing constraints through green credit, tax incentives, and other measures, thereby enhancing their capacity to respond to carbon pricing. Finally, environmental information disclosure should be strengthened to promote standardized and institutionalized reporting of corporate carbon emissions and ESG data, thereby optimizing carbon market governance efficiency.

In summary, this study not only confirms the catalytic role of carbon pricing in corporate green transformation but also reveals its underlying logic and implementation pathways. By integrating differentiated policy design with complementary institutional arrangements, the efficacy of carbon pricing policies can be further unleashed in the future, providing robust support for China's pursuit of its "3060" dual carbon goals and high-quality development.

References

[1] Jie X, Han Y. How can local manufacturing enterprises achieve a "gorgeous transformation" through green innovation?—A multi-case study based on the attention-based view[J]. Management World, 2022, 38(03): 76-106.

[2] Kroh J, Schultz C. In favor or against: The influence of skeptical stakeholders in urban innovation projects for green transformation[J]. International Journal of Project Management, 2023, 41(7): 102515.

[3] Lu H, Li F, Lu J, et al. Equity pledge and corporate green transformation: The moderating role of firm characteristics and government behavior[J]. Science & Technology Progress and Policy, 2023, 40(07): 79-90.

[4] Gong X, Du J. Digital economy, green innovation and enterprises' green total factor productivity[J]. Statistics & Decision, 2024, 40(02): 35-40.

[5] Wu Y, Qi J, Xian Q, et al. The carbon emission reduction effect of China's carbon market: From the perspective of synergistic effects between market mechanisms and administrative intervention[J]. China Industrial Economics, 2021, (08): 114-132.

[6] Hu J, Fang Q, Long W. Carbon emission regulation, corporate emission-reduction incentives and total factor productivity: A

natural experiment based on China's emissions trading scheme[J]. Economic Research Journal, 2023, 58(04): 77-94.

[7] Xue F, Zhou M.-L. The emission reduction effect of the scale of China's carbon trading market[J]. East China Economic Management, 2021, 35(06): 11-21.

[8] Shi J, Cai H, Tang L, et al. The impact of the carbon trading mechanism on China's economy and environment: Based on a CGE model[J]. Chinese Journal of Management Science, 2015, 23(S1): 801-806.

[9] Cheng, B., Ioannou, I., & Serafeim, G. Corporate social responsibility and access to finance[J]. Strategic Management Journal, 2014, 35(1), 1–23.