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A Study Based on Quasi-Natural Experiment with Double Difference Method: Can Carbon Trading Policies Improve Firms' Green Total Factor Productivity?

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Abstract: With the continuous development of society and economy, climate change has attracted widespread attention from all sectors. Currently, China is in a critical period of coordinating development and environmental governance, and carbon trading policies are advancing steadily. Against this background, whether carbon trading policies can promote the improvement of enterprises' green total factor productivity has become a hot issue. Based on this question, this study verifies and analyzes through a quasi-natural experiment using the difference-in-differences method, and explores targeted suggestions and countermeasures, aiming to provide a reference for relevant personnel and jointly contribute to the realization of the "dual carbon" goals and the promotion of green development.

Keywords: Carbon trading policies; Green Total Factor Productivity (GTFP); Green innovation capability; Financing efficiency; Difference-in-differences method

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1. Introduction

Carbon trading policies have played an effective role in curbing carbon emissions. However, it can be seen that China's goal in implementing this policy is not limited to emission reduction, but to rely on this tool to assist enterprises' digital transformation and drive high-quality economic development. For most enterprises, if the only goal is emission reduction, it is only necessary to reduce costs, but this is also contrary to the concept of sustainable development [1]. Therefore, under this policy background, how to promote the improvement of enterprises' production efficiency on the basis of advancing the implementation of emission reduction goals has become a sociological issue [2]. In this regard, it is imperative and timely to conduct an in-depth analysis of the impact of carbon trading policies on the improvement of enterprises' Green Total Factor Productivity (hereinafter referred to as GTFP).

2. Research hypotheses

Hypothesis 1: Carbon trading policies can significantly improve enterprises' GTFP.

Hypothesis 2: Carbon trading policies promote the improvement of GTFP by enhancing enterprises' green innovation capabilities.

Hypothesis 3: Financing efficiency plays an important role in promoting enterprises' GTFP.

3. Research design

3.1. Samples and data

This study takes A-share listed companies (2009-2022) as the research sample. The data sources mainly include carbon trading pilot enterprises and enterprise-level relevant data [3]. To ensure the quality of the sample, ST and *ST enterprises, as well as sample enterprises with missing key data, are excluded. On this basis, 28,790 sample objects are finally determined for research and analysis.

3.2. Model construction

3.2.1. Baseline regression model (Testing Hypothesis 1)

Considering that carbon trading policies were launched at different times in some regions, a multi-period difference-in-differences method is used to construct the corresponding baseline model. The specific formula is as follows:

$$GTFP_{it} = \beta_0 + \beta_1 DID_{it} + \alpha \sum Control_{it} + Firm_i + Year_t + \xi_{it}$$

Note: Where *i* represents the enterprise, *t* represents the year; $GTFP_{it}$ refers to the GTFP of enterprise *i* in year *t*; DID_{it} indicates whether enterprise *i* participates in the carbon trading policy in year *t* (1 if yes, 0 otherwise); $Control_{it}$ is the set of control variables; $Firm_i$ denotes the enterprise fixed effect; $Year_t$ denotes the year fixed effect; ξ_{it} is the random error term. If β1 is significantly positive, it indicates that the policy can improve enterprises' GTFP; that is, Hypothesis 1 holds.

3.2.2. Mediation effect model (Testing Hypotheses 2 and 3)

To effectively test enterprises' financing efficiency (PE) and green innovation capability (GI), a mediation effect model is introduced:

Step 1: Baseline regression to test the overall impact of the policy on enterprises' GTFP.

Step 2: Test the impact of the policy on mediating variables. The specific formula is as follows:

$$Mediator_{it} = \beta_0 + \beta_2 DID_{it} + \alpha \sum Control_{it} + Firm_i + Year_t + \xi_{it}$$

Step 3: Incorporate both policy variables and mediating variables to test the mediation effect. The specific formula is as follows:

$$GTFP_{it} = \beta_0 + \beta_3 DID_{it} + \beta_4 Mediator_{it} + \alpha \sum Control_{it} + Firm_i + Year_t + \xi_{it}$$

Note: Mediator in the formula is the mediating variable, representing PE and GI. If β_2 is significant in Step 2, and both β_3 and β_4 are significant in Step 3, it indicates a partial mediation effect; if only one coefficient is significant, the mediation effect does not exist.

3.3. Variable description

3.3.1. GTFP (Dependent variable)

The calculation of the dependent variable GTFP refers to previous research methods, mainly estimating enterprises' GTFP by estimating the logarithmic Cobb-Douglas production function. The specific formula is as follows:

$$\ln Y_{ijt} = \beta_{0jt} + \beta_{1jt} \ln K_{ijt} + \beta_{2jt} \ln L_{ijt} + \beta_{3jt} \ln M_{ijt} + \beta_{4jt} \ln C_{ijt} + \varepsilon_{ijt}$$

Note: In the formula, Y represents the enterprise's operating income (unit: thousand yuan); K represents its net fixed assets (unit: thousand yuan); L is the number of enterprise employees (unit: thousand people); M is the intermediate input indicator; C is its carbon emissions (unit: thousand tons); *i*, *j*, and *t* represent listed companies, industries, and years respectively.

3.3.2. DID (Core independent variable)

If an enterprise participates in carbon trading in year *t*, DID_{it} = 1; otherwise, DID_{it} = 0. In addition, relevant data lists will be obtained through government official websites and matched with the CSMAR database to effectively ensure the validity and accuracy of the assignment.

3.3.3. GI, PE (Mediating variables)

(1) Green Innovation Capability (GI): Calculated as: GI of the enterprise in year t - [(number of green patent applications from t-1 to t - number of green patent applications from t-2 to t-1) / number of green patent applications from t-2 to t-1 × number of green patent applications from t-1 to t].

(2) Financing Efficiency (PE): Determined by the ratio of the enterprise's Return on Equity (ROE) to the Weighted Average Cost of Capital (WACC). A higher ratio indicates higher PE.

3.3.4. Other variables

Seven control variables are also introduced in this study, including ownership nature (SOE: 1 for state-owned enterprises, 0 for non-state-owned enterprises), enterprise size (Size), asset-liability ratio (Level), operating income growth rate (Growth), price-to-book ratio (PB), financing constraint index (SA), and listing years (ListAge).

4. Empirical results analysis

4.1. Baseline regression results: Total effect of carbon trading policies on GTFP

Table 1. Baseline regression results

Variables	GTFP (Without Control Variables)	GTFP (With Control Variables)
DID	0.058***(3.238)	0.057***(3.298)
SOE	—	0.012(0.822)
Size	—	0.029***(4.135)
Level	—	-0.200***(-8.202)
Growth	—	0.344***(13.497)
PB	—	0.023***(3.119)
ListAge	—	0.040***(2.855)
SA	—	0.079(1.516)
_cons	-0.001(-0.163)	-0.856***(-3.293)
Year	Yes	Yes
Firm	Yes	Yes
N	28790	28790
R2	0.006	0.058

Note: Values in parentheses are *t*-values; *p<0.1, **p<0.05, ***p<0.01, the same below.

Based on the above information, whether control variables are added or not, the coefficient of the core independent variable DID is significantly positive at the 1% level, indicating that Hypothesis 1 holds [4–6]. At the same time, the coefficients of enterprise size and price-to-book ratio are significantly positive at the 1% level, indicating that enterprises with larger scale, higher revenue growth rate, and longer listing years have more significant GTFP improvement; the asset-liability ratio coefficient is significantly negative at the 1% level, and high debt may squeeze green investment; the coefficients of ownership nature and financing constraints are not significant, having no obvious impact on GTFP.

4.2. Mediation effect: The role of green innovation and financing efficiency

4.2.1. Impact of the policy on mediating variables

Table 2. Impact of carbon trading policies on mediating variables

Variables	GI	FE
DID	0.250***(3.400)	0.005*(1.846)
SOE	0.000(0.010)	0.002(0.578)
Size	0.057***(3.602)	0.009***(6.718)
Level	0.003(0.055)	-0.081***(-16.375)
Growth	-0.020(-0.766)	0.036***(11.190)
PB	-0.027*(-1.648)	-0.017***(-5.240)
ListAge	0.061*(1.693)	0.001(0.559)
SA	0.534***(3.772)	0.013**(2.009)
_cons	0.853(1.611)	-0.126***(-2.997)
Year	Yes	Yes
Firm	Yes	Yes
N	28790	28790
R2	0.032	0.052

Based on the above information, the coefficient of DID on GI is 0.250 (significant at the 1% level), meaning that the green innovation capability of enterprises participating in the policy is improved by 25%; the coefficient on PE is 0.005 (significant at the 10% level), meaning that the financing efficiency of participating enterprises is improved by 0.5%, indicating that the policy can effectively enhance both.

4.2.2. Complete test of mediation effect

Table 3. Mediation effect regression results

Variables	GTFP (GI as Mediator)	GTFP (PE as Mediator)
DID	0.056***(3.234)	0.056***(3.230)
GI	0.005**(2.352)	—
FE	—	0.231**(2.492)
SOE	0.012(0.822)	0.011(0.798)
Size	0.029***(4.094)	0.027***(3.827)
Level	-0.200***(-8.204)	-0.181***(-7.117)

Table 3 (Continued)

Variables	GTFP (GI as Mediator)	GTFP (PE as Mediator)
Growth	0.344***(13.501)	0.336***(13.140)
PB	0.023***(3.136)	0.027***(3.631)
ListAge	0.040***(2.836)	0.040***(2.841)
SA	0.077(1.469)	0.076(1.462)
_cons	-0.860***(-3.309)	-0.827***(-3.188)
Year	Yes	Yes
Firm	Yes	Yes
N	28790	28790
R2	0.058	0.062

Based on the above information, after adding GI, the DID coefficient is 0.056 (significant at the 1% level), slightly lower than the baseline, and the GI coefficient is 0.005 (significant at the 5% level), so Hypothesis 2 holds, and green innovation capability plays a partial mediation role; after adding PE, the DID coefficient is 0.056 (significant at the 1% level), and the PE coefficient is 0.231 (significant at the 5% level), so Hypothesis 3 holds, and financing efficiency also plays a partial mediation role. Further calculation shows that the mediation effect of green innovation accounts for 2.28% of the total effect, and that of financing efficiency accounts for 0.5%, with the former being a more critical path.

4.3. Heterogeneity analysis: Moderating role of enterprise characteristics

First, an interaction term between DID and pollution degree (Pollute) is constructed. The results show that the interaction term is significantly positive at the 1% level, indicating that the carbon trading policy has a stronger effect on improving GTFP of heavily polluting enterprises than lightly polluting ones. Second, interaction terms are constructed with PC (whether there is a political connection) and PCLevel (connection level). The regression results show that both interaction terms are significantly positive at the 1% level, indicating that the policy has a more significant effect on improving GTFP of enterprises whose management has political connections, and the higher the connection level, the stronger the effect [7–9].

4.4. Robustness test: Reliability of results

4.4.1. Placebo test

Randomly generating false policy variables for 500 regressions, the results show that the mean coefficient of false variables is close to 0, most are not significant, and the distribution is normal, excluding the interference of unobservable factors, indicating that the baseline results are reliable.

4.4.2. PSM-DID test

Table 4. PSM-DID regression results

Variables	GTFP
DID	0.075***(4.154)
SOE	-0.001(-0.029)
Size	0.025(1.296)
Level	-0.148**(-2.292)
Growth	0.422***(6.649)

Table 4 (Continued)

Variables	GTFP
PB	0.045***(2.693)
ListAge	0.040(1.225)
SA	0.107(1.087)
_cons	-0.854(-1.502)
Year	Yes
Firm	Yes
N	4310
R2	0.071

The treatment group and control group are matched by 1:2 nearest neighbor matching, and the parallel trend holds after matching. Regression based on the matched sample shows that the DID coefficient is 0.075 (significant at the 1% level), consistent with the baseline conclusion, and the coefficient is larger. After excluding sample selection bias, the net effect of the policy is more accurate, indicating that the conclusion is robust.

5. Conclusion

The research shows that carbon trading policies have a significant effect on improving enterprises' GTFP (the GTFP of participating enterprises has increased by 5.7–5.8%), while green innovation capability (accounting for 2.28% of the mediation effect) and financing efficiency (accounting for 0.5%) are key mediation paths. The policy has a more prominent effect on heavily polluting enterprises and enterprises whose management has political connections. Based on this, relevant departments should further expand the coverage of the policy and improve relevant supporting services. At the same time, enterprises should increase investment in green innovation and optimize their financing structure [10]. Finally, due to the limitations in the estimation of carbon emission data in this study, future research can combine enterprises' actual carbon data and expand mediating variables to deepen the research.

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