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Green Factory Certification and Corporate Innovation Efficiency: Evidence from Chinese Manufacturing Firms

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Abstract: China has entered a new stage of green and low-carbon transition and high-quality economic development. As major actors in the national economy, firms bear substantial responsibility for advancing the green transition and the high-quality development of manufacturing. How policy interventions can stimulate corporate innovation is therefore an important question in both the evaluation of environmental regulation and related theoretical research. Using data on manufacturing firms listed on the Shanghai and Shenzhen A-share markets from 2007 to 2020, this study treats the first five batches of green factories announced by the Ministry of Industry and Information Technology as a quasi-natural experiment. The results show that green factory certification significantly improves corporate innovation efficiency, and the finding remains robust to winsorization, lagged control variables, placebo tests, alternative fixed-effects specifications, and adjustments to clustered standard errors. These findings clarify the innovation consequences of green factory certification and support differentiated policy design based on firm ownership and governance capacity.

Keywords: Green factory certification, corporate innovation efficiency, staggered difference-in-differences, R&D investment, total factor productivity, financing constraints.

1. Introduction

Growing global environmental pressures and commitment to the Sustainable Development Goals have accelerated the green transformation of manufacturing. In China, the carbon-peaking and carbon-neutrality goals have further increased the urgency of reconciling industrial development with environmental protection [1]. Green factory certification has consequently emerged as an important policy instrument for advancing green manufacturing and new industrialization. By encouraging firms to improve production processes, management practices, resource-use efficiency, and environmental performance, the program aims to generate both environmental and economic benefits. The General Principles for Assessment of Green Factories (GB/T 36132-2018) [2] established a national framework for green factory assessment and continuous improvement.

Green factory certification may influence corporate innovation through three main channels. First, requirements concerning resource recycling, energy efficiency, waste reduction, and cleaner production may encourage firms to upgrade production processes and improve the allocation of R&D resources. Existing evidence shows that green factory development promotes corporate green innovation by stimulating technological upgrading and R&D-process optimization [3]. Second, certification may improve access to government subsidies and green credit, thereby reducing financing constraints and increasing the resources available for innovation [4]. Third, as a government-backed environmental signal, certification may enhance corporate reputation, attract investor attention, and create additional market opportunities [5]. Nevertheless, the existing literature has three limitations. Most studies focus on environmental performance or green innovation output rather than firms' overall innovation efficiency. Mechanism analyses generally examine financing, technological upgrading, or market signaling separately instead of evaluating their complementary roles within an integrated framework. Evidence also remains limited on whether certification effects vary with firm ownership and internal governance.

Corporate innovation efficiency reflects a firm's ability to convert innovation inputs into technological outputs. By jointly considering R&D resources and patent output, it provides a more direct assessment of innovation-resource allocation than examining innovation inputs or outputs separately [6]. This perspective makes it possible to distinguish between an increase in innovation expenditure and an improvement in the productivity of that expenditure. It is therefore particularly appropriate for evaluating whether green factory certification enables firms to generate more innovation output from their R&D resources.

This study addresses three questions. First, does green factory certification significantly improve corporate innovation efficiency? Second, are financing constraints, R&D investment, and the technological-change componentof total factor productivity plausible channels through which certification operates? Third, does the estimated effect vary with firm ownership and the effectiveness of internal governance? To answer these questions, this study uses data on manufacturing firms listed on the Shanghai and Shenzhen A-share markets from 2007 to 2020. Green factory certification is treated as a quasi-natural experiment, and a staggered difference-in-differences model with firm and year fixed effects is used to estimate its effect on corporate innovation efficiency. Mechanism and heterogeneity analyses are then conducted to examine how and for which firms the policy operates.

The results show that green factory certification significantly improves corporate innovation efficiency, and this finding remains robust to winsorization, lagged control variables, an alternative sample window, placebo tests, alternative fixed-effects specifications, and different standard-error adjustments. The mechanism results are consistent with three potential channels: alleviating financing constraints, increasing R&D investment, and promoting the technological-change component of total factor productivity. The positive effect is also more pronounced among non-state-owned enterprises and firms classified as having effective internal governance. This study contributes to the literature in three respects. First, it shifts attention from innovation inputs or outputs alone to the efficiency with which firms convert R&D resources into patent output. Second, it evaluates financing constraints, R&D investment, and technological progress within an integrated framework. Third, it provides firm-level evidence on ownership and governance heterogeneity, offering a more differentiated basis for the design of green manufacturing policy.

2. Literature Review

China's green industrial policy has gradually expanded from selected emerging industries to the green transformation of the broader manufacturing sector. In 2016, the Ministry of Industry and Information Technology formally introduced the green factory certification program through the Notice on Developing a Green Manufacturing System [7]. Unlike policies limited to particular industries, the program covers a wide range of traditional manufacturing activities and may generate demonstration effects across industrial chains. It has three main institutional features: a comprehensive assessment framework, a stringent review process involving government authorities and third-party assessment bodies, and access to policy and financial resources. Certified firms may receive government subsidies, tax incentives, green credit, preferential guarantees, and other forms of support. Green factory certification therefore functions not only as an environmental standard but also as an institutional arrangement that may affect firms' technological decisions, resource access, and market recognition.

Research on environmental regulation initially focused on whether regulatory pressure stimulates or crowds out corporate innovation. The Porter hypothesis proposes that well-designed environmental regulation can induce innovation that partly or fully offsets compliance costs [8]. Studies of China's green factory program provide evidence consistent with this argument. Certification has been associated with improved resource allocation, technological capabilities, and cleaner production, thereby facilitating the green transformation of manufacturing [9]. Green factory development may also promote green innovation through tax incentives and green credit, with stronger effects among technology-intensive firms [3]. Related evidence indicates that certification can increase access to environmental subsidies and green credit, alleviate financing constraints, attract long-term institutional investors, and improve the quality of green patents [4]. These findings suggest that policy resources, financing conditions, R&D investment, and technological upgrading are important channels linking certification to corporate innovation.

The economic consequences of green factory certification extend beyond green innovation. Certification has been linked to greater outward foreign direct investment through improvements in green innovation and international competitiveness [10]. It may also increase firms' export technological sophistication through innovation, policy incentives, and reputational effects [11]. In addition, green manufacturing certification has been associated with employment expansion through output, innovation, and environmental-risk channels [12]. Outward investment, export sophistication, and employment are not mechanism variables directly examined in this study. However, these findings demonstrate that certification may reshape firms' productive capabilities, organizational resources, and market opportunities rather than affecting green patent output alone.

Three complementary theoretical perspectives help organize this literature. Environmental regulation theory explains how certification requirements create pressure for cleaner production, process optimization, and technological upgrading. Evidence from heavily polluting firms supports the view that regulatory pressure can stimulate technological improvement and increase innovation efficiency [13]. The resource-based view emphasizes that certification can expand access to government subsidies, preferential credit, R&D resources, and complementary production and organizational resources. Public support may reduce the cost and uncertainty of innovation, relax financing constraints, and increase R&D investment and patent output [14, 15]. Signaling theory explains how government-backed certification can reduce information asymmetry by communicating environmental quality and operational reliability to investors, creditors, customers, and other market participants. Favorable capital-market responses to green factory certification indicate that this policy signal may improve financing conditions and support the allocation of resources to innovation [5]. Together, these perspectives link certification to regulatory pressure, resource acquisition, and information signaling. The specific mechanisms and corresponding hypotheses are developed in the following section.

Despite the growing literature, three gaps remain. First, innovation-related studies primarily focus on the quantity or quality of green patents rather than the efficiency with which firms convert innovation inputs into outputs [3, 4]. Patent-output measures alone cannot determine whether certification enables firms to generate more innovation output from a given level of R&D investment. Second, previous studies generally examine financing, innovation investment, technological upgrading, or reputational effects separately, leaving their complementary roles insufficiently integrated. Third, although heterogeneous effects have been documented across industries and firm types, limited evidence explains how ownership and internal governance shape firms' ability to benefit from certification. This study addresses these gaps by directly examining corporate innovation efficiency, integrating financing constraints, R&D investment, and the technological-change component of total factor productivity within a common framework, and investigating heterogeneity by ownership and internal governance.

3. Theoretical Analysis and Hypothesis Development

3.1. Direct Effect of Green Factory Certification on Corporate Innovation Efficiency

Green factory certification may improve corporate innovation efficiency through regulatory pressure, resource support, and market signaling. First, its technical requirements for energy use and cleaner production encourage firms to replace inefficient capacity and adopt cleaner technologies, thereby improving the utilization of R&D resources [13]. Second, certified firms may obtain tax incentives, subsidies, and preferential green credit, which reduce the cost and risk of innovation [14, 15]. Third, government-backed certification signals environmental compliance and operational reliability, reducing information asymmetry and improving access to external resources and green supply-chain networks [5]. Together, these effects facilitate technological upgrading and the conversion of innovation inputs into outputs.

H1. Green factory certification has a positive effect on corporate innovation efficiency.

3.2. Mechanisms Linking Green Factory Certification to Corporate Innovation Efficiency

Building on the preceding theoretical framework, this study examines three mechanisms linking certification to corporate innovation efficiency.

First, certification may alleviate financing constraints by signaling favorable environmental performance and reducing lenders' perceived risks. Certified firms can consequently obtain green credit and other external financing on more favorable terms. Improved financing conditions provide the liquidity required for sustained innovation and reduce disruptions to long-term R&D activities [4, 5, 16].

H2a. Green factory certification improves corporate innovation efficiency by alleviating financing constraints.

Second, tax incentives, subsidies, and related policy resources reduce R&D costs and support investment in cleaner technologies and production methods [3]. Certification requirements may also encourage firms to improve the allocation and management of R&D resources. Innovation efficiency increases when the resulting growth in innovation output exceeds the increase in R&D input [11].

H2b. Green factory certification improves corporate innovation efficiency by promoting productive R&D investment.

Third, certification standards encourage firms to adopt cleaner technologies, upgrade production processes, and improve resource utilization. Environmental assessment and continuous-improvement requirements can generate learning-by-doing effects and accelerate technological diffusion across green supply chains [17, 18]. Such technological progress improves the conversion of R&D inputs into innovation outputs.

H2c. Green factory certification improves corporate innovation efficiency by promoting total factor productivity.

4. Research Design

4.1. Sample Selection and Data Sources

The sample consists of manufacturing firms listed on the Shanghai and Shenzhen A-share markets from 2007 to 2020. Firms designated as ST or PT are excluded. The initial unbalanced panel contains 20,158 firm-year observations, although variable availability reduces the sample to 15,353 observations in the fully specified baseline regression. Financial and accounting data are obtained from the China Stock Market & Accounting Research (CSMAR) database, and certification status is identified from the first five green factory lists published by the Ministry of Industry and Information Technology. Continuous variables are winsorized at the 1st and 99th percentiles only in a robustness test.

4.2. Variable Definitions

4.2.1. Dependent Variable

Corporate innovation efficiency (InnoE) captures how effectively a firm converts innovation inputs into innovation outputs. Following an input–output approach, it is measured as follows:

$$InnoE_{it} = \frac{PatentApplications}{RDInvestment}$$

R&D investment is expressed in RMB 100 million. This input-output ratio captures patent-generating efficiency and facilitates comparison across firm-year observations [14, 19–21]. It should be interpreted as a focused measure rather than a comprehensive indicator of all forms of organizational innovation.

4.2.2. Core Explanatory Variable

The core explanatory variable is green factory certification (DID), constructed from the first five certification lists [3]. DID equals one in the certification year and all subsequent years and zero otherwise.

4.2.3. Control Variables

Following He et al. [22], the model controls for leverage (tl), measured as total liabilities divided by total assets; firm size (lnSale), measured as the natural logarithm of operating revenue; firm age (lnage), measured as the natural logarithm of firm age; return on equity (roe); capital expenditure (invt), measured as cash paid for long-term asset acquisition divided by total assets; cash holdings (cash), measured as cash and tradable financial assets divided by total assets; the current asset ratio (cr); and asset tangibility (tang), measured using fixed assets and inventories relative to total assets.

4.3. Model Specification

$$InnoE_{it} = \alpha + \beta \times DID_{it} + \gamma \times X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

In the baseline model, X_it denotes the control variables, while firm and year fixed effects absorb time-invariant firm characteristics and common annual shocks. Standard errors are clustered at the firm level.

4.4. Descriptive Statistics

Table 1 reports the descriptive statistics. Innovation efficiency varies substantially across firms, while post-certification observations account for 5.12% of the initial panel.

Table 1. Descriptive Statistics

Variable	Symbol	Obs.	Mean	Std. dev.	Min.	Max.
Debt-to-asset ratio	tl	20,158	0.449	0.203	0.00708	1.280
Asset tangibility	tang	20,134	0.407	0.173	3.19e-05	0.971
Current asset ratio	cr	20,158	0.547	0.204	0.0143	0.999
Cash holdings	cash	20,158	0.170	0.118	0.000479	0.915
Capital expenditure	invt	20,151	0.0507	0.0485	0	0.642
Return on equity	roe	20,154	0.0331	0.808	-50.08	2.324
Firm size	lnSale	20,158	21.62	1.463	13.54	28.72
Firm age	lnage	20,158	2.264	0.629	1.099	3.401
Green factory certification	DID	20,158	0.0512	0.221	0	1
Innovation efficiency	InnoE	15,482	34.89	74.53	0	685.2

5. Empirical Results

5.1. Baseline Regression Results

Table 2. Baseline Regression Results

VARIABLES	(1) InnoE	(2) InnoE	(3) InnoE	(4) InnoE
DID	-2.6242 (3.012)	5.6098* (2.958)	6.8690** (3.081)	8.2172*** (2.979)
tl		27.9123*** (6.963)		5.2840 (9.470)
lnSale		-6.7314*** (1.052)		-15.4416*** (2.325)
lnage		-6.9341*** (1.876)		-4.2870 (5.806)
roe		-1.0871 (1.652)		-0.3881 (1.133)
invt		5.0735 (26.765)		8.7584 (27.457)
cash		41.8605*** (9.393)		-4.2371 (10.396)
cr		3.9404 (8.283)		7.9152 (12.031)
tang		35.0982*** (8.638)		-7.6773 (11.280)
Firm fixed effects	No	No	Yes	Yes
Year fixed effects	No	No	Yes	Yes
Constant	35.0673*** (1.246)	160.5831*** (19.757)	34.4389*** (0.203)	374.8975*** (50.207)
Observations	15,482	15,471	15,366	15,353
R-squared	0.000	0.025	0.508	0.514

Notes: Firm-clustered robust standard errors are reported in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The same convention applies to subsequent tables unless otherwise indicated.

Table 2 reports the baseline estimates. In the preferred specification in Column (4), which includes the controls and firm and year fixed effects, the DID coefficient is 8.2172 and statistically significant at the 1% level. Green factory certification is therefore associated with higher corporate innovation efficiency, supporting H1. This finding is consistent with resource-support explanations of certification [23], while the proposed channels are examined in Section 6.

5.2. Parallel-Trends Test

An event-study specification is used to assess the parallel-trends assumption:

$$InnoE_{it} = \alpha + \sum_{\tau=-10}^{t=3} \beta_1 \times DID_{it} + \gamma \times X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Event time is defined relative to certification, with the year immediately preceding certification (t = -1) omitted as the reference period. As shown in Figure 1, the pre-certification coefficients are statistically indistinguishable from zero, supporting the parallel-trends assumption. The estimated effect becomes significant in the certification year.

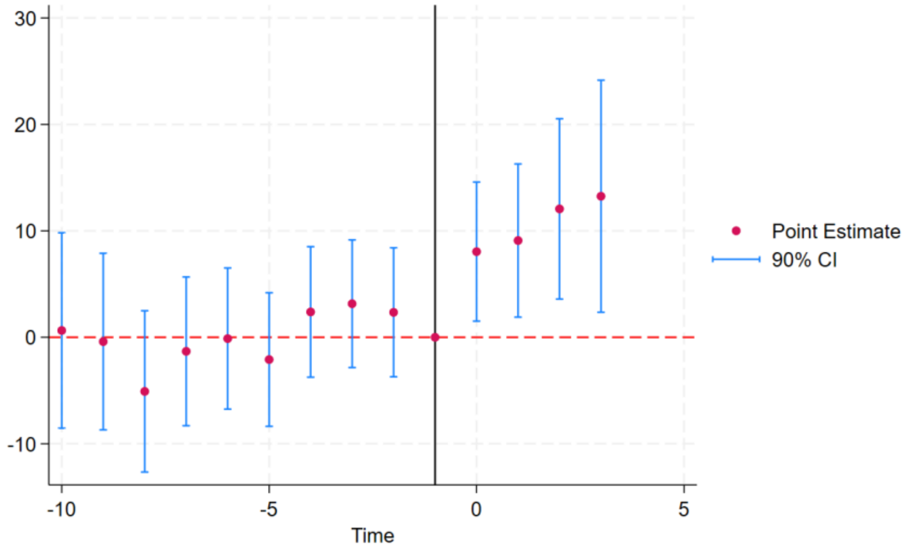

Figure 1. Event-study estimates and parallel-trends test

5.3. Robustness Tests

Table 3. Robustness Tests

VARIABLES	(1) Winsorized	(2) Lagged controls	(3) 2009-2019
DID	7.8567*** (2.912)	5.6718* (3.041)	7.0788** (3.351)
Controls	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	15,353	13,150	12,557
R-squared	0.518	0.512	0.527

Notes: Firm-clustered robust standard errors are reported in parentheses.

Table 3 shows that the DID coefficient remains positive and statistically significant after winsorizing continuous variables, lagging the controls by one year, and restricting the sample to 2009-2019. The estimates range from 5.6718 to 7.8567, indicating that the baseline finding is not driven by outliers, contemporaneous controls, or the exceptional periods at the beginning and end of the sample.

5.3.1. Placebo Tests

Two placebo tests randomly reassign treated firms and, separately, both treated firms and certification years. Each procedure is repeated 500 times. In Figures 2 and 3, the placebo estimates are concentrated around zero, whereas the actual coefficient of 8.2172 lies in the right tail of each distribution. The baseline result is therefore unlikely to arise from random treatment assignment or policy timing.

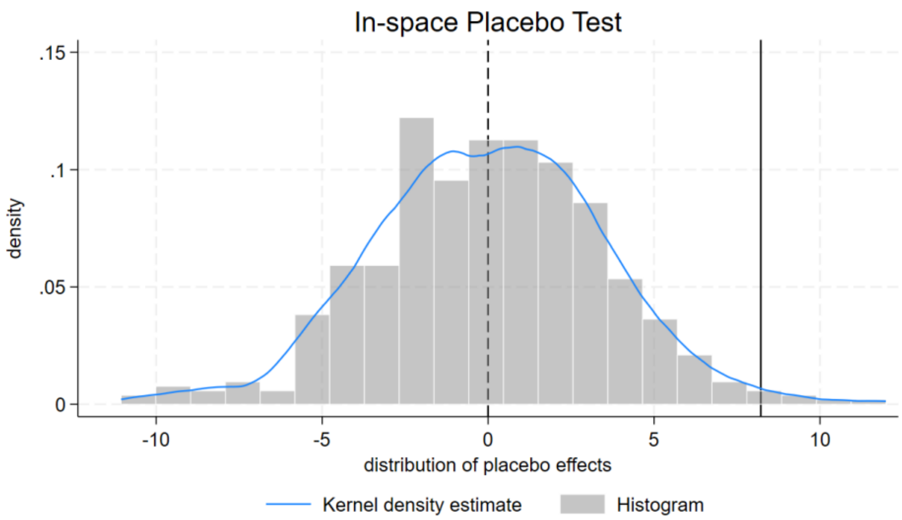

Figure 2. Placebo test with randomly assigned treated firms

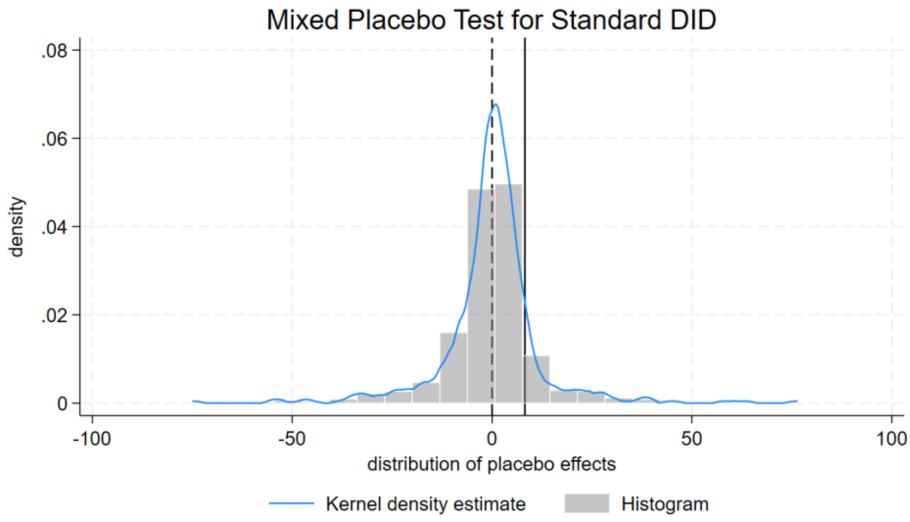

Figure 3. Placebo test with randomly assigned firms and treatment years

5.3.2. Alternative Fixed-Effects Specifications

The estimated effect remains positive across alternative combinations of firm, year, city, industry, and industry-by-year fixed effects (Figure 4). It is also statistically distinguishable from zero under conventional, heteroskedasticity-robust, city-clustered, firm-clustered, and firm-and-year two-way-clustered standard errors (Figure 5). These tests confirm that the result is not sensitive to a single fixed-effects structure or inference method.

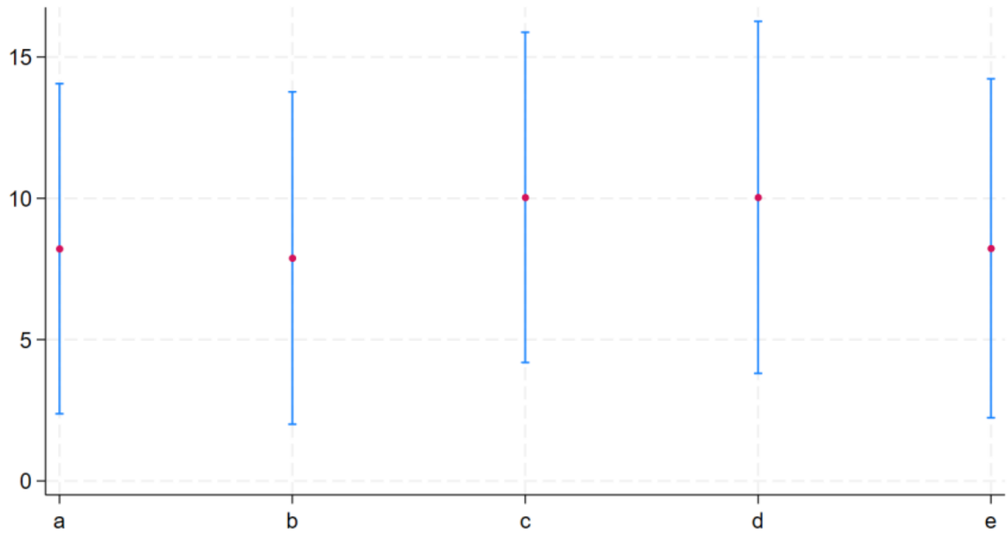

Figure 4. DID estimates under alternative fixed-effects specifications; dots denote point estimates and bars denote 95% confidence intervals

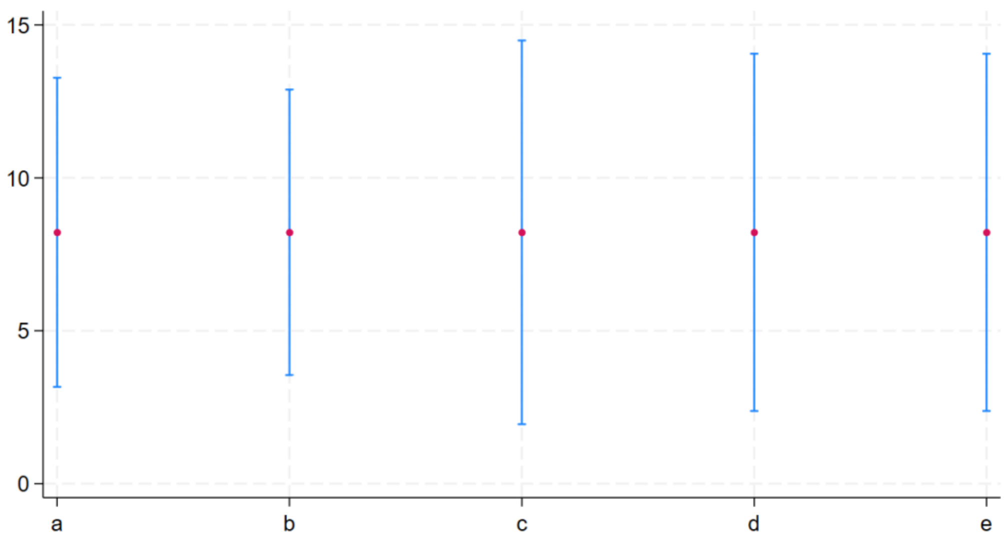

Figure 5. DID estimates under alternative standard-error adjustments; dots denote point estimates and bars denote 95% confidence intervals

6. Mechanism and Heterogeneity Analyses

6.1. Mechanism Tests

The following auxiliary specification examines whether certification is associated with the three proposed mechanism variables:

$$Mechanism_{it} = \alpha + \beta \times DID_{it} + \gamma \times X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Mechanism_it denotes the financing-constraint index (FC_index), R&D intensity (RDSpendSumRatio), or the technological-change component of total factor productivity (TECCH). The models include the baseline controls and firm and year fixed effects, with standard errors clustered at the firm level.

Table 4. Mechanism Tests

VARIABLES	(1) FC_index	(2) RDSpendSumRatio	(3) TECCH
DID	-0.0282*** (0.006)	0.4165*** (0.143)	0.0024*** (0.001)
Controls	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	19,692	14,388	19,591
R-squared	0.859	0.743	0.798

Notes: Firm-clustered robust standard errors are reported in parentheses.

6.1.1. Financing Constraints

Larger values of FC_index indicate more severe financing constraints. Column (1) of Table 4 reports a DID coefficient of -0.0282, significant at the 1% level. Certification is therefore associated with lower financing constraints, consistent with H2a and with the view that a government-backed green signal improves access to external finance [4, 5, 16].

6.1.2. R&D Investment

RDSpendSumRatio is measured as R&D expenditure divided by operating revenue. Column (2) reports a DID coefficient of 0.4165, significant at the 1% level, indicating an increase of approximately 0.42 percentage points in R&D intensity after certification. The estimate is consistent with certification affecting firms' R&D investment and with evidence that public support can stimulate innovation activity [24]. Because R&D investment also enters the denominator of InnoE, however, this result alone does not establish that additional R&D is converted into patent output more efficiently.

6.1.3. Technological Progress

TECCH captures the technological-change component of total factor productivity. Column (3) reports a positive DID coefficient of 0.0024, significant at the 1% level. This result is consistent with H2c and suggests that certification is associated with technological progress that may improve the conversion of innovation inputs into outputs.

Taken together, the auxiliary regressions provide evidence consistent with financing, R&D-investment, and technological-progress channels. Because they do not constitute a complete causal mediation design, the estimates should not be interpreted as a decomposition of the total certification effect.

6.2. Heterogeneity Analysis

Table 5. Heterogeneity by Ownership and Internal Governance

VARIABLES	(1) Non-SOEs	(2) SOEs	(3) Governance-ineffective	(4) Governance-effective
DID	10.8938*** (2.965)	0.1795 (10.343)	31.5937 (19.960)	5.8440** (2.917)
Controls	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	13,431	1,662	616	14,456
R-squared	0.546	0.602	0.678	0.540

Notes: Firm-clustered robust standard errors are reported in parentheses.

6.2.1. Heterogeneity by Ownership

Columns (1) and (2) of Table 5 show that the DID coefficient is 10.8938 and significant at the 1% level for non-SOEs, but small and insignificant for SOEs. The pattern suggests that certification benefits non-SOEs more, possibly because their greater financing constraints increase the marginal value of government endorsement and green finance. As differences in statistical significance do not constitute a formal test of coefficient equality, the result should be interpreted as suggestive heterogeneity.

6.2.2. Heterogeneity by Internal Governance

Firms are divided into governance-effective and governance-ineffective groups using the study's governance classification. Columns (3) and (4) show that the DID coefficient is 5.8440 and significant at the 5% level in the governance-effective group, whereas the estimate for the governance-ineffective group is not significant. Effective governance may help firms allocate certification-related resources and coordinate technological change more efficiently [25]. Without a formal cross-group test, this pattern should likewise be interpreted as suggestive rather than conclusive evidence of heterogeneity.

7. Conclusions and Policy Implications

7.1. Main Findings

Using a staggered difference-in-differences design and data on Chinese A-share manufacturing firms from 2007 to 2020, this study finds that green factory certification is associated with higher corporate innovation efficiency. The result remains robust across alternative samples, specifications, placebo assignments, and inference methods. The mechanism analyses show that certification is associated with lower financing constraints, greater R&D intensity, and technological progress. The subsample estimates further suggest that the positive effect is concentrated among non-SOEs and firms with effective internal governance. Overall, the effectiveness of green manufacturing policy appears to depend on both access to external resources and firms' capacity to convert policy support into technological and organizational change.

7.2. Contributions

This study extends research on green industrial policy by shifting attention from innovation output to the efficiency with which firms convert R&D inputs into patent output. It also integrates financing constraints, R&D investment, technological progress, ownership, and internal governance into a unified firm-level analysis of green factory certification.

7.3. Policy Implications

Green factory policy should combine credible certification standards with targeted fiscal, tax, and green-finance support. The suggestive ownership heterogeneity indicates that such support should pay particular attention to credit-constrained non-SOEs without weakening assessment standards. Financial institutions can support this objective by developing transparent green-credit products and risk-assessment procedures. Firms should also strengthen internal governance, information disclosure, resource allocation, and managerial coordination to convert certification-related resources into sustained innovation.

7.4. Limitations and Future Research

Several limitations remain. First, the innovation-efficiency measure focuses on patent applications relative to R&D investment and does not capture all forms of managerial, process, or non-patented innovation. Second, the auxiliary mechanism regressions do not identify the causal share of the total effect transmitted through each channel. Third, the subsample estimates do not formally establish coefficient differences across ownership and governance groups. Finally, the sample is limited to listed Chinese manufacturing firms. Future research could employ broader innovation measures, stronger mediation and cross-group tests, and samples covering unlisted firms and other institutional settings.

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