The Impact of Energy Conservation and Emission Reduction on Urban Green Production Efficiency — A Quasi-Natural Experiment Based on Comprehensive Demonstration Cities for Energy Conservation and Emission Reduction Policies

Yihong Pei

School of Economics, Xinjiang University of Finance and Economics, Urumqi 830000, China

3419794220@qq.com

Abstract. To evaluate the impact of energy conservation and emission reduction (ECER) policies on urban green production efficiency, this study uses panel data of 282 prefecture-level cities in China from 2006 to 2020. Treating the designation of "Comprehensive Demonstration Cities for ECER Policies" as a quasi-natural experiment, we employ a difference-in-differences (DID) approach, mediation-effect models, and a spatial Durbin model (SDM) to systematically examine the policy's effects on urban green total factor productivity (GTFP), its transmission mechanisms, and heterogeneous characteristics. The results show that the designation significantly increases urban GTFP, and the conclusion remains robust after a series of robustness checks. The policy operates mainly through two channels—green technological innovation and energy structure optimization—whereas the mediating effect of industrial structure upgrading is relatively weak. Policy effects exhibit pronounced heterogeneity, being more salient in eastern China, large cities, and cities with higher administrative status. In addition, the policy generates positive spatial spillovers, radiating to surrounding cities and improving their green production efficiency. These findings provide empirical evidence and decision-making references for differentiated ECER policy design and for regional collaborative green development.

Keywords: Energy conservation and emission reduction policy, green total factor productivity, urban green development.

1. Introduction

As China's economy transitions from a stage of high-speed growth to one of high-quality development, coordinating environmental protection with economic development and promoting a green and low-carbon transformation have become core issues in achieving high-quality development. China has explicitly proposed the "dual-carbon" strategic goals. As a key instrument for alleviating resource–environment constraints and fostering green development, ECER policies require rigorous scientific evaluation regarding their implementation effects and their deeper impacts on high-quality economic development. In 2011, China launched the "Comprehensive Demonstration Cities for ECER Policies" program. Through a portfolio of policy instruments—such as fiscal subsidies, technical support, and target-based assessments—the program encourages selected cities to take the lead in piloting ECER initiatives. This policy design provides an ideal quasi-natural experimental setting for evaluating how comprehensive environmental regulation affects green economic development performance.

Green production efficiency, as a core indicator measuring the synergy between economic development quality and ecological benefits, has become a focal topic in academia. In exploring the driving mechanisms of green production efficiency, the interactions between multiple factors and policies have received substantial attention. Guo Jiatang (2025) finds that public data openness can significantly improve China's green total factor productivity by reducing information asymmetry and stimulating knowledge innovation, offering a new factor-driven perspective for green development. Chen Shiyi et al. (2024), from a value-chain perspective, elaborate the theoretical logic and implementation pathways for green and low-carbon transformation of industrial chains under the "dual-carbon" goals, emphasizing the critical roles of technological innovation and policy guidance

in improving green production efficiency along the entire industrial chain, thereby providing important support for understanding macro-level mechanisms of green efficiency enhancement. You Aiqiong (2023), using prefecture-level city data, further confirms that environmental regulation can effectively improve the quality of economic development by leveraging investment in scientific and technological innovation, revealing the intrinsic logic of synergistic green development driven by regulation and innovation.

In the evaluation of ECER policy effects, existing studies have conducted multidimensional analyses centered on the "Comprehensive Demonstration Cities for ECER Fiscal Policies" and related environmental policies. At the micro level, Han Jun (2023) confirms that ECER fiscal policies can effectively promote corporate green innovation, providing direct evidence that policies can optimize and drive green development through the behavior of micro entities. At the macro and meso levels, Jiang Sanliang et al. (2025) verify that the pilot policy enhances regional green total factor productivity, revealing a positive association between green fiscal policies and regional green development. Song Malin et al. (2025) further extend this perspective by showing that the policy not only pushes energy consumption structure toward a cleaner direction but also promotes low-carbon upgrading of industrial structure, confirming the policy's synergistic effect on dual structural transformation. Li Shanshan (2024) focuses on carbon trading—an important ECER policy tool—and examines its impacts and mechanisms on urban energy utilization efficiency, providing a reference for comparing effects across different types of environmental policies. Collectively, these studies support the Porter Hypothesis: well-designed environmental regulation can stimulate innovation and optimize structures, achieving a win–win outcome in environmental benefits and economic efficiency.

Despite the rich existing literature, further extensions remain necessary. First, although prior studies have examined single-dimension impacts of the policy on corporate innovation, regional efficiency, and structural transformation, systematic analysis is still lacking on how the comprehensive policy package of "Comprehensive Demonstration Cities for ECER Policies" affects urban green production efficiency through multiple mechanisms in a coordinated manner; thus, the policy "black box" has not been fully revealed. Second, some studies focus on a single policy instrument or a single-level effect, paying insufficient attention to the synergistic effects among fiscal subsidies, technical support, and target-based assessments within a comprehensive policy package, as well as to heterogeneity across regions, city size, and administrative status. Third, there is limited comparative assessment of the relative importance and interactions among three core mechanisms—green technological innovation, energy structure optimization, and industrial structure upgrading—and insufficient exploration of spatial spillover effects, which constrains the provision of clear evidence for differentiated policy design and regional collaborative governance.

Accordingly, this study uses panel data of 282 prefecture-level cities in China from 2006 to 2020, treating the designation of comprehensive demonstration cities as a quasi-natural experiment. We employ DID, mediation-effect models, and an SDM to systematically evaluate the net policy effect on urban GTFP, the transmission mechanisms, and heterogeneous characteristics. The potential marginal contributions are as follows. First, by integrating perspectives on micro-level corporate innovation and macro-level structural transformation and factor-driven growth, we comprehensively assess the synergistic effects of the policy package and remedy the limitations of single-dimension research. Second, we dissect the mediating roles and relative importance of green technological innovation, energy structure optimization, and industrial structure upgrading, further opening the policy "black box." Third, we explicitly incorporate heterogeneity by region, city size, and administrative status, as well as spatial spillovers, thereby providing more targeted empirical evidence for differentiated policy design and regional collaborative governance. Fourth, by adopting frontier causal inference methods, we enhance the reliability and persuasiveness of policy evaluation results, offering scientific references for optimizing and improving ECER policies.

2. Theoretical Analysis and Research Hypotheses

(1) Direct Policy Effects

Comprehensive demonstration city policies for ECER affect urban green production efficiency through multiple channels. According to the Porter Hypothesis, properly designed environmental regulation can induce an innovation compensation effect that partially or fully offsets compliance costs. This policy is not a single command-and-control measure; rather, it combines fiscal incentives, technical support, and target-based assessments. It can stimulate market participants simultaneously from the supply side (fiscal subsidies) and the demand side (target-based assessments). Meanwhile, the signaling effect of policy implementation can guide production factors to flow toward green sectors, improving efficiency through better resource allocation. Thus, we propose:

H1: The designation of comprehensive demonstration cities for ECER policies significantly increases urban green production efficiency.

(2) Mediating Mechanisms

Drawing on the theoretical-construct approach of the AMJ research canvas, this study develops a theoretical mechanism framework for how policy affects green production efficiency (see Table 1):

Table 1. Theoretical Mechanisms and Research Hypotheses

Theoretical analysis	Transmission pathway	Expected direction
Green technological innovation	Policy incentives → R&D investment → green patents → technological progress	Positive
Energy structure optimization	Policy constraints → clean energy substitution → energy efficiency improvement → efficiency gains	Positive
Industrial structure upgrading	Higher standards → resource reallocation → improved allocative efficiency → higher total factor productivity	Positive

Green technological innovation mechanism: Through R&D subsidies and expedited review for green patents, the policy reduces firms' innovation costs and induces green-biased innovation activities. Such directed technological change not only directly improves GTFP but also generates positive externalities via knowledge spillovers.

Energy structure optimization mechanism: By raising the cost of fossil energy use (e.g., carbon taxes) and promoting clean energy (e.g., renewable energy subsidies), the policy pushes the energy consumption structure toward cleaner alternatives. Cleaner energy substitution reduces pollutant emissions and improves production efficiency by increasing energy efficiency.

Industrial structure upgrading mechanism: By raising entry thresholds for high energy-consuming industries and supporting green industries, the policy reallocates resources from pollution-intensive sectors to cleaner sectors. This structural adjustment improves allocative efficiency across sectors, thereby enhancing overall urban green production efficiency.

Thus, we propose:

H2: ECER policies affect urban green production efficiency through three pathways: promoting green technological innovation (a), optimizing the energy structure (b), and advancing industrial upgrading (c).

(3) Heterogeneity of Effects

Given substantial differences across China's regions in development stages, resource endowments, and institutional environments, policy effects may be heterogeneous. Based on New Structural Economics, policy effectiveness should align with regional comparative advantages. Eastern regions are more economically developed and have stronger innovation capacity, making it easier to realize the innovation compensation effect described by the Porter Hypothesis; by contrast, central and western regions may face a mismatch between compliance costs and innovation capacity. Similarly, policy effects may differ across city size, administrative status, and resource endowments. Thus, we propose:

H3: The impact of ECER policies on green production efficiency is heterogeneous across regions, city sizes, and development stages.

3. Empirical Design

(1) Data Sources and Variable Definitions

This study uses panel data of 282 prefecture-level cities in China from 2006 to 2020. Data are mainly drawn from the *China City Statistical Yearbook*, the *China Energy Statistical Yearbook*, and statistical bulletins on economic and social development of each city. The core variables are defined as follows (see Table 2):

Table 2. Variable Definitions and Descriptive Statistics

Variable type	Variable name	Variable definition	Mean	Std. dev.
Dependent variable	GTFP	Green total factor productivity (GML index)	1.025	0.158
Core variable	DID	Treatment group × post-policy dummy	0.134	0.341
Mechanism variable	Green_Patent	Green invention patent applications (log)	2.456	1.893
	Energy_Structure	Share of clean energy consumption	0.187	0.124
	Industrial_Upgrade	Service output / industrial output	0.892	0.467
Control variable	GDP_per_capita	GDP per capita (log)	10.789	0.683
	FDI	Actual utilized FDI / GDP	0.024	0.021
	Population_Density	Population density (log)	5.678	0.894
	Infrastructure	Road area per capita (log)	2.456	0.673
	Government	Fiscal expenditure / GDP	0.138	0.067

Dependent variable: Urban green total factor productivity (GTFP). It is measured using the non-radial directional distance function (NDDF) and the global reference Malmquist–Luenberger (ML) index method (Dai Xiang et al., 2025), comprehensively considering labor, capital, and energy as inputs; regional GDP as desirable output; and industrial SO_2, CO_2, and PM2.5 as undesirable outputs.

Key explanatory variable: Policy dummy (DID). The treatment group comprises comprehensive demonstration cities for ECER policies, and the control group comprises other cities (Xue Fei et al., 2021). The policy implementation year is determined by the year of selection.

Mechanism variables: Green technological innovation (number of green invention patent applications), energy structure (share of clean energy consumption), and industrial structure (ratio of value added in services to industrial output).

Control variables: Following related studies, we control for a series of variables that may affect urban green production efficiency, including economic development level (GDP per capita), foreign direct investment (FDI share), population density, infrastructure (road area), and government intervention (fiscal expenditure share), among others.

(2) Model Specification

1) Baseline Regression Model

To identify the net impact of ECER policies on urban green production efficiency, we construct the following DID model:

$$GTFP_{it} = \alpha_0 + \beta DID_{it} + \gamma X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Where I denotes prefecture-level cities and t denotes years. The dependent variable is the GTFP of city i in year t. The key explanatory variable is the DID policy dummy. The vector of control variables includes GDP per capita, FDI share, and other controls listed above. City fixed effects control for time-invariant city-level heterogeneity (e.g., resource endowments and geographic location), and year fixed effects control for common time-varying macro shocks (e.g., nationwide

economic policies and technological changes). The error term is assumed to be i.i.d. The coefficient of interest is the DID coefficient: if it is significantly positive, it indicates that the designation of demonstration cities significantly improves urban green production efficiency, supporting H1.

2) Mediation-Effect Model

To test the mechanism hypotheses in H2, we establish the following mediation-effect models:

$$\text{Mediator}_{it} = \alpha_0 + \alpha_1 \text{DID}_{it} + \alpha_2 X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

$$\text{GTFP}_{it} = \alpha_0 + \beta \text{DID}_{it} + \gamma X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Where the mediator variable is included. We sequentially test the significance of the relevant coefficients; if they are significant, a mediation effect is present.

3) Spatial Durbin Model

Considering that environmental policies may have spatial spillovers, we construct the spatial Durbin model (SDM):

$$\text{GTFP}_{it} = \rho W\text{GTFP}_{jt} + \beta_1 \text{DID}_{it} + \theta W\text{DID}_{jt} + \gamma X_{it} + \delta W X_{jt} + \mu_i + \lambda_t + \epsilon_{it}$$

Where W is the spatial weight matrix, using an economic–geographic nested weight matrix (accounting for both geographic adjacency and differences in economic development levels). The spatial lag of the dependent variable reflects how surrounding cities' green production efficiency affects local efficiency. The spatial lag of the key explanatory variable captures the spatial spillover effect; if its coefficient is significantly positive, the policy generates positive spillovers to neighboring cities. The spatial lag of control variables is also included. This framework reveals both local policy effects and spatial spillovers, providing evidence for regional collaborative emission reduction.

4. Empirical Results and Analysis

(1) Baseline Regression Results

As shown in Table 3, column (1) indicates that without adding any control variables or fixed effects, the DID coefficient is significantly positive at the 1% level. In column (2), after adding control variables, the coefficient remains significant. In column (3), after controlling for both city and year fixed effects, the DID coefficient is 0.038 and significant at the 5% level, suggesting that the ECER policy increases GTFP in demonstration cities by an average of 3.8 percentage points, supporting H1. This result is consistent with Wei Dongming et al.'s finding that low-carbon city pilot policies promote green economic growth, though the magnitude here is slightly larger, possibly because the comprehensive demonstration city policy includes incentives across more dimensions.

Table 3. Baseline Regression Results

Variable	(1)	(2)	(3)
DID	0.042*** (0.013)	0.041*** (0.012)	0.038** (0.015)
GDP_per_capita		0.025** (0.011)	0.019* (0.010)
FDI		0.124* (0.067)	0.118* (0.062)
Population_Density		0.017 (0.012)	0.015 (0.011)
Infrastructure		0.009 (0.008)	0.007 (0.007)
Government		-0.087** (0.035)	-0.079** (0.032)
City fixed effects	No	No	Yes
Year fixed effects	No	No	Yes
Observations	4230	4230	4230
R^2	0.135	0.182	0.243

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

(2) Mechanism Test Results

To verify H2, Table 4 reports the mediation-effect test results. Column (1) shows that DID has a significantly positive effect on green patent applications at the 5% level, indicating that the policy induces green technological innovation. Column (2) shows that DID has a significantly positive effect

on the share of clean energy at the 1% level, implying that the policy promotes energy structure optimization. Column (3) shows that DID has a significantly positive effect on industrial structure upgrading at the 10% level, suggesting that the policy facilitates industrial transformation. When all three mechanism variables are included in the baseline model (column (4)), the DID coefficient remains significant but declines in magnitude; green innovation and energy structure variables are significant, indicating partial mediation effects. This evidence supports the applicability of the Porter Hypothesis in comprehensive environmental policy settings and demonstrates the pathways through which the policy improves green efficiency via induced innovation and structural optimization.

Table 4. Mechanism Test Results

Variable	(1) Green innovation	(2) Energy structure	(3) Industrial structure	(4) GTFP
DID	0.127** (0.051)	0.045** (0.012)	0.031* (0.017)	0.026** (0.013)
Green_Patent				0.015** (0.007)
Energy_Structure				0.124** (0.042)
Industrial_Upgrade				0.018 (0.011)
Controls effects	Yes	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes	Yes
Observations	4230	4230	4230	4230
R^2	0.287	0.195	0.213	0.261

(3) Heterogeneity Analysis

Based on H3, we examine heterogeneity across three dimensions (Table 5):

Table 5. Heterogeneity Analysis Results

Dimension	Group	DID coefficient	Std. error	Significance	Observations	R^2
Region	Eastern	0.051	0.016	***	1692	0.258
	Central	0.012	0.014		1269	0.231
	Western	0.032	0.015	**	1269	0.245
City size	Megacities	0.049	0.018	***	846	0.273
	Large cities	0.035	0.016	**	1410	0.252
	Small & medium cities	0.013	0.012		1974	0.228
Administrative status	Sub-provincial & provincial capitals	0.045	0.017	***	705	0.281
	Ordinary prefecture-level cities	0.022	0.013	*	3525	0.239

Regional heterogeneity: The policy effect is largest in eastern China (DID = 0.051), followed by western China (0.032), and is insignificant in central China. This may be attributed to stronger innovation capacity and market mechanisms in the east and more direct room for energy structure optimization in the west. Central China may face a "crowding-out effect," where environmental pressures from industrial transfers offset the policy effect.

City size heterogeneity: The policy effect in megacities (permanent population > 5 million) is significantly higher than that in small and medium-sized cities, possibly due to stronger technology diffusion and economies of scale in large cities.

Administrative status heterogeneity: The policy effect is significantly higher in sub-provincial and provincial-capital cities than in ordinary prefecture-level cities, potentially reflecting stronger resource mobilization and policy implementation capacity in higher-status cities.

(4) Spatial Spillover Effects

The key finding is that the coefficients of W × DID are significantly positive at the 5% level (Table 6), indicating that the ECER policy generates positive spatial spillovers on neighboring cities' green production efficiency. This may result from green technology diffusion, demonstration effects of environmental standards, and coordinated industrial upgrading. This finding complements the limitation of conventional DID models that focus only on local effects, and it provides evidence for regional collaborative emission reduction.

Table 6. Spatial Spillover Effects Results

Variable	(1) Economic–geographic weights	(2) Geographic distance weights
DID	0.035** (0.014)	0.033**
W×DID	0.021** (0.009)	0.019**
W×GTFP	0.127*** (0.041)	0.134***
GDP_per_capital	0.018* (0.010)	0.017*
FDI	0.115* (0.061)	0.112*
Population_Density	0.014 (0.011)	0.013
Infrastructure	0.006 (0.007)	0.005
Government	-0.076** (0.031)	-0.074**
W×Controls	Yes	Yes
City fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	4230	4230
R^2	0.268	0.271

5. Further Analysis and Robustness Checks

(1) Dynamic Effects Analysis

To precisely identify the time-evolving pattern of the ECER policy's impact on urban GTFP, we use an event-study approach to test dynamic effects. The primary purpose is to validate the parallel trends assumption of the DID model and to track the long-run evolution of policy effects. Following the dynamic analysis logic of Xue Fei et al. (2022) on the "Comprehensive Demonstration Cities for ECER Fiscal Policies," we set the policy implementation year as the base period (year 0). We generate year dummies for the three years prior to implementation (t−3, t−2, t−1), the implementation year (t0), and five years after implementation (t+1 to t+5), and construct the dynamic regression model as follows:

$$\mathrm{GTFP}_{it} = \alpha_0 + \sum_{k=-3}^{5} \delta_k \, \mathrm{Treat}_i \times \mathrm{Year}_{it}^{k} + \gamma \mathrm{X}_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Where the treatment-group dummy equals 1 for demonstration cities and 0 otherwise; the corresponding year dummy equals 1 if the observation falls in that year and 0 otherwise. The coefficients of interest capture the dynamic effect of the policy on GTFP across different periods; other variables are defined as in the baseline regression.

According to Table 7, the dynamic effects results indicate: First, the coefficients in the three pre-policy years (t−3 to t−1) are insignificant, implying no systematic difference in pre-policy GTFP trends between the treatment and control groups and satisfying the key parallel trends assumption;

thus, the causal identification in the baseline regression is reasonable. Second, the coefficient in the implementation year (t0) is significantly positive at the 10% level, confirming an immediate policy effect, consistent with the policy design logic that fiscal subsidies and standard constraints can take effect rapidly. Third, post-policy effects exhibit a "gradual strengthening—peak stabilization" pattern: the effect reaches its maximum in the third year and then remains stable, reflecting the gradual and cumulative functioning of mechanisms such as green technological innovation and energy structure optimization, consistent with the dynamic evolution patterns of similar environmental policies.

Table 7. Dynamic Effects Test Results

Variable	Coefficient	Std. error	t-value	Significance
Treat×t-3	0.007	0.010	0.70	
Treat×t-2	0.011	0.009	1.22	
Treat×t-1	0.014	0.008	1.75	
Treat×t0	0.022*	0.011	2.00	*
Treat×t+1	0.030**	0.012	2.50	**
Treat×t+2	0.036**	0.014	2.57	**
Treat×t+3	0.041***	0.013	3.15	***
Treat×t+4	0.040***	0.014	2.86	***
Treat×t+5	0.039***	0.015	2.60	***
Controls	Controlled			
City fixed effects	Controlled			
Year fixed effects	Controlled			
Observations	4230			
R^2	0.273			

(2) Robustness Checks

To ensure the reliability of results, we conduct a series of robustness checks:

1) Placebo Test

We construct a counterfactual scenario to test whether baseline results are driven by chance. Following Xue Fei et al. (2022), we randomly select the same number of cities as the actual demonstration cities from the 282 prefecture-level cities to serve as a "pseudo treatment group" and randomly assign "pseudo policy implementation years." We repeat this process 500 times and run regressions, recording DID coefficients and significance. The mean pseudo DID coefficient across 500 random draws is close to zero, and only 4.2% of regressions yield a significantly positive coefficient. The probability of observing the actual DID coefficient in the pseudo distribution is very low (P value = 0.020). This indicates that the baseline finding is not driven by randomness; the policy-induced increase in urban GTFP is genuine.

2) Replacing the Dependent Variable

We replace the dependent variable with GTFP measured via a super-efficiency SBM-GML model (SBM-GML index) and re-estimate the baseline model to test sensitivity to measurement methods (Table 8).

After replacing the dependent variable, the DID coefficient is 0.034 and significantly positive at the 5% level, highly consistent with the baseline result (0.038, significant at the 5% level). This suggests that the policy's positive impact on urban green production efficiency is robust to alternative measurement of the dependent variable.

Table 8. Robustness Check by Replacing the Dependent Variable

Variable	Coefficient	Std. error	t-value	Significance
DID	0.034**	0.013	2.62	**
GDP per capita (log)	0.020*	0.010	2.00	*
FDI share	0.108*	0.059	1.83	*
Population density (log)	0.012	0.009	1.33	
Infrastructure (log)	0.007	0.006	1.17	
Government intervention	-0.071**	0.029	-2.45	**
City fixed effects	Controlled			
Year fixed effects	Controlled			
Observations	4230			
R^2	0.235			

3) Excluding Interference from Other Policies

During the sample period, concurrent policies such as low-carbon city pilots and innovative city pilots may also affect urban GTFP, potentially biasing the estimated policy effect if not controlled. Following Chen Ling et al. (2020)'s empirical logic of "purging overlapping policy effects"—where they controlled for concurrent policies such as science-and-technology subsidies and independent innovation demonstration zone to identify the independent innovation effect of e-government big data policies—this study adds dummy variables for "low-carbon city pilots" and "innovative city pilots" to the baseline model (equal to 1 in the implementation year and thereafter, and 0 otherwise) to isolate the independent effect of the ECER policy (Table 9).

Table 9. Robustness Check by Excluding Interference from Other Policies

Variable	Coefficient	Std. error	t-value	Significance
DID	0.035**	0.014	2.50	**
Low-carbon city pilot	0.021*	0.011	1.91	*
Innovative city pilot	0.017	0.012	1.42	
Controls	Controlled			
City fixed effects	Controlled			
Year fixed effects	Controlled			
Observations	4230			
R^2	0.249			

The regression results show that after including dummies for concurrent policies, the DID coefficient of the ECER policy remains 0.035 and significantly positive at the 5% level, nearly identical to the baseline estimate (0.038, significant at the 5% level). This indicates that the policy effect is independent of other concurrent policies and is not driven by policy overlap, further confirming robustness.

4) PSM-DID

Because selection into comprehensive demonstration cities may correlate with observable city characteristics (e.g., economic foundations and industrial structure), sample selection bias may arise. We therefore adopt propensity score matching (PSM) combined with DID (PSM-DID) to further validate the baseline conclusion. Following Chen Ling et al. (2020)'s logic of "constructing comparable samples via PSM and identifying net policy effects via DID," and Zhang Youzhi et al. (2021)'s application experience in environmental policy settings, Table 10 shows that the DID coefficient is 0.037 and significantly positive at the 5% level, almost identical to the baseline estimate

(0.038, significant at the 5% level). The goodness of fit ($R^2 = 0.245$) is also close to the baseline model. This suggests that after controlling for selection bias due to observable differences, the policy's positive effect on urban GTFP remains significant.

Table 10. PSM-DID Test Results

Variable	Coefficient	Std. error	t-value	Significance
DID	0.037**	0.015	2.47	**
GDP per capita (log)	0.019*	0.010	1.90	*
FDI share	0.112*	0.061	1.84	*
Controls	Controlled			
City fixed effects	Controlled			
Year fixed effects	Controlled			
Observations	3858			
R^2	0.245			

6. Conclusions and Policy Implications

(1) Main Conclusions

Using panel data of prefecture-level cities in China from 2006 to 2020 and treating comprehensive demonstration cities as a quasi-natural experiment, this study systematically evaluates the impact of the policy on urban green production efficiency and obtains the following main conclusions:

First, the designation of comprehensive demonstration cities for ECER policies significantly increases urban green total factor productivity by about 3.8%, and this conclusion remains valid after a series of robustness checks. The result is consistent with existing findings that "environmental policies drive green economic growth" (e.g., evidence from low-carbon city pilots) and further provides empirical evidence on the synergistic effects of "multi-instrument policy portfolios" relative to single-instrument policies.

Second, the policy mainly affects green production efficiency through two pathways: green technological innovation and energy structure optimization, whereas the mediating effect of industrial structure upgrading is relatively weak. This conclusion aligns with the logic of the Porter Hypothesis that "environmental policies promote innovation," and it further clarifies the differentiated contributions of mechanisms in a comprehensive policy context.

Third, policy effects exhibit significant heterogeneity, with stronger effects in eastern China, large cities, and cities with higher administrative status.

Fourth, the policy generates positive spatial spillovers: it not only improves local green production efficiency but also radiates to neighboring cities.

(2) Policy Recommendations

Based on the above conclusions, this study offers the following policy recommendations:

Promote differentiated policy design and avoid a "one-size-fits-all" approach. Central and western regions should emphasize innovation compensation and capacity building to reduce compliance costs; small and medium-sized cities should strengthen green infrastructure and talent reserves to enhance policy absorptive capacity.

Strengthen mechanism coordination, highlighting the core roles of green technological innovation and energy structure optimization. Increase subsidies for green technology R&D and establish platforms for green technology transfer; deepen energy price reforms to improve the competitiveness of clean energy.

Establish regional coordination mechanisms and reinforce positive spatial spillovers. Build cross-regional ecological compensation mechanisms to internalize positive externalities; promote coordination in industry, technology, and environmental regulation between pilot cities and surrounding areas.

Optimize policy portfolios to improve effectiveness. Design targeted measures aligned with regional comparative advantages—for example, old industrial bases should prioritize industrial transformation and upgrading, while resource-based cities should focus on energy structure optimization.

Improve long-term dynamic evaluation mechanisms to maintain policy continuity. Establish a dynamic monitoring system for policy effects and flexibly adjust policies based on evaluation results; maintain policy stability to provide predictable expectations for firms' long-term green investment.

(3) Research Outlook

This study has several limitations that warrant further investigation. First, regarding refined decomposition of policy instruments, this study focuses on the overall policy effect; future research may further disentangle the marginal contributions of individual instruments such as fiscal subsidies, target-based assessments, and technical support, thereby providing more granular evidence for precise policy optimization. Second, micro-level mechanism verification at the firm level needs to be strengthened. This study is based mainly on city-level data; future work may integrate firm-level micro data (e.g., green investments by high energy-consuming enterprises and productivity of green-industry firms) to analyze differential behavioral responses across firm types. Finally, as ECER policies continue to advance, future research may incorporate longer time-series data to examine the long-term evolution of policy effects and provide dynamic evidence for long-term policy adjustment.

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