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The Impact of the New Energy Demonstration City Pilot Policy on Urban Green Total-Factor Energy Efficiency: Evidence from China

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Abstract: With the continuous growth of total energy consumption, non-fossil energy utilization and energy efficiency have become increasingly important for promoting high-quality urban development. Policy instruments play a crucial role in improving regional energy efficiency. Based on panel data of 282 prefecture-level cities in China from 2006 to 2023, this study first measures urban green total-factor energy efficiency (GTFEE) using the super-efficiency SBM model. Then, a difference-in-differences (DID) model is employed to examine the impact of the New Energy Demonstration City pilot policy on GTFEE. The empirical results show that: (1) The pilot policy significantly enhances urban green total-factor energy efficiency. (2) By employing the super-efficiency SBM model to measure the green total-factor energy efficiency (GTFEE) of cities, this study evaluates the effectiveness of the new energy demonstration city policy. Furthermore, the mechanisms of its impact are verified through parallel trend tests and placebo tests, providing more targeted evidence for the precision adjustment and optimization of related policies. (3) The effects of the New Energy Demonstration City pilot policy on energy efficiency exhibit notable heterogeneity across cities.

Keywords: New Energy Demonstration City Pilot Policy; Green Total-Factor Energy Efficiency; Policy Effects; Difference-in-Differences Model.

1. Introduction

Against the backdrop of rapid global economic growth and accelerating urbanization, energy serves as the cornerstone of economic development and has been a key driver of China's rapid economic expansion. Since the launch of the reform and opening-up policy, China's economy has relied on continuous energy consumption for development; however, the traditional energy-driven growth model has increasingly become a bottleneck for the country's sustainable economic progress. Promoting a green and low-carbon transformation, developing renewable energy, increasing the proportion of non-fossil energy consumption, and improving green total factor energy efficiency are therefore of great significance. To further advance the optimization of the energy structure and fully harness the comprehensive benefits of new energy in both economic development and ecological protection, the central government has successively introduced a series of supportive policies, giving rise to the New Energy Demonstration City Policy.In January 2014, the National Bureau of Statistics issued the Notice on the Publication of the List of New Energy Demonstration Cities (Industrial Parks) (First Batch) and related documents, officially designating the first group of 81 new energy demonstration cities and 8 industrial parks. The pilot program encompasses 22 provinces, 4 autonomous regions, and 2 municipalities directly under the central government [1]. As a major policy instrument for energy transition, the New Energy Demonstration City initiative not only offers a practical setting for exploring green energy development models but also serves as a key institutional arrangement to foster regional green growth and enhance energy efficiency.

Existing studies suggest that well-designed energy policies can substantially optimize regional energy consumption structures [2]. Environmental regulation, as a primary policy lever, plays a significant role in improving environmental quality: by tightening pollution control and emission management, it can effectively reduce regional pollutant discharges, thereby raising energy utilization efficiency from the perspective of minimizing undesirable outputs [3]. Meanwhile, the New Energy Demonstration City Policy carries the dual nature of both an energy policy and an environmental regulatory measure. When these two policy instruments operate in tandem, they not only stimulate regional economic activity but also boost energy efficiency through increased desirable outputs [4], directly shaping the evolution of urban energy mixes. This interplay further underscores the positive role of policy pilots in advancing energy performance.

Energy efficiency serves both as a critical indicator for evaluating the quality of economic growth at national and regional levels and as an essential metric for industrial upgrading and urban green development [5]. In terms of measurement, the Data Envelopment Analysis (DEA) approach is widely adopted in the literature [6], given its suitability for handling models with multiple desirable and undesirable outputs. K. Tone [7] introduced the Super-Efficiency SBM model in 2002, which relaxes the proportional assumption between inputs and outputs. This model not only distinguishes efficiency variations among multiple efficient decision-making units but also addresses the slack variable issue, allowing further differentiation of units with efficiency scores exceeding one.

Using panel data for 282 prefecture-level cities in China over the period 2006–2023, this paper employs the Super-Efficiency SBM model to measure urban green total factor energy efficiency, providing empirical evidence for its enhancement. Through a Difference-in-Differences (DID) framework, we confirm that the New Energy Demonstration City pilot policy exerts a significant and positive impact on urban green total factor energy efficiency, and we explore the underlying mechanisms driving this effect. In addition, by systematically examining the heterogeneous responses of the pilot policy across cities with varying regional attributes, energy consumption patterns, and administrative hierarchies [8], the study offers practical insights for the future roll-out of new energy policies and the pursuit of high-quality urban development.

2. Research Hypotheses

2.1. Promoting Effect of the New Energy Demonstration City Pilot Policy on Green Total-Factor Energy Efficiency

The New Energy Demonstration City pilot policy is expected to enhance green total factor energy efficiency (GTFEE) through multiple channels. One such channel lies in the policy's emphasis on coordinated multi-energy system development as part of environmental governance and energy efficiency improvement [9]. By encouraging the complementary use of electricity, wind, biomass, and solar power, and by strengthening cross-system coordination, the policy facilitates optimal energy resource allocation and thus raises overall urban energy efficiency. Another channel involves the frequent integration of the demonstration city initiative with low-carbon transportation policies. Under this framework, the diffusion of new energy vehicles has gained momentum, leading to structural changes in transportation energy consumption. These changes reduce reliance on fossil fuels, lower carbon emissions, and contribute to enhanced energy efficiency [10]. A further channel is the suite of supporting incentive mechanisms, including fiscal subsidies and tax incentives [11]. Such institutional provisions stimulate both enterprises and residents to adopt clean energy technologies and energy-saving equipment. In parallel, policy advocacy and behavioral guidance help raise public awareness of energy conservation, gradually fostering a societal norm of energy saving that further promotes efficiency gains.

Based on the above theoretical reasoning, we formulate the following hypothesis:

Hypothesis 1: The New Energy Demonstration City pilot policy has a significant positive effect on the green total factor energy efficiency (GTFEE) of the pilot cities.

2.2. Regional Heterogeneity of the New Energy Demonstration City Pilot Policy

However, whether such a policy can exert a consistently positive effect on GTFEE may depend on regional heterogeneity and various local characteristics. The impact of the pilot policy on energy efficiency can be influenced by regional policy differences, energy consumption scale, administrative hierarchy, fiscal capacity, human capital mobility, and technological spillovers. Cities across China exhibit notable disparities in resource endowment and development orientation. According to the List of the First Batch of New Energy Demonstration Cities released by the National Energy Administration, different regions emphasize distinct new energy development paths. For example, western provinces such as Ningxia and Qinghai focus on solar energy development, central provinces such as Henan and Hubei emphasize biomass energy, and eastern provinces such as Zhejiang and Hebei prioritize geothermal energy utilization [1].

During the ongoing energy transition, pilot cities have gradually formed technological accumulation and competitive advantages [12]. Nevertheless, the diffusion of relevant technologies to other areas can be constrained by limited talent mobility and intellectual property protection. Furthermore, due to differences in industrial foundations and technological structures, receiving regions may have weaker absorptive capacities, making it difficult to effectively assimilate and utilize advanced technologies [1]. Therefore, the spillover effect of technological diffusion on the improvement of GTFEE across non-pilot or recipient cities might be limited.Based on regional, technological, and administrative disparities, the following hypothesis is proposed:

Hypothesis 2: The enhancement effect of the new energy demonstration city pilot policy on GTFEE is significantly stronger for western cities than for eastern cities; significantly stronger for cities with high energy consumption than for low energy-consuming cities; and significantly stronger for cities with higher administrative levels than for ordinary prefecture-level cities.

3. Reaction Design

3.1. Model Specification

This study employs the difference-in-differences DID approach for empirical analysis. In the model specification, both time fixed effects and city fixed effects are incorporated to construct a two-way fixed effects model, which effectively controls for unobservable time shocks and city-specific characteristics. This design helps mitigate potential endogeneity that may bias the estimation results.

Cities implementing the new energy demonstration city pilot policy are defined as the treatment group, with their corresponding dummy variable assigned as treat = 1, while cities not included in the pilot program serve as the control group, with treat = 0. A time dummy variable time is introduced to capture the timing of policy implementation: years during and after the policy implementation are coded as 1, and years before implementation are coded as 0. Based on this setup, an interaction term treat × time is constructed to represent the combined effect of the treatment and timing variables. This interaction term is designated as the core explanatory variable did = treat × time, reflecting the net effect of the new energy demonstration city pilot policy [7].The baseline DID model is specified as:

$$GTFEE_{it} = \alpha + \beta \cdot did_{it} + \gamma \cdot X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Where $GTFEE_{it}$ denotes the green total-factor energy efficiency of city i in year t; did is the core explanatory variable;X_{it}represents a vector of control variables, including economic development level, degree of trade openness, fixed asset investment, environmental regulation intensity, and human capital level; μ_i and λ_t denote city and time fixed effects, respectively; $\varepsilon_{it}$is the random disturbance term; $\beta$is the key estimated coefficient, measuring the net impact of the pilot policy on urban energy efficiency;$\alpha$is the constant term; and γ denotes the estimated coefficients of the control variables.The primary focus of this analysis is the estimated coefficient β. A significantly positive β would confirm Hypothesis 1, indicating that the policy has a significant effect in improving urban GTFEE and thus validating its effectiveness. Conversely, a negative and significant β would imply that the pilot policy has reduced urban GTFEE.

3.2. Variable Definition and Data Sources

3.2.1. Variable Definition

(1) Dependent Variable: Green Total Factor Energy Efficiency (GTFEE).

Following the approach of Kong Lingqian (2023) [13], the super-efficiency Slack-Based Measure (SBM) model is employed to measure GTFEE. Labor and capital are selected as non-energy input indicators, represented respectively by the number of employed persons at the end of the year and the capital stock of each city. The actual gross domestic product (GDP) of each city is adopted as the desirable output indicator, with all relevant data deflated to constant 2006 prices to eliminate the influence of price fluctuations.To capture the environmental impacts generated during the energy utilization process, industrial sulfur dioxide (SO_2) emissions, industrial dust emissions, and industrial wastewater discharges are included in the system of undesirable output indicators. In the model setting, each city is regarded as an independent Decision Making Unit (DMU). Based on this framework, production frontiers are constructed for different time periods to compare and evaluate the energy use efficiency of each DMU.Furthermore, by integrating both desirable and undesirable output indicators, the SBM model for measuring total-factor energy efficiency is established [7]. The basic form of the model is expressed as follows:

$$\rho^* = min \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_i^g}{y_{r0}^g}+\sum_{r=1}^{s_2}\frac{s_r^b}{y_{r0}^b}\right)} \quad (2)$$

$$s.t.\begin{cases} x_0=X\lambda+s^- \\ y_0^g=Y^g\lambda-s^g \\ y_0^b=Y^b\lambda+s^b \\ s^-\geq 0, s^g\geq 0, s^b\geq 0, \lambda\geq 0 \end{cases} \quad (3)$$

In the model, ρ^* represents the value of the objective function. X , Y^g , and Y^b denote the vectors of inputs, desirable outputs, and undesirable outputs for each city, respectively.m,s_1, ands_2 correspond to the number of inputs, desirable outputs, and undesirable outputs. s^-, s^g, and s^b are slack variables, and λ represents the weight coefficient variable.The estimated efficiency values derived from the SBM model are used as the dependent variable, reflecting each city's GTFEE performance during 2006–2023.

(2) Core Explanatory Variable

The main explanatory variable is the Difference-in-Differences (DID) interaction term, defined as the product of treat and time:treat = 1 for cities designated as New Energy Demonstration City pilot areas (treatment group), and 0 for non-pilot cities (control group);time = 1 for years during and after the policy implementation, and 0 for years prior to policy initiation.

Using this setup, the study constructs a panel dataset of 282 prefecture-level cities in China from 2006 to 2023, and estimates the coefficient of the policy interaction term to assess how the pilot policy influences GTFEE dynamics.

(3) Control Variables:

To control for potential confounding factors, the model incorporates several city-level control variables:

Economic Development Level (GDP_per): Calculated as GDP divided by total population; the logarithmic form of per capita GDP is used in the regression model.

Trade Openness (trade): Measured as the ratio of total import and export volume to GDP.

Fixed Asset Investment (invest): Measured as the ratio of total fixed asset investment to GDP.

Environmental Regulation Intensity (env): Measured as the proportion of environmental protection expenditure in total fiscal expenditure.

Human Capital Level (HC): Measured as the ratio of the number of students enrolled in regular higher education institutions to the total population at year-end.

3.2.2. Data Sources

The study period spans 2006 to 2023, covering both the pre-policy and post-policy phases. The years 2006–2013 are treated as the baseline period, capturing the natural trajectory of urban green total factor energy efficiency (GTFEE) before the policy was introduced. The interval from 2014 to 2019 constitutes the core observation window, during which the policy effects can be dynamically assessed. The years 2020–2023 are also included in the dataset, but the empirical analysis treats these observations with due caution, given the potential distortions introduced by the COVID-19 pandemic.

The sample consists of 282 prefecture-level cities across China, after excluding those with severe missing data to ensure sample representativeness. Primary data sources include the China City Statistical Yearbook (economic and social indicators), the China Energy Statistical Yearbook (energy consumption), and the China Environmental Statistical Yearbook (pollution measures). The official list of New Energy Demonstration Cities was obtained from the National Energy Administration's website, while green patent data were drawn from the CNRDS database. Missing values were supplemented using provincial and municipal statistical yearbooks. All data underwent rigorous cleaning, outlier treatment, and variable matching, resulting in a unified panel dataset that supports reliable empirical estimation. Table 1 reports the descriptive statistics for all variables

Table 1. Descriptive statistics of variables

Variable	Number of Observations	Mean	Standard Deviation	Minimum	Maximum
GTFEE	5065	1.3930	0.6365	0.3000	2.4994
did	5065	0.3050	0.4605	0	1
GDP_per	5065	9.9786	1.1566	8.0004	11.9992
trade	5065	0.3490	0.1442	0.1001	0.5999
invest	5065	0.5526	0.1453	0.3000	0.7999
env	5065	0.0850	0.0372	0.0200	0.1500
HC	5065	0.0456	0.0201	0.0100	0.0800

4. Empirical Analysis

4.1. Baseline Regression Results

We estimate the policy effect on GTFEE using a two-way fixed effects model with stepwise inclusion of control variables, namely economic development, trade openness, fixed asset investment, environmental regulation, and human capital. Table 2 reports the baseline regression results. The coefficient on the policy dummy (did) remains around 0.024 across different specifications. Moreover, after controlling for covariates, its statistical significance improves from the 10% level to the 1% level, suggesting a robust policy impact. Among the control variables, fixed asset investment exhibits a significantly positive coefficient, while the signs of the other variables are generally consistent with theoretical expectations. The model's R-squared is stable at 0.67.

Overall, the baseline estimates provide strong support for Hypothesis 1, confirming that the pilot policy exerts a positive and significant effect on GTFEE. Although the significant coefficient on investment may indicate a partial mediating channel, the policy effect itself remains the primary driver, which lays a foundation for the subsequent mechanism analysis.

Table 2. Baseline regression results

Variables	(1) Without Controls	(2) + Economic Development	(3) + Trade Openness	(4) + Fixed Asset Investment	(5) + Environmental Regulation	(6) + Human Capital
did	0.0247* (0.0135)	0.0238*** (0.0059)	0.0240*** (0.0059)	0.0240*** (0.0059)	0.0240*** (0.0059)	0.0239*** (0.0059)
ln_GDP_per	—	0.0043 (0.0110)	0.0044 (0.0110)	0.0045 (0.0110)	0.0045 (0.0113)	0.0045 (0.0113)
Invest	—	—	0.0183** (0.0083)	0.0181** (0.0083)	0.0182** (0.0083)	0.0181** (0.0083)
Trade	—	—	—	0.0067 (0.0086)	0.0068 (0.0086)	0.0068 (0.0087)
HC	—	—	—	—	-0.0334 (0.0631)	-0.0339 (0.0628)
Env	—	—	—	—	—	0.0183 (0.0339)
City and Time Fixed Effects	YES	YES	YES	YES	YES	YES
Clustered Std. Errors (City level)	YES	YES	YES	YES	YES	YES
R^2	0.675	0.668	0.668	0.668	0.668	0.668

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

4.2. Robustness Tests

4.2.1. Parallel Trend Test

The validity of the Difference-in-Differences (DID) estimator rests on the parallel trends assumption, which requires that the treatment and control groups exhibit comparable trends prior to the policy shock. Using panel data for the period 2006–2023, we plot the average GTFEE trajectories for pilot and non-pilot cities around the policy intervention in 2014. Figure 1 presents these time-series patterns, offering a preliminary visual check of the parallel trends condition.

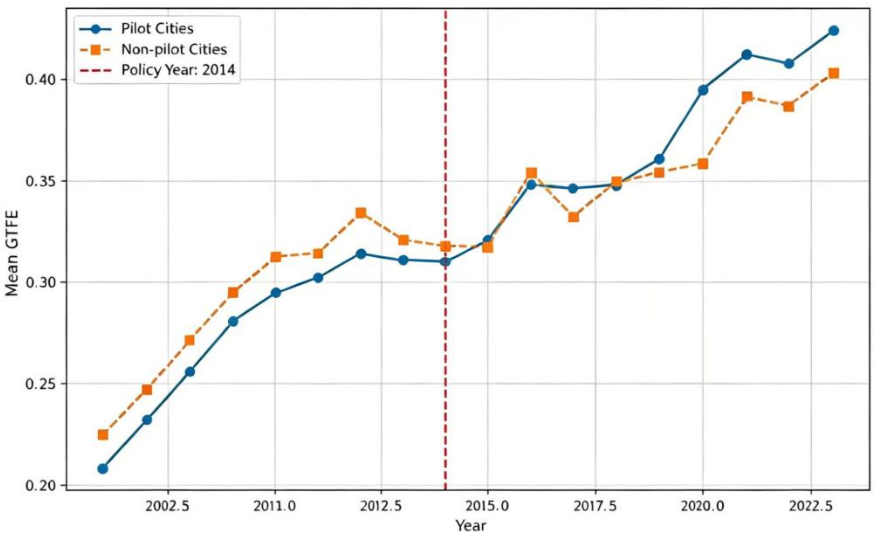

Fig 1. parallel trends test plot

Figure 1 plots the average GTFEE trends for pilot and non-pilot cities from 2007 onward. In the pre-2014 period, the two series move in parallel: both exhibit a steady upward trend, with non-pilot cities maintaining a marginally higher level throughout. The slopes of the two lines are broadly similar, and no pronounced crossing or divergence is visible, which lends initial support to the parallel trends assumption. After 2014, the gap begins to widen, and by 2017 the pilot cities overtake the non-pilot cities. This delayed and widening divergence suggests that the policy effect may be dynamic—either because the intervention takes time to materialize, or because its intensity increased over time. Such a pattern is consistent with the use of a DID framework, as it captures not only the immediate impact but also the evolving long-term effect. Overall, the post-treatment acceleration in the treatment group relative to the control group provides preliminary evidence of a positive policy effect.

4.2.2. Placebo Test

As a further check on whether the baseline estimates are confounded by differential pre-trends between the treatment and control groups, we conduct a placebo test by shifting the policy implementation year forward by one to five years and re-estimating the model with these fictitious intervention dates. Under the hypothesis that the observed effect is genuinely driven by the actual policy, the coefficients on these artificial policy dummies should be small in magnitude and statistically indistinguishable from zero.

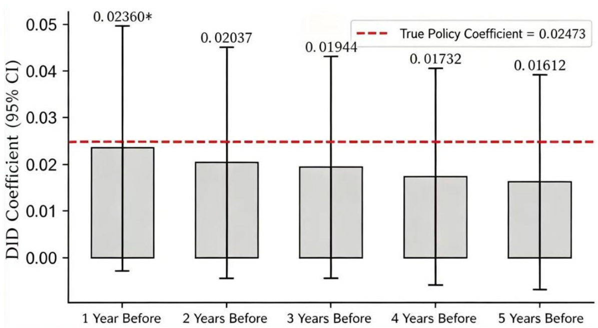

Fig 2. placebo test: fictitious policy years advanced by 1-5 years

The results show that the 95% confidence intervals for all placebo coefficients contain zero, and the point estimates tend to cluster around zero. In terms of statistical significance, the only exception is the one-year-ahead placebo, which is marginally significant at the 5% level; the coefficients for the two- to five-year-ahead placebos are not statistically significant. Overall, this pattern suggests that the baseline findings are unlikely to be spurious.

4.3. Heterogeneity Analysis

4.3.1. Regional Heterogeneity

We divide the sample cities into eastern, central, and western regions and find that the policy effects vary considerably across these areas. Specifically, the coefficient for the eastern region is 0.0003 and not statistically significant; for the central region, it is 0.0155, significant at the 10% level; and for the western region, it is 0.0229, significant at the 1% level.

These results suggest that the New Energy Demonstration City pilot policy has the strongest positive effect on GTFEE in the western region, followed by the central region, while its impact in the eastern region is negligible. This pattern likely stems from the eastern region's already high baseline energy efficiency and well-developed market institutions, which limit the additional gains from the policy. In contrast, the western region, with its relatively less advanced energy structure, appears to benefit more from the demonstration and spillover effects of the initiative. Although the policy also exerts a significant influence in the central region, the magnitude is smaller than that observed in the west.

Overall, the pilot policy yields a pronounced marginal effect in western cities, implying greater room for improvement and a more effective realization of policy dividends in these areas.

4.3.2. Heterogeneity by Energy Consumption Scale

We split the sample into high- and low-consumption groups according to the median of total urban energy consumption. As reported in Table 3, the policy coefficient for the high-consumption group is 0.0167 and is significant at the 5% level, whereas the coefficient for the low-consumption group is 0.0113 and statistically insignificant. This suggests that the pilot policy exerts a stronger effect in cities with higher energy consumption.

A plausible explanation is that high-consumption cities face greater pressure to conserve energy and reduce emissions, leaving more room for clean energy substitution. In contrast, low-consumption cities have inherently lower energy demand, which limits the marginal gains from the policy intervention.

4.3.3. Heterogeneity by Administrative Hierarchy

Table 3. baseline regression results

Variable	Regional Heterogeneity			Energy Consumption Scale Heterogeneity		Administrative Level Heterogeneity	
	Eastern Region	Central Region	Western Region	High Energy Consumption Cities	Low Energy Consumption Cities	High Administrative-Level Cities	Ordinary Administrative-Level Cities
did	0.0003 (0.0102)	0.0155* (0.0091)	0.0229*** (0.0068)	0.0167** (0.0081)	0.0113 (0.0095)	0.0864* (0.0463)	-0.0046 (0.0051)
City and Time Fixed Effects	YES	YES	YES	YES	YES	YES	YES
R^2	0.6405	0.6563	0.7228	0.6911	0.6956	0.7641	0.6756
Adjusted R^2	0.6134	0.6303	0.6989	0.6480	0.6531	0.7345	0.6543
Sample Size	1800	1782	1494	2340	2736	468	4608

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

For the group of cities with higher administrative status (including municipalities directly under the central government, provincial capitals, sub-provincial, and separately listed cities), the policy coefficient is 0.0864, which is positively significant at the 10% level. In contrast, for ordinary prefecture-level cities, the coefficient is -0.0046, negative and statistically insignificant. Clearly, the policy effect is more pronounced in cities with higher administrative status. This may be attributed to their stronger technological talent pools, fiscal resources, policy implementation capacity, and demonstration spillover effects, which enable them to fulfill the requirements of the new energy demonstration program more effectively. Conversely, ordinary prefecture-level cities may be constrained by limited fiscal capacity, human capital, and technological support, resulting in less effective policy implementation.

In conclusion, Hypothesis 2 is supported: the pilot policy for new energy demonstration cities exerts a significantly stronger positive effect on GTFEE in western cities compared with eastern ones; a stronger effect in high energy consumption cities compared with low consumption cities; and a stronger effect in high administrative status cities compared with ordinary prefecture-level cities.

5. Conclusion

The New Energy Demonstration City Pilot Policy is designed to advance the transformation of energy production and consumption, promote ecological civilization, and enhance the role of renewable energy in restructuring the energy mix and protecting the environment. Based on panel data of 282 prefecture-level cities in China from 2006 to 2023, this study employs a difference-in-differences (DID) model to empirically examine the promoting effect of the policy on green total-factor energy efficiency (GTFEE). The main findings are as follows:

The pilot policy yields a significant and robust positive effect on GTFEE in the treated cities. In the baseline specification with two-way fixed effects and full controls, the coefficient on the policy dummy remains around 0.024 and reaches significance at the 1% level. A battery of robustness checks—including parallel trend and placebo tests—supports a causal interpretation and rules out concerns over sample selection bias and differential pre-trends.

The policy effect also varies considerably across city characteristics. Geographically, the impact is largest in the western region, followed by the central region, while no significant effect is detected in the eastern region. In terms of energy consumption, cities with above-median total energy use exhibit a stronger policy response, suggesting that higher baseline demand and greater pressure for transition leave more scope for clean-energy substitution and efficiency gains. Moreover, the effect is significant in cities at higher administrative levels but not in ordinary prefecture-level cities, implying that stronger fiscal, technological, and administrative capacities facilitate effective policy implementation. Conversely, cities with limited resources may encounter greater difficulties in translating the policy into measurable improvements.

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