China's New Energy Policies and Green Economic Development – A Quasi-Natural Experiment Based on New Energy Demonstration City Policies

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Abstract

The "New Energy Demonstration City" plan plays a key role in promoting ecological modernization and achieving the "dual carbon" goals in China. This study uses data from 277 prefecture level cities between 2009 and 2022 to examine the impact of this policy on the development of green economy. We view the implementation of policies as an opportunity to approach natural experimentation, using a difference-in-differences (DID) method and controlling for the common factors that vary over time and the unique characteristics of each city. The results show that once a city is listed as a demonstration city, its green total factor productivity will significantly improve, with an average

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increase of approximately 0.1 units, and this effect will become stronger over time. However, the benefits of policies are not the same everywhere. The response is more pronounced in cities in the eastern region, as well as those that do not rely on mining or resource extraction for their livelihoods; However, resource dependent cities have seen almost no substantial improvement. In addition, the local technological innovation capability plays an amplifying role, and the policy effect is much stronger in cities where green patent activities are more active. These findings indicate that whether a city can successfully promote low-carbon transformation largely depends on its existing institutional foundation and innovation strength.

Keywords: New energy demonstration city, green economic development, technological innovation capacity, PSM-DID.

1 Introduction

As the global climate problem becomes increasingly severe, countries around the world are facing a common task of accelerating the transition to a sustainable energy system and developing a model that can both prosper the economy and not break through the ecological bottom line. In China, this global challenge is closely linked to the domestically proposed "dual carbon" goal, which aims to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. In the face of this urgent task, the 20th National Congress of the Communist Party of China explicitly proposed to "actively and steadily promote carbon peak and carbon neutrality", and regard the new generation of energy pilot cities as a key lever to promote national energy transformation, adjust industrial structure, guide green transformation, and enhance climate adaptability. This work relies on a three-tier promotion system, including top-level design, industry implementation plans, and system collaboration mechanisms, with the aim of gradually breaking away from China's long-standing high dependence on fossil fuels such as coal. In this context, structural transformation and green growth have become increasingly important. In fact, as early as 2014, the National Energy Administration announced the first batch of "renewable energy demonstration cities and demonstration zones" and began exploring clean energy driven urban development models at the local level. The goal of these pilot projects is to explore a replicable and scalable set of experiences, paving the way for the national low-carbon transformation and accumulating practical wisdom for long-term ecological and economic prosperity. By the end of 2023, these efforts have shown initial results. The proportion of coal in China's primary energy consumption has decreased from 67.4% in 2013 to 55.3%. The installed capacity of renewable energy exceeds 1.5 billion kilowatts, accounting for more than half of the country's total power generation installed capacity. At the same time, the national carbon market continues to improve, and China has signed climate cooperation agreements with 42 developing countries and reached 53 South South cooperation memorandums of understanding, focusing on jointly enhancing environmental resilience and promoting sustainable development.

The "New Energy Demonstration City" plan directly intervenes in China's energy infrastructure, embedding ecological governance concepts into practical systems such as power grids, transportation, and factories [1]. It is not gently encouraging change, but actively breaking the long-standing dependence on fossil fuels. But this process is not balanced. From 2009 to 2013, it was a trial and error phase with unclear direction; From 2014 to 2016, a preliminary institutional framework was established, but implementation varied across different regions; Since 2017, policies have been rapidly promoted nationwide through a top-down approach. Cities mainly obtain demonstration qualifications through competitive applications, but regardless of their size or location, they generally face similar administrative and institutional barriers. The core requirement of the policy is to integrate solar energy, wind energy, and biomass energy into all aspects of urban operation, such as power supply, subway construction, and industrial production, and to form replicable experience models. But it is still unclear whether this policy has brought about real green economic growth. To understand this issue, it is necessary to identify which institutional, technological, and regulatory factors truly affect policy effectiveness, as well as how local environmental and socio-economic conditions regulate these effects. Only in this way can decision-makers break free from slogan like promises, come up with practical and feasible solutions, and turn the concept of "high-quality development" from a PPT into tangible progress visible to the people.

The academic discussion on this issue can be roughly divided into three categories. Firstly, there is research focusing on green growth and innovation-driven development, which primarily involves analyzing carbon emission and pollution data to assess ecological impacts [2, 3], and examining advances in clean technologies along with the growth in the number of green patents [4]. Some studies also use economic methods to introduce new indicators, such as multi factor productivity that considers environmental sustainability, or livelihood indicators related to ecological environment improvement, to evaluate the green performance of cities [5, 6]. In these studies, some scholars regard pilot cities as "living laboratories" for energy transformation. More evidence also suggests that such pilot projects can not only improve environmental quality [5], but also stimulate green city activities [6], and even unexpectedly activate local innovation ecosystems, contributing to global climate resilience [4]. Secondly, a body of research focuses on the factors influencing new energy policies and green economic development. Existing literature has centered on China's unique environmental conditions, green policy frameworks, and related dimensions, examining the nation's green transition process from multiple perspectives. Studies have demonstrated that China's New Energy Demonstration Cities policy, acting as a quasi-natural experiment, has yielded a significant impetus for the overall green economic development of target cities. This policy not only markedly elevates the green total factor productivity of pilot cities [8] and total factor energy efficiency, facilitating the optimal allocation of energy inputs and outputs [9], but also bolsters urban development vitality by enhancing green innovation capacity and accelerating the R&D and transformation of green technologies [10]. It underpins green, sustainable, and high-efficiency development, driving the green transition of cities, especially resource-dependent ones [11]. Additionally, city-specific endowment characteristics, the intensity of government support, the stringency of environmental regulations, the foundation of innovation resources, and the level of industrial agglomeration all modulate the efficacy of new energy policies in advancing green economic development, reflecting a complex interplay of these factors [8, 12, 13]. Thirdly, research dedicated to dissecting the mechanisms linking energy policies and green economic development suggests that such policies exert their impacts through three core pathways. First, they incentivize enterprises to pursue green transformation and upgrading via fiscal subsidies and tax incentives, stimulate technological innovation, and foster the generation of new green energy patents and technologies [10]. Second, by phasing out backward production capacity and cultivating new energy sources, they reduce reliance on traditional energy, harness industrial structure effects, and propel the optimization and upgrading of economic industrial structures [8]. Third, by transmitting policy signals to the market, they guide the optimal allocation of production factors toward low-carbon sectors, thereby improving resource allocation efficiency [9, 14].

This study attempts to answer some unresolved questions in China's clean energy transition by analyzing long-term data from 277 cities from 2009 to 2023. Based on endogenous growth theory and energy substitution model, we adopt a multi-level empirical method to explore how setting cities as pioneers of clean energy can change their ecological and economic development trajectory, and through which intermediate links these changes are achieved. Previous studies have found that pilot programs can reduce pollution and promote the iteration of green technologies [15], but the mechanisms behind how policies are gradually translated into actual results are still unclear. Therefore, we will analyze from three perspectives. Firstly, the research investigates the mechanisms through which national-level demonstration city policies promote green economic development by means of resource allocation optimization and green technology innovation-driven growth, with the core objective of rigorously identifying the policy's efficacy in elevating green total factor productivity and accelerating the transition and upgrading of low-carbon industrial sectors. This perspective also hopes to better match the deployment of renewable energy with the actual operational capabilities and institutional conditions of local governments. Secondly, closely adhering to the "dual carbon" goal, evaluate how the continuous improvement of urban technological capabilities affects the effectiveness of demonstration projects, especially whether it can accelerate the technological breakthroughs and large-scale development of emerging low-carbon industries. Thirdly, extract practical suggestions from real pilot experiences to provide tailored and actionable references for policy makers in China and other countries, and assist in the design and promotion of decarbonization strategies.

2 Theoretical Analysis and Research Hypotheses

2.1 Impact of Policies on Green Economy

According to the theory of endogenous growth, setting cities as pioneers of clean energy will incentivize companies to adopt environmental protection technologies [16]. This policy signal helps companies cope with internal difficulties and external regulatory or market pressures, thereby accelerating industrial greening. At the same time, pilot cities can also receive special funds and technical support to upgrade their power grids and strengthen their environmental governance capabilities [17]. These measures combine carbon reduction targets with investment adjustments and innovation driven initiatives, laying the institutional and infrastructure foundation for sustained growth of the green economy. This type of intervention directly challenges the phenomenon of "carbon lock-in" in high emission industries, weakens the dependence of enterprises on fossil fuels, and effectively improves the sustainable development level of cities [18]. Local governments usually set hard renewable energy targets, accompanied by tax reductions or subsidies, to encourage small improvements and support major technological breakthroughs. These policies not only accelerate the popularization of green technologies, but also reduce energy costs, improve industrial efficiency, and form a virtuous cycle-innovation brings lower emissions and higher returns [4]. On the supply side, reform promotes the withdrawal of capital from inefficient or outdated projects, curbs overcapacity, and guides enterprises to shift towards high value-added areas. This structural transformation frees up space for emerging low-carbon industries, optimizes resource allocation, accelerates knowledge dissemination, and supports overall economic transformation. Empirical evidence also shows that after becoming a demonstration city, the green total factor productivity of enterprises significantly improves [19]. Under the dual promotion of regulation and market, enterprises in these cities are more willing to invest in research and development, deploy renewable energy such as solar energy on a larger scale, in order to improve energy efficiency, reduce polluting fuels and waste. As cities gradually become centers of clean energy, local enterprises can improve their profitability while complying with environmental regulations, which is a solid step towards a mature green economy.

Based on the above evidence, we propose the first hypothesis: assuming all other conditions remain constant, designating some cities as pioneers of renewable energy can help them embark on a more environmentally friendly and resilient economic development path. Even if there are delays or institutional obstacles encountered during the implementation process, this effect still exists.

2.2 The Regulatory Role of Technological Innovation

Different energy sources can often be replaced by each other, and there is an economic rationale behind this substitution logic. When an energy supply is unstable, people will turn to other options. At the same time, new energy technologies are somewhat like public goods, with large initial investment and benefits that everyone can enjoy. They often require long-term financial and strategic support from the government in order to move from pilot projects to large-scale applications. Therefore, technological progress is crucial for the development of low-carbon cities, industrial upgrading, and energy efficiency improvement [20]. With continuous innovation to reduce costs and improve conversion efficiency, renewable energy is becoming increasingly competitive and gradually replacing fossil fuels. This not only reduces traditional fuel consumption and pollution emissions [21], but also promotes sustainable practices that integrate environmental protection with economic growth. However, the innovation capabilities of different cities vary greatly, resulting in uneven policy effects [22]. In areas with weak research and development capabilities, governments often have to rely on administrative measures, such as forcibly shutting down high carbon factories, to complete short-term environmental protection tasks. Although effective in the short term, it may harm industry competitiveness and limit future vitality.

On the contrary, cities with strong innovation ecosystems are not only able to introduce technology, but also redefine the application boundaries of clean energy with technology. They use less electricity, have less financial pressure, and often exceed decarbonization targets. More importantly, their pilot experience can drive the surrounding areas and change the development path of the entire region. Whether a city "absorbs" surrounding resources or "drives" everyone to upgrade together depends on how strong its technological foundation is. Regions with weak innovation often continue to use outdated industrial models, and even copy the plans of advanced cities to eliminate them; Cities with strong research and development capabilities actively output cutting-edge solutions, setting new environmental standards in the entire urban agglomeration and generating greater returns on regional policy investment [23]. So, a city's innovation capability is not just helping it meet policy requirements, but also turning policies into engines for continuous improvement and systemic change.

As a critical external policy intervention tool, the effectiveness of new energy policies hinges on the absorption and adaptation capacities of different urban entities. Technological innovation capability serves as a key indicator of a city's ability to optimize resource allocation, integrate external resources, and adapt to environmental changes, and disparities in this capability will lead to notable heterogeneity in policy outcomes across cities. Furthermore, the introduction of the "DID$\times$Tech" interaction term, where technological innovation capability is incorporated as a moderating variable, allows us to verify the role of technological innovation and diffusion while accurately evaluating the genuine impact of the policies.

Therefore, we propose the second hypothesis: under other constant conditions, the level of technological innovation in cities does not simply add points to policy effectiveness, but significantly enhances the driving effect of new energy demonstration policies on green economic development.

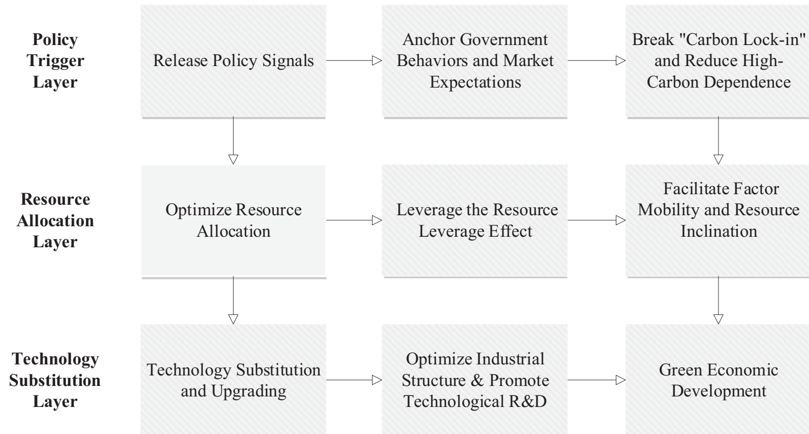

Figure 1 Theoretical logic diagram.

3 Research Design

3.1 Model Construction

This study uses the difference-in-differences (DID) method to estimate the causal impact of the "New Energy Demonstration City" policy on the development of green economy. The benchmark model is set as follows:

$$GTFP_{i,t} = \alpha_0 + \beta DID_{i,t} + \delta X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \tag{1}$$

In this model, *i* represents the city and *t* denotes the year. The dependent variable is Green Total Factor Productivity (GTFP), which measures the degree of green transformation in a city. The core explanatory variable $DID_{i,t}$ is the product term of the treatment group dummy variable and the policy implementation time dummy variable. $X_{i,t}$ is a set of control variables used to eliminate the interference of inherent urban characteristics and common temporal trends. The model also incorporates urban fixed effects μ_i and annual fixed effects γ_t to control for non time varying urban differences and national time shocks. Finally, $\varepsilon_{i,t}$ captures individual specific random fluctuations as the error term.

To test whether technological innovation moderates policy effectiveness, we added an interaction term based on the benchmark model, which is the product of the DID variable and the local innovation capability indicator.

$$GTFP_{i,t} = \alpha_0 + \beta DID_{i,t} + \varphi DID_{i,t} \times Tech_{i,t} + \delta X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \tag{2}$$

The innovation capability here $Tech_{i,t}$ is measured by the logarithm of the number of green invention patent authorizations at the city level. The definitions of other variables remain the same as before.

3.2 Variable Specification

3.2.1 Dependent variable: Green economic development (GTFP)

The study adopts GTFP as the primary indicator of green economic development. GTFP reflects both urban eco-efficiency and the sustainability of economic advancement by integrating environmental constraints into traditional productivity measurement. To account for heterogeneous production frontiers across prefecture-level cities, we first estimate baseline total factor productivity using the Stochastic Frontier Approach (SFA) for the initial year of the sample period. This base-year productivity level is then compounded annually with the corresponding growth index of green total factor productivity to construct a time series of GTFP for each city [17, 18].

3.2.2 Core explanatory variable: New energy demonstration city policy (DID)

The core explanatory variable is constructed using a standard DID design. It is defined as the interaction between a city-level treatment indicator and a post-policy time dummy: $DID_{it} = Treat_i \times policy_t$. $DID_{i,t}$ takes the value 1 only for cities that received formal designation and for observations in or after 2014; it is 0 in all other cases. To maintain policy homogeneity and analytical clarity, the sample deliberately excludes areas classified exclusively as new energy demonstration industrial parks. Only prefecture-level cities listed in the inaugural national program are retained in the empirical analysis.

3.2.3 Control variables

To reduce the bias caused by omitted variables, the model refers to existing research and includes the following control variables [1, 2, 15]. Urban density (pd): measured by the natural logarithm of registered residence population per administrative unit; Financial depth (fdl): calculated by dividing the sum of year-end bank deposit and loan balances by the regional GDP; Foreign direct investment openness (fdi): expressed as the proportion of actual utilization of foreign direct investment to regional GDP; Degree of government intervention (ge): measured by the proportion of public financial expenditure to regional GDP; Industrial structural transformation (str): defined as the difference between the proportion of service industry added value and the

Table 1 Variables correlation table

	Variable Name	Variable Symbol	Variable Source
Dependent Variable	Green Economic Development	GTFP	The China Statistical Yearbook, China Urban Statistical Yearbook, China Energy Yearbook, and China Environmental Yearbook
Core Explanatory Variable	New Energy Demonstration City Policy	DID	National Energy Administration
Moderating Variable	Technological Innovation	Tech	The patent database of the China National Intellectual Property Administration
Control	Urban density	pd	The China Urban
Variables	Financial depth	fdl	Statistical Yearbook
	Foreign direct investment openness	fdi	
	Degree of government intervention	ge	
	Industrial structural transformation	str	
	Education expenditure	edl	

proportion of industrial added value; Education expenditure (edl): measured by the proportion of public expenditure on education to total government expenditure.

3.2.4 Moderating variable: Technological innovation (Tech)

This study draws on the approach of scholars such as Tian Hong and uses the logarithm of the number of green invention patent authorizations obtained by various prefecture level cities to measure technological innovation capability [26]. The identification method of green patents is to match the Chinese patent classification number with the "Green Patent List" published by the World Intellectual Property Organization (WIPO), which provides an internationally recognized classification standard for environmental protection related technologies.

3.3 Data Processing and Descriptive Statistics

This study uses publicly available data to analyze the impact of some cities being designated as pioneers of clean energy on their long-term economic

Table 2 Descriptive statistics

Variables	Obs.	Mean	S.D.	Min	Max
GTFP	3852	1.304	0.509	0.165	6.168
DID	3852	0.143	0.350	0.000	1.000
Tech	3852	4.390	1.797	0.000	9.850
pd	3852	5.770	0.914	1.604	8.100
fdl	3852	2.507	1.218	0.588	21.301
fdi	3852	0.003	0.003	0.000	0.029
ge	3852	0.195	0.095	0.044	1.027
str	3852	1.041	0.594	0.109	5.650
edl	3852	0.177	0.039	0.044	0.356

resilience. The sample includes 277 prefecture level cities in China from 2009 to 2022, of which 61 are officially recognized as demonstration cities for new energy, serving as the treatment group, and the remaining 216 are the control group. The technical innovation data is from the patent database of the China National Intellectual Property Administration. The green economy indicators integrate information from various statistical yearbooks, including infrastructure construction, electricity consumption patterns, and pollutant emissions. When necessary, reference should also be made to local government work reports and planning documents for calibration. The descriptive statistics of all key variables are shown in Table 2.

4 Empirical Results and Analysis

4.1 Analysis of Benchmark Regression Results

The (1)–(7) columns of Table 3 show that regardless of how the model is adjusted, the coefficient of the DID interaction term remains positive and significant at the 5% level. This finding demonstrates that by designating pilot cities as clean energy pioneers, the policy clearly guides local government actions while transmitting market expectations and policy signals to enterprises. In doing so, it reduces enterprises' reliance on fossil fuels, facilitates the reallocation of production factors toward low-carbon sectors, and effectively elevates cities' sustainable development levels. Furthermore, as evidenced by the DID coefficient in the table, the policy effect remains significant and stable even after controlling for variables such as pd and fdl. This reflects that the policy can leverage resource allocation to amplify green transformation effects by compelling local governments to optimize infrastructure development, lower clean energy utilization costs, and incentivize

Table 3 Baseline regression results

	(1) GTFP	(2) GTFP	(3) GTFP	(4) GTFP	(5) GTFP	(6) GTFP	(7) GTFP
DID	0.100**	0.099**	0.098**	0.103**	0.103**	0.103**	0.103**
	(2.19)	(2.21)	(2.21)	(2.28)	(2.29)	(2.31)	(2.31)
pd		0.137	0.160	0.138	0.147	0.145	0.143
		(0.43)	(0.52)	(0.44)	(0.48)	(0.47)	(0.47)
fdl			0.022	0.019	0.016	0.016	0.016
			(1.43)	(1.27)	(1.08)	(1.08)	(1.05)
fdi				−13.221**	−13.349**	−13.363**	−13.331**
				(−1.99)	(−2.00)	(−2.00)	(−2.00)
ge					0.109	0.116	0.135
					(0.37)	(0.35)	(0.35)
str						−0.005	−0.006
						(−0.08)	(−0.09)
edl							0.076
							(0.15)
_cons	1.289***	0.501	0.313	0.480	0.414	0.425	0.423
	(197.35)	(0.28)	(0.17)	(0.27)	(0.23)	(0.24)	(0.24)
id	Yes	Yes	Yes	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3852	3852	3852	3852	3852	3852	3852
r2_a	0.703	0.703	0.704	0.705	0.705	0.705	0.705
F	4.784	2.440	2.501	2.940	2.369	2.009	1.740

t statistics in parentheses *p < 0.1, **p < 0.05, ***p < 0.01.

enterprises to develop green and energy-efficient technologies. Additionally, the adoption of green technologies in demonstration cities optimizes urban energy consumption structures, improves corporate production efficiency, generates technology spillovers, and lays the groundwork for subsequent mechanism tests. Collectively, these results confirm that the New Energy Demonstration Cities policy has significantly enhanced green total factor productivity, thereby providing robust empirical support for Hypothesis 1.

4.2 Robustness Tests

4.2.1 Parallel trends test and policy dynamics test

To determine whether the policy has truly changed the trajectory of the green economy, we first tested the parallel trend hypothesis, which is a prerequisite for the validity of the DID method. That is to say, before the

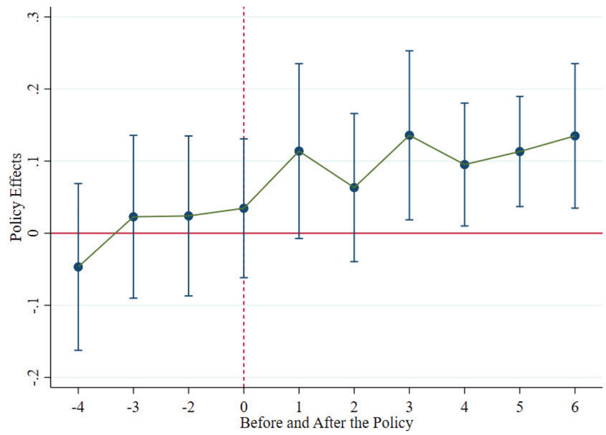

Figure 2 Parallel trend chart.

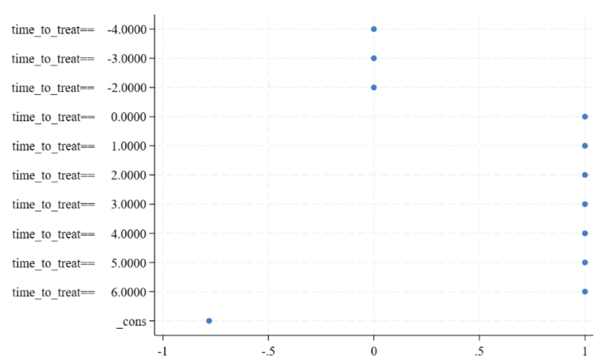

Figure 3 Parallel trend test (95% confidence interval).

policy is introduced, the development trends of demonstration cities and non-demonstration cities should be similar. Figures 2 and 3 show that in the years before policy implementation $(\mathrm{t} = -4, -3, -2)$, there was no significant difference in the green economy performance between the two groups of cities, with estimated values fluctuating slightly around the zero line and a narrow confidence interval. This indicates that the trend before the policy is basically consistent, meeting the requirement of parallel trend and enhancing the credibility of causal inference. In the years following the implementation of the policy ($\mathrm{t} = 1$ to $\mathrm{t} = 6$), the effect steadily increased and remained significant. This indicates that the policy not only took effect quickly, but also had a cumulative impact year by year, truly bringing about lasting environmental and economic improvements. Overall, these results suggest that the observed differences are likely due to the policies themselves, rather than the fact that these cities are already developing faster.

4.2.2 Alternative propensity score matching (PSM) specifications

In order to test the robustness of the policy effect estimation results, this study adopted four different propensity score matching strategies, namely nearest neighbor matching, caliper matching, radius matching, and kernel matching. The results in Table 4 show that when using the nearest neighbor matching method, the DID estimator no longer has statistical significance. But when using caliper matching, radius matching, or kernel matching methods, the estimated coefficients are significantly positive at the 5% level. Although the direction and magnitude of the core estimation values are basically the same under different matching methods, the significance of some control variables fluctuates slightly due to differences in weight settings and sample

Table 4 Estimation results of policy effects under different PSM methods

	(1) Nearest Neighbor Matching	(2) Caliper Matching	(3) Radius Matching	(4) Kernel Matching
DID	0.057	0.134**	0.103**	0.093**
	(0.76)	(2.12)	(2.29)	(2.20)
pd	0.550	0.365	0.147	0.123
	(1.27)	(0.87)	(0.48)	(0.40)
fdl	−0.006	0.001	0.023	0.027
	(−0.12)	(0.05)	(0.91)	(1.08)
fdi	1.241	3.570	−14.082*	−13.900*
	(0.07)	(0.27)	(−1.95)	(−1.87)
ge	−0.343	−0.091	0.092	0.174
	(−0.33)	(−0.13)	(0.23)	(0.46)
str	−0.057	−0.051	−0.006	−0.039
	(−0.85)	(−0.86)	(−0.11)	(−0.82)
edl	−0.006	−0.068	0.044	0.042
	(−0.01)	(−0.07)	(0.08)	(0.08)
_cons	−1.680	−0.725	0.399	0.544
	(−0.67)	(−0.30)	(0.22)	(0.30)
id	Yes	Yes	Yes	Yes
year	Yes	Yes	Yes	Yes
N	894	1352	3849	3801
r2_a	0.759	0.751	0.705	0.710
F	0.673	0.978	1.688	1.648

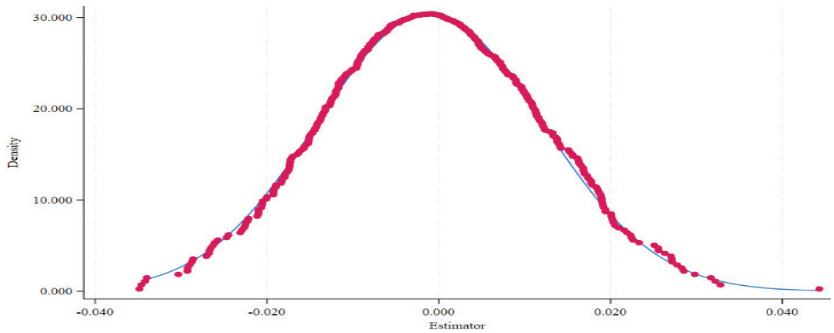

Figure 4 Placebo treatment effect distribution.

composition among various matching algorithms. These differences indicate that the results of propensity score matching are sensitive to the choice of specific methods, especially in how to select and balance the control group and treatment group samples. However, regardless of which matching method is used, the main conclusion remains stable. The finding that the policy of new energy demonstration cities has a positive impact on the development of green economy holds true under most matching strategies. This consistency enhances our confidence in the benchmark results and also indicates that the research conclusions do not depend on a specific matching method.

4.2.3 Placebo test

To further test the robustness of the policy effect estimation results, a placebo test was conducted by randomly reallocating the treatment group identities of each city and then re estimating the model. As shown in Figure 4, the distribution of pseudo policy effects obtained from this is concentrated between negative 0.040 and positive 0.040, and closely surrounds the zero value. In contrast, the actual estimated policy effects are significantly outside of this range. This clear separation indicates that the observed policy impact is unlikely to be caused by random factors or unobserved, time invariant features. Therefore, this result further enhances our confidence in the validity of the benchmark conclusion.

4.2.4 Adjusting the sample time window

In order to test whether the estimated results of policy effects are sensitive to the choice of observation window, the study used a narrower time range to re-estimate the baseline regression model, including only samples from the first four years before and after the official implementation of the policy. This

Table 5 Regression results after adjusting the sample time window

	(1)	(2)
	GTFP	GTFP
DID	0.091**	0.091**
	(2.53)	(2.53)
pd	0.031	0.031
	(0.10)	(0.10)
fdl	0.029*	0.029*
	(1.83)	(1.83)
fdi	−14.591**	−14.591**
	(−2.17)	(−2.17)
ge	0.099	0.099
	(0.28)	(0.28)
str	−0.042	−0.042
	(−0.81)	(−0.81)
edl	−0.289	−0.289
	(−0.58)	(−0.58)
_cons	1.134	1.134
	(0.64)	(0.64)
id	Yes	Yes
year	Yes	Yes
N	3608	3608
r2_a	0.696	0.696
F	2.128	2.128

adjustment helps to mitigate the interference that may arise from long-term structural changes or sustained external shocks, thereby more clearly identifying the causal effects of policies. As shown in Table 5, the coefficient of the DID term remains positive and statistically significant at the 5% level, with a point estimate of 0.091, which is almost identical to the results of the full sample analysis. Whether using a complete sample or a shortened time window, the estimation results are highly stable in terms of size and significance. This further supports our conclusion that being recognized as a new energy demonstration city has indeed had a real and measurable positive impact on green total factor productivity.

4.3 Heterogeneity Analysis

4.3.1 Resource endowment heterogeneity analysis

The implementation of policies for new energy demonstration cities is closely related to the local ecological and resource conditions, which directly affect the feasibility and effectiveness of green transformation strategies. According to the National Sustainable Development Plan for Resource Based Cities (2013–2020), prefecture level cities are officially classified into two categories: resource dependent and non-resource dependent. This provides a basis for examining how natural resource endowments regulate policy effectiveness [27]. As shown in Table 6, there are significant differences in the impact of policies in these two types of cities. In non-resource dependent cities, policies have significantly improved the performance of green economy, reflecting greater flexibility in institutions and industries. They typically have more flexible fiscal systems and less rigid industrial structures, enabling them to adopt clean energy technologies more quickly. In contrast, resource dependent cities, especially those dominated by coal, oil, or mining, have shown little measurable response to policies. Their energy systems are still deeply tied to traditional infrastructure, and the structural inertia of high carbon industries greatly limits the space for substantive reforms, thereby weakening the potential for policy transformation.

4.3.2 Regional heterogeneity analysis

To examine the spatial differences in policy effectiveness, the study divided cities into three major regions: the eastern, central, and western regions, and conducted regression analysis on each sub sample to evaluate the impact of identifying new energy demonstration cities on the effectiveness of green economy in different regions. As shown in Table 6, the policy only produced statistically significant positive effects in the eastern region, with a DID coefficient of 0.146 and significant at the 5% level. In contrast, although

Table 6 Heterogeneity analysis

	Resource Endowment Heterogeneity		Regional Heterogeneity		
Explanation Variable	Non-resource-based Cities	Resource-based Cities	Eastern	Central	Western
DID	0.138**	0.053	0.146**	0.026	0.123
	(2.34)	(0.97)	(2.01)	(0.43)	(1.29)
Control variables	Yes	Yes	Yes	Yes	Yes
_cons	−1.489	6.528***	−0.727	2.179	1.611
	(−0.76)	(2.90)	(−0.25)	(0.97)	(0.70)
N	2301	1551	1385	1369	1098
r2	0.741	0.703	0.594	0.801	0.765
r2_a	0.718	0.676	0.557	0.782	0.742

the estimated values in the central and western regions are positive, there is no significant difference from zero. This result indicates that the policy's ability to promote green economic development is significantly stronger in eastern cities. This regional difference is likely due to differences in the existing development foundations of different regions. Eastern cities generally have more abundant financial resources, more intensive innovation driven enterprises, more advanced technological infrastructure, and stronger public investment in clean energy systems. These advantages contribute to the rapid adoption and effective implementation of renewable energy initiatives. However, cities in the central and western regions often face challenges such as budget constraints, weak innovation ecosystems, outflow of technical talents, and lagging institutional reforms. These factors collectively hinder the effective transformation of policy requirements into actual green growth, resulting in weak or delayed policy effects.

4.4 Mechanism Testing

To test whether technological innovation constitutes a key channel for the policy impact of new energy demonstration cities on green economic development, the study introduced a DID variable and an interaction term (DID$\times$Tech) between the urban innovation capability index and the benchmark regression model. As shown in column (2) of Table 7, the coefficient of this interaction term is 0.086, which is significantly positive at the 1% level, indicating that the stronger the local innovation capability, the more obvious the promotion effect of policies on green total factor productivity. It is worth noting that when this interaction term is added, the estimated value of the DID main effect changes from 0.103, which is significantly positive in column (1), to -0.363, which is significantly negative in column (2). This reversal indicates that if the moderating effect of technological innovation capability is not considered, it may not only mask the true effectiveness of policies but also lead to misjudgment of their direction and magnitude. Figure 5 further provides intuitive evidence demonstrating the marginal effects of policies at different levels of innovation capability. The curve in the graph clearly slopes upwards, indicating that with the improvement of urban innovation capabilities, the role of policies in promoting sustainable development effectiveness is also constantly increasing. This graphical result is consistent with statistical analysis, confirming that technological progress does play a positive regulatory role, and its effectiveness depends on the maturity of the local innovation ecosystem. Overall, these findings indicate that in order

Table 7 Moderating effect test

	(1)	(2)
	GTFP	GTFP
DID	0.103^{**}	-0.363^{***}
	(2.31)	(−2.61)
Tech		-0.077^{***}
		(−4.18)
DID×Tech		0.086^{***}
		(3.08)
pd	0.143	0.116
	(0.47)	(0.43)
fdl	0.016	0.011
	(1.05)	(0.71)
fdi	-13.331^{**}	-12.601^{*}
	(−2.00)	(−1.92)
ge	0.135	0.183
	(0.35)	(0.48)
str	−0.006	−0.010
	(−0.09)	(−0.19)
edl	0.076	0.023
_cons	0.423	0.937
	(0.24)	(0.61)
id	Yes	Yes
year	Yes	Yes
N	3852	3852
r2_a	0.705	0.713
F	1.740	3.610

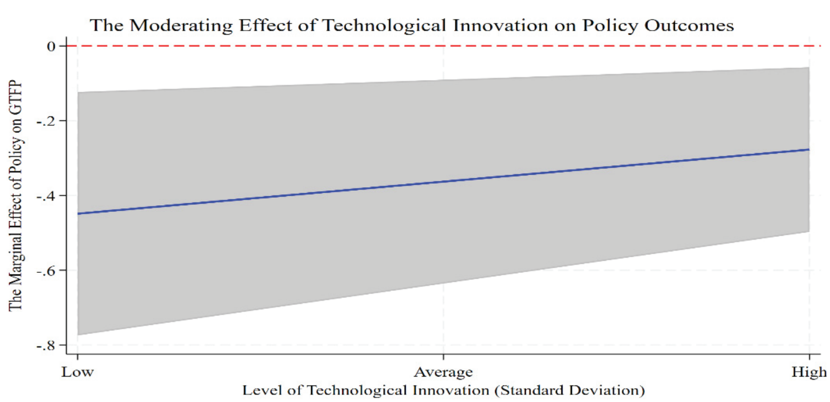

Figure 5 The marginal variation of policy effects with innovation capability level.

for new energy demonstration city policies to maximize their benefits, they must be closely integrated with local innovation capabilities. Only when policy implementation matches the foundation of regional innovation can its potential for promoting green transformation be truly unleashed.

5 Conclusions and Policy Implications

5.1 Conclusions

This study adopts a difference-in-differences (DID) framework to evaluate the impact of a city being recognized as a new energy demonstration city on its green economy development path. The results provide reliable evidence that the policy has indeed effectively promoted the development of the green economy, manifested in a significant increase in green total factor productivity. A series of robustness tests further validated the reliability of this discovery. However, policy dividends are not evenly distributed across all regions and resource backgrounds. Cities in the eastern region and those that do not rely on resource extraction industries have shown significantly stronger improvement effects. Further analysis reveals that local technological innovation capability is a key intermediary channel for policy implementation. Cities with more mature innovation ecosystems are better able to translate policy requirements into substantive integration results of ecological environment and economic development.

5.2 Policy Implications

Based on the theoretical analysis and empirical findings of this study, several practical and feasible policy recommendations can be proposed. Firstly, given that the New Energy Demonstration City Plan has effectively driven green economic transformation, local governments should escalate support for green technology R&D among enterprises and research institutions, such as by offering green patent subsidies, implementing tax incentives for clean technology pilot projects, and introducing other targeted measures. They should also integrate technological resources, lower innovation barriers, stimulate R&D dynamism among enterprises and relevant research institutions, and enhance the implementation efficiency of existing policies. Secondly, policy implementation frameworks must take into account heterogeneities in resource endowments and other attributes across different cities. Customized strategies should be formulated based on local conditions to actively support high-carbon enterprises in reallocating production factors to low-carbon sectors. For resource-based cities, efforts should be made to reduce their reliance on traditional energy industry development paths and improve social security policies to alleviate the shocks of industrial transformation. Meanwhile, a counterpart support mechanism involving eastern pilot cities should be established to guide the cross-regional flow of innovation resources from eastern regions, thereby facilitating the adoption and transformation of advanced green technologies in central and western areas. Thirdly, differentiated assessment systems tailored to various city types should be developed to regularly monitor the implementation effects of new energy policies, evaluate policy efficacy across heterogeneous urban contexts, and promptly adjust the policy toolkit in response to issues identified during evaluations. This will ensure that policies remain closely aligned with the evolving demands of green economic development.

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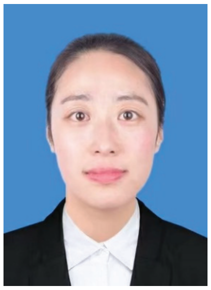

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