frontiers | Frontiers in Environmental Science

ORIGINAL RESEARCH
published: 06 June 2022
doi: 10.3389/fenvs.2022.896661

Research on the Impact of Green Finance Policy on Regional Green Innovation-Based on Evidence From the Pilot Zones for Green Finance Reform and Innovation

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To develop green finance and ensure the goal of carbon peaking and carbon neutrality, China set up the pilot zones for green finance reform and innovation in 2017. We empirically tested the policy effect of the pilot zones with data from 2010 to 2019 for prefecture-level cities in China. The study shows that the pilot zones have induced an effect on regional green technology innovation, reflected in the application and acquisition of both green invention patents and green utility patents, and the promotion effect is better for green utility patents than green invention patents, which is supported by the robustness test using PSM-DID. This study provides theoretical support and empirical evidence for evaluating the policy effects of the pilot zones and provides a reference for the differentiated formulation of green financial policies.

Keywords: green finance, green patent, green technology innovation, green financial reform, Policy effect

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Specialty section:
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

Received: *15 March 2022*
Accepted: *13 May 2022*
Published: *06 June 2022*

Citation:
Zhang C, Cheng X and Ma Y (2022) Research on the Impact of Green Finance Policy on Regional Green Innovation-Based on Evidence From the Pilot Zones for Green Finance Reform and Innovation. Front. Environ. Sci. 10:896661. doi: 10.3389/fenvs.2022.896661

1 INTRODUCTION

With the Chinese government's increased investment in sustainable development in recent years, the low-carbon economy and green economy featuring low pollution, low energy consumption, and low emissions are gradually replacing the development model of high pollution, high energy consumption, and high emissions. The green economy has become the inevitable direction of regional development. Therefore, integrating finance with the concept of sustainable development and developing a green finance model has become an unavoidable direction and a realistic choice for the development of China and other countries in the world. Green finance means that the financial sector takes environmental protection as a basic policy, considers potential ecological impacts in investment and financing decisions, integrates potential returns, risks, and costs related to environmental conditions into the daily business of finance, focuses on the protection of the ecological environment and the management of environmental pollution in financial operations, and promotes the sustainable development of society through the guidance of social and economic resources. With the government's strong advocacy of green finance, various regions also regard green finance as a strong driving force to promote the high-quality development of the green economy. Several provinces and cities in China have started to explore green finance practices actively, including setting up pilot zones for green finance innovation, establishing green industry funds, providing support for green credit and tax policies.

TABLE 1 | Comparison of pilot zones for green finance reform and innovation.

Region	Planned design program
Zhejiang	The pilot zone design should focus on green development, support the transformation and upgrading of industrial structure, integrate the industrial chain as an entry point, accelerate the transformation and upgrading of the traditional chemical industry, and optimize the regional economic structure
Guangdong	The pilot zone should support broadening financing channels through green industries, issuing green bonds for financing in green recycling and low-carbon development, and steadily promoting the construction of an environmental equity trading market.
Jiangxi	The pilot zone needs to explore effective ways of financial support for ecological-economic development, build a green financial organization system, explore innovative credit products and financing models that support energy conservation and emission reduction, clean energy, and other fields, and actively explore the policy effects of financial support for green financial development
Guizhou	The pilot zone needs to explore effective ways for green finance to guide the economic transformation and development of less developed areas in the west and innovate agricultural green credit products to support modern urban agriculture, organic and ecological agriculture, rural water conservancy project construction, agricultural production and sewage treatment and other agricultural industry projects
Xinjiang	The pilot zone should combine the comparative advantages in agriculture, natural resources, clean energy resources, energy-related high-end manufacturing, etc., and innovate wind power index insurance, major technology and equipment insuranceetc.

In this context, in June 2017, The State Council, China's Cabinet, announced it is setting up pilot zones for green finance reform and innovations[1]. The pilot zones were in the Xinjiang Uygur autonomous region and Guangdong, Guizhou, Jiangxi, and Zhejiang provinces. The State Council decided to build pilot zones for green finance reform and innovations with their characteristics and explore replicable ways to boost green financing in the institutional mechanism. **Table 1** shows the planned development programs for different regions. As shown in **Table 1** [2], the pilot zones can be divided into three categories: Zhejiang and Guangdong, the second category are Guizhou and Jiangxi, and the third category is Xinjiang. Zhejiang should explore applying the development concept of "lucid waters and lush mountains are invaluable assets" in the financial field and innovate green finance to transform and upgrade traditional industries. Guangdong focuses on developing green financial markets. Xinjiang focuses on exploring green finance to support modern agriculture, clean energy resources, etc. Guizhou and Jiangxi need to explore how to avoid the old path of "grow first, clean up later" and use the abundant green resources to develop green finance and build a green development approach.

As we all know, China's planning generally takes 5 years as a cycle, such as now in the 14th Five-Year Plan period, and the entire plan should be evaluated after 5 years for subsequent decision-making. As the pilot zones have been established for nearly 5 years since June 2017, there is an imminent need to evaluate the policy effects of the pilot zones. In these 5 years, the progress made in green finance development and innovation in the pilot zones compared to other regions is also a common issue of interest for both the government and academia. Because of this, this paper examines the impact of the establishment of the pilot zones on regional green innovation activities by using green patents as the research object and examines the heterogeneity of the impact through further classification of green innovation activities. This study theoretically helps to understand the mechanism of policy influence on regional green innovation and provides a realistic basis for summarizing the successful experience of the pilot zones and extending it to other regions.

When implementing green financial policies, discovering variables that can "catalyze" the effect of regional green innovation is of great value in improving supporting policies. The moderating effect model can determine the "catalyst" variable, that is, the moderating variable, by examining the reasons for the change in the strength of the causal relationship between the two variables. The goal of green financial policies is to achieve green development. In green development, regional environmental regulations affect the promotion effect of policies on green innovation. Under the pressure of energy conservation and emission reduction, enterprises in the region will upgrade their technologies to meet environmental protection needs and strengthen green technology innovation.

This paper analyzes data from 261 prefecture-level cities in 31 provinces in China from 2010-to 2019 using the difference-in-difference (DID) method. The results show that pilot zones can promote green technology innovation at the regional level to a certain extent, confirmed by robustness tests. Further study found that the induced effect of policies on regional green technology innovation was reflected in the application and acquisition of green invention patents and green utility patents, and there was heterogeneity in different types of patents. This finding provides theoretical support and empirical evidence for evaluating the policy effects of pilot zones for green finance reform and innovation and provides a reference for the formulation of differentiated green finance policies.

The marginal contributions of this paper are: first, it tests the macro policy effects of establishing pilot zones from the perspective of regional green technology innovation, which enriches the empirical studies related to pilot zones for green

[1]http://www.gov.cn/zhengce/2017-06/14/content_5202609.htm.

[2]http://www.gov.cn/xinwen/2017-06/27/content_5205758.htm.

financial reform and innovation. Second, using the exogenous event of establishing the pilot zones to construct a quasi-natural experiment helps alleviate the interference of endogeneity issues on the estimation results and provides reliable empirical evidence on the relationship between green financial policies and regional green technology innovation. Third, considering the heterogeneity that regional green technology innovations differ significantly in terms of patent types, this paper further examines the positive externalities of green finance policies on green technology innovation, which provides a reference for the formulation and implementation of differentiated green finance policies.

The rest of the paper follows: **Section 2** reviews the literature, **Section 3** introduces the data and models, **Section 4** is the empirical analysis and robustness tests, and **Section 5** concludes and proposes policy recommendations.

2 LITERATURE REVIEW

2.1 Concept of Green Finance

In the era of globalization, financial and natural resources are important indicators that contribute significantly to mitigating environmental degradation and promoting economic growth (Usman et al., 2022a; Usman et al., 2022b; Zhang C et al., 2022). Green finance integrates financial and natural resources into consideration and directs financial resources to energy-saving and emission-reducing production activities through environmental regulation to achieve sustainable development while ensuring economic growth (Criscuolo & Menon, 2015). On the one hand, green finance can promote environmental protection and governance (Al Mamun et al., 2022), allocating resources from highly polluting and energy-consuming industries to industries with advanced production concepts and environmental technologies (Falcone, 2020). On the other hand, environmental protection regulations can also promote green finance (Cojoianu et al., 2020), as confirmed by several studies, and the regulations are spatially heterogeneous and firm-heterogeneous in promoting green finance in different regions of China (Xu et al., 2022).

In recent years, research on green finance and green finance policies has attracted the attention of an increasing number of scholars (Pu et al., 2018; Zhang C et al., 2019; Zhang D et al., 2019; Azhgaliyeva & Liddle, 2020; Akomea-Frimpong et al., 2021; Sun et al., 2021; Jahanger et al., 2022; Jiang et al., 2022; Pu & Yang, 2022). Several scholars have developed a framework for green finance and defined it (Wang & Zhi, 2016; Taghizadeh-Hesary & Yoshino, 2019; Hafner et al., 2020; Zhang et al., 2020). Lindenberg explains the concept of green finance as policies from financial institutions to sustain a green economy (Blinder, 2012; Lindenberg, 2014). The 'financial' aspect of the concept demonstrates the allocation and investment of capital through the financial system (Berensmann et al., 2017; Weber & ElAlfy, 2019). The 'green' attribute requires that the allocation of financial resources should extend to environmental protection, clean energy, green buildings, climate change, and corporate governance in all economic sectors (Yuan & Gallagher, 2018; Urban & Wójcik, 2019).

TABLE 2 | Descriptive statistics of explained variables.

Variable	Mean	Std. Dev	Min	Max
lngrvg	0.0267	1.0541	−0.2351	20.2093
lngrvgrt	−0.0047	0.9031	−1.2702	9.4341
Ugrmg	0.0403	1.0500	−0.3605	13.2877
Ugrmgrt	−0.0344	0.8101	−2.1113	9.8871
lngrva	0.0364	1.0433	−0.3317	15.3303
lngrvart	−0.0022	0.9225	−1.8901	13.2606
Ugrma	0.0409	1.0416	−0.3833	17.7224
Ugrmart	−0.0338	0.7473	−1.9021	9.5840

According to the official definition from the Chinese government[3], green finance includes the following aspects. First, green finance aims to provide financial support for projects related to environmental protection to address the problems caused by climate change and improve energy efficiency. Secondly, green finance is divided into green bonds (Sinha et al., 2021), green credits, and green stock indices. Furthermore, green securities, green investments, climate finance, carbon finance, green insurance, green credit, and green infrastructural bonds are banks' major green finance products. Finally, it clearly states that green finance involves green project financing and risk management, and carbon finance issues. A clear definition of green finance helps label green financial products and attract green companies and investors to make more green investments. Since then, green finance policies have been introduced in various regions of China (Lee, 2020; Muganyi et al., 2021), and many scholars have conducted studies on the impact of green finance policies (Xu & Li, 2020; D.; Zhang D et al., 2021).

2.2 Green Finance and Economic Development

In terms of the relationship between green finance and regional economic development, the development of green finance in China has shown a general upward trend, with high-value regions located mainly in the east, followed by the central and western regions, and the coupled coordination between green finance and environmental performance has increased from uncoordinated to primary coordination over time (H. Zhang H et al., 2022). It was found that green finance can improve total factor productivity in Chinese regions, and this effect is more pronounced in provinces with high economic and social conditions and higher pollution levels (Lee & Lee, 2022). Meanwhile, the green finance development index shows a general upward trend. However, the overall development level in China is not high, which restricts the coordinated development of green finance and the economy in different aspects and leads to the insignificant support of green finance for economic growth (Yin & Xu, 2022). The gap in green finance development between different regions is narrowing, and the development level is distributed according to a ladder of East China, Central China, West China, and Northeast China (Lv et al., 2021).

[3]http://www.gov.cn/xinwen/2016-09/02/content_5104583.htm.

TABLE 3 | | Definition and description of explained variables.

Type	Name of explained variable Symbol	Symbol
Green Patent Acquisition	Number of green invention patents obtained	lngrvg
	Percentage of the number of green invention patents to the total number of patents obtained	lngrvgrt
	Number of green utility patents obtained	Ugrmg
	Percentage of the number of green utility patents to the total number of patents obtained	Ugrmgrt
Green Patent Application	Number of green invention patents applied	lngrva
	Percentage of the number of green invention patents to the total number of patents applied	lngrvart
	Number of green utility patents applied	Ugrma
	Percentage of the number of green utility patents to the total number of patents applied	Ugrmart

In terms of promoting industrial development, green finance has the highest correlation with the output value of tertiary industries, followed by primary and secondary industries. The highest impact on industrial structure upgrading is in the east, followed by central and western China (Wang & Wang, 2021). In addition, green finance can impact high-quality economic development through three aspects: ecological environment, economic efficiency, and economic structure, and the development of financial technology can help strengthen this impact (Yang et al., 2021). In terms of energy market impact, the impact of green finance on energy consumption shows spatial heterogeneity, with the level of green finance development in the eastern region having a more pronounced positive impact on energy consumption structure (Sun & Chen, 2022). Green finance has also played a significant and positive role in improving environmental ecology and investment in renewable resources (Li et al., 2022), especially after the Covid-19 outbreak in 2020 (Arif et al., 2022). It has been shown that green finance has a U-shaped effect on China's regional economic and ecological development, which is more pronounced in the central region (Sun & Chen, 2022). This fact has also been verified in other studies such as the study that found a negative correlation between green finance and eco-efficiency, showing a non-linear U-shaped trend, also more pronounced in the central and western regions (Wang et al., 2022).

2.3 Policy Research of Green Finance

In the policy research on green finance, some researchers used data-driven scientometric methods from the literature and found four policies that are considered to have great future potential, including carbon taxes, government subsidies, green bonds, and some other policies. Green bonds have received the most attention (Wang et al., 2021). Green finance policies effectively mitigate the effects of financing constraints, and green innovation suffers when firms face higher financing constraints, but green finance policies do not seem to benefit private firms (Yu et al., 2021). Firms in economically developed regions are more strongly affected by green credit than firms in less economically developed regions, and both green credit policies and green credit development increase the cost of debt financing for energy-intensive and polluting firms but reduce the cost of debt financing for green firms (Xu & Li, 2020). The debt financing of heavily polluting Chinese firms declined significantly after introducing green credit policies, suggesting that the green credit policy system plays a guiding role in credit resource allocation (Liu et al., 2019). In addition, industrial gas emissions decreased significantly during the green finance policy review period (Muganyi et al., 2021; Meo & Abd Karim, 2022), while there are also studies showing that green credit policies help reduce sulfur dioxide and wastewater emissions (S. Zhang S et al., 2021).

Regarding the impact of pilot zones for green finance reform and innovation, due to the short period after the establishment, most studies on pilot zones for green finance reform and innovation have focused on theoretical aspects, emphasizing the inspiration of relevant policy experiences on regional economic development (Jingzhi et al., 2017; Wencong & Weijun, 2020; Yunfan et al., 2021), or discuss the impact of pilot zones on firms' green innovation (Lu & Xianchun, 2020; Ying & Yao, 2021). A synthesis of existing research on green finance and green financial policies reveals that the existing literature is rich in research on the policy effects of green finance. However, it mainly focuses on the implementation effects of green credit policies in green finance, and the research on pilot zones for green finance reform and innovation is still very limited. Second, based on the availability of data, most of the existing studies focus on the effects of green finance on regional economic development, environmental governance, and corporate investment and financing behaviors, and there is a lack of literature that examines the implementation effects of pilot zones from the perspective of innovation. Third, the research on green financial policies on green technology innovation is focused on the enterprise level, and there is a lack of spatial perspective to test the effect of policy implementation. Because of this, this paper takes Chinese cities as the research object and adopts a DID model to conduct a multidimensional empirical test on the policy effects of pilot zones for green finance reform and innovation.

3 DATA AND METHODS

3.1 Data

In this paper, we select the data of Chinese cities and green patents from 2010 to 2019. In the end, 2,890 observations were finally obtained from 297 cities, and the samples were standardized. The city economic data were obtained from China City Statistical Yearbook from 2011 to 2020, and the

TABLE 4 | Definition and description of explanatory and control variables.

	Variable	Symbol	Variable Definition
Explanatory variables	Treatment variable	$Treat_r$	1 for the treatment group, 0 for the control group
	Time variable	$Time_t$	0 before 2017, 1 after 2017, and 1 in 2017
	Net Effect of Pilot Zones	$Treat_r$* $Time_t$	The net effect of pilot zone
Control variables	Population	$Popu_{it}$	Total urban year-end population
	Employees	$Empl_{it}$	Number of urban employees
	Researchers	$Rese_{it}$	Number of employees in research and technical services
	Population density	$Dpop_{it}$	population per square kilometer
	Urban Output	$perGDP_{it}$	Per capita gross regional product
	Number of enterprises	$Ente_{it}$	Number of industry scale enterprises
	Science and Technology Expenditure	$Stex_{it}$	Urban science and technology expenditure
	Higher Education Level	$Hedu_{it}$	Number of full-time teachers in the urban general higher education institutions
	Mobile Phone User	$Mobi_{it}$	Number of cell phone subscribers

TABLE 5 | Baseline regression results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ingrvg	Ingrvgrt	Ugrmg	Ugrmgrt	Ingrva	Ingrvart	Ugrma	Ugrmart
Treat * Time	0.066	−0.025	0.303**	−0.124	0.370**	−0.063	0.335**	−0.146*
	(1.166)	(−0.342)	(2.013)	(−1.557)	(1.983)	(−0.834)	(2.346)	(−1.942)
Time	0.147***	0.166***	0.222***	0.194***	0.309***	0.238***	0.348***	0.196***
	(4.390)	(3.695)	(6.112)	(4.835)	(5.742)	(5.461)	(7.219)	(5.651)
Treat	0.041	−0.111	−0.021	−0.119	0.006	−0.100	0.192**	−0.114
	(0.723)	(−1.641)	(−0.247)	(−1.522)	(0.076)	(−1.199)	(2.128)	(−1.551)
Popu	−0.003	−0.000	−0.058**	−0.065***	−0.081*	0.036**	−0.160***	−0.036**
	(−0.181)	(−0.022)	(−2.032)	(−3.612)	(−1.695)	(2.081)	(−2.970)	(−2.496)
Empl	0.109	0.015	0.542***	−0.031	0.438*	−0.041	0.539	−0.029
	(1.010)	(0.549)	(4.649)	(−0.679)	(1.667)	(−1.026)	(1.624)	(−0.706)
Rese	1.012***	−0.011	0.369***	0.091***	−0.318	0.032	−0.473**	−0.013
	(6.601)	(−0.631)	(4.660)	(3.162)	(−1.378)	(0.875)	(−2.276)	(−0.472)
Dpop	−0.012	0.004	−0.008	−0.006	−0.006	0.009	0.018	−0.002
	(−1.307)	(0.175)	(−0.454)	(−0.339)	(−0.243)	(0.284)	(0.541)	(−0.148)
perGDP	0.005	0.007	0.011	−0.010***	0.009	−0.009***	0.007	−0.005**
	(0.629)	(0.996)	(0.738)	(−2.589)	(0.534)	(−2.970)	(0.422)	(−2.189)
Ente	−0.044	−0.045***	0.181**	−0.013	0.053	−0.007	−0.024	−0.015
	(−0.723)	(−3.362)	(2.493)	(−0.589)	(1.211)	(−0.589)	(−0.526)	(−0.829)
Stex	0.074**	0.008	−0.033	−0.043***	0.223*	−0.061**	0.288**	0.005
	(2.540)	(0.436)	(−0.442)	(−2.641)	(1.872)	(−2.437)	(2.331)	(0.391)
Hedu	−0.071	0.045	0.024	0.136***	0.385**	0.075**	0.321**	0.137***
	(−0.881)	(1.538)	(0.316)	(4.297)	(2.354)	(2.070)	(2.237)	(4.809)
Mobi	0.003***	−0.003	0.003	−0.013	0.004	0.038	−0.004	0.009
	(2.940)	(−1.037)	(1.505)	(−0.917)	(1.391)	(1.287)	(−0.739)	(0.376)
Cons	−0.031	−0.031	−0.043	−0.061*	−0.083**	−0.047	−0.122***	−0.062**
	(−1.060)	(−0.782)	(−1.550)	(−1.760)	(−2.049)	(−1.004)	(−3.674)	(−2.014)

*, **, and *** indicate that the statistical value is significant at the 10%, 5%, and 1% levels, respectively.

regional green patent data were obtained from the Chinese Research Data Services (CNRDS) Platform.

3.2 Model

This paper aims to test whether pilot zones for green finance reform and innovation can promote regional green technology innovation. In the existing literature, DID is a more effective method used to test policy effect. In this paper, the five provinces of Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang are used as the treatment group, and the remaining provinces are used as the control group. To verify whether the pilot zones for green finance reform and innovation help promote regional green technological innovation, we construct a model 1) with the following model settings.

$$Tgreen_{it} = \beta_0 + \beta_1 Treat_r * Time_t + \beta_2 Treat_r + \beta_3 Time_t + \rho X_{it} + \delta_r + \gamma_t + \varepsilon_{irt} \quad (1)$$

$Tgreen_{it}$ denotes the number of green patents of city i in the year t. $Treat$ denotes the dummy variable for pilot zones for green finance reform and innovation and takes one if the city is located

TABLE 6 | Regression results after changing the explanatory variable measure.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	lngrvg	**lngrvgrt**	**Ugrmg**	**Ugrmgrt**	**lngrva**	**lngrvart**	**Ugrma**	**Ugrmart**
Treat * Time	0.083	–0.015	0.363**	–0.139	0.408**	–0.064	0.281**	–0.156*
	(1.266)	(–0.190)	(1.971)	(–1.571)	(2.012)	(–0.739)	(2.130)	(–1.867)
Time	0.192***	0.189***	0.304***	0.225***	0.390***	0.321***	0.437***	0.202***
	(4.269)	(3.874)	(5.440)	(4.612)	(5.071)	(5.950)	(5.930)	(4.456)
Treat	0.039	–0.115*	–0.020	–0.123	0.014	–0.104	0.220**	–0.119*
	(0.701)	(–1.731)	(–0.237)	(–1.569)	(0.170)	(–1.268)	(2.297)	(–1.652)
Popu	–0.010	–0.004	–0.071**	–0.069***	–0.092*	0.024	–0.172***	–0.037**
	(–0.604)	(–0.229)	(–2.279)	(–3.718)	(–1.907)	(1.278)	(–3.104)	(–2.520)
Empl	0.095	0.006	0.517***	–0.042	0.411	–0.065*	0.514	–0.036
	(0.890)	(0.192)	(4.757)	(–0.939)	(1.596)	(–1.715)	(1.566)	(–0.856)
Rese	1.010***	–0.014	0.365***	0.088***	–0.328	0.026	–0.485**	–0.016
	(6.632)	(–0.807)	(4.570)	(3.142)	(–1.410)	(0.758)	(–2.307)	(–0.562)
Dpop	–0.010	0.004	–0.005	–0.005	–0.003	0.014	0.020	–0.004
	(-1.073)	(0.183)	(–0.249)	(–0.318)	(–0.120)	(0.428)	(0.586)	(–0.245)
perGDP	0.006	0.008	0.012	–0.008**	0.011	–0.008**	0.009	–0.003
	(0.729)	(1.194)	(0.805)	(–2.236)	(0.649)	(–2.435)	(0.570)	(–1.083)
Ente	–0.047	–0.047***	0.173**	–0.014	0.046	–0.010	–0.027	–0.016
	(–0.785)	(–3.399)	(2.456)	(–0.647)	(1.097)	(–0.855)	(–0.601)	(–0.882)
Stex	0.101***	0.027	0.014	–0.023	0.280**	–0.019	0.344**	0.018
	(2.931)	(1.352)	(0.168)	(–1.184)	(2.061)	(–0.802)	(2.445)	(1.112)
Hedu	–0.068	0.046	0.030	0.138***	0.390**	0.080**	0.325**	0.138***
	(–0.855)	(1.599)	(0.395)	(4.397)	(2.408)	(2.246)	(2.286)	(4.885)
Mobi	0.003***	–0.002	0.004	–0.013	0.005	0.039	–0.003	0.008
	(2.650)	(–0.910)	(1.474)	(–0.920)	(1.373)	(1.324)	(–0.674)	(0.367)
Cons	–0.035	–0.028	–0.052*	–0.059*	–0.087**	–0.056	–0.127***	–0.054*
	(–1.159)	(–0.717)	(–1.916)	(–1.675)	(–2.272)	(–1.193)	(–4.074)	(–1.717)

, **, and * indicate that the statistical value is significant at the 10%, 5%, and 1% levels, respectively.*

in a pilot zone, otherwise takes 0. *Time* is the dummy variable before and after the policy, this paper assigns the year 2017 to 1, the years after 2017 to 1, and the years before 2017 to 0. X_{it} is a matrix of control variables, including nine indicators of the city, as detailed in **Table 2**.

In the benchmark analysis, the coefficient β_1 of the DID term Treat $_r$* Time $_t$ is the focus of this paper. The coefficient reflects the impact of the pilot zones on regional green technology innovation before and after the announcement between pilot and non-pilot zones. If β_1 is significantly positive, it indicates that pilot zone helps promote green technology innovation. In addition, the model controls for province fixed effects and year fixed effects over time, denoted as δ_r and γ_t, respectively, and ε_{irt} is a random disturbance term.

3.3 Variables Selection

1) Explained variables.

The research perspective of this paper is to examine the effectiveness of pilot zones on regional green technology innovation activities. Therefore, the number of regional green patents is adopted as the explained variable. Patents are an effective indicator of technological innovation, and green patents can most intuitively reflect the output of regional green technological innovation activities. The patent data can be further classified according to different technological properties to reflect innovation activities' different value connotations and contributions. In the specific study, this paper explores the influence of pilot zones on different kinds of green innovation behaviors in the region from two aspects of patent application and patent acquisition, respectively. There are four indicators for each aspect, and eight indicators in total, as detailed in **Table 3**. The indicators for each aspect have been subdivided into two subdivisions, i.e., the number of patents and the percentage of the number of patents, representing the absolute achievement and relative advantage of the regional green innovation level, respectively. **Table 3**shows the descriptive statistical information of the explained variables after standardization. From the descriptive statistics of the explained variables, the level of green innovation in technology varies unevenly and widely among regions according to the mean, maximum, and standard deviation.

2) Control variables.

This paper selects a series of city-level influencing factors as control variables. First, the larger the total population in a city jurisdiction, the more people are likely to engage in green technology innovation, and the more patents are obtained. Second, if students' level of education in the area is higher, the greater the probability that students will engage in innovative activities and achieve results in school and their graduate work. Finally, as the size of firms in a city increases, firms' profitability increases due to scale expansion. At this time, the enterprises are more likely to provide their employees with platform support and financial assistance to conduct green innovation activities.

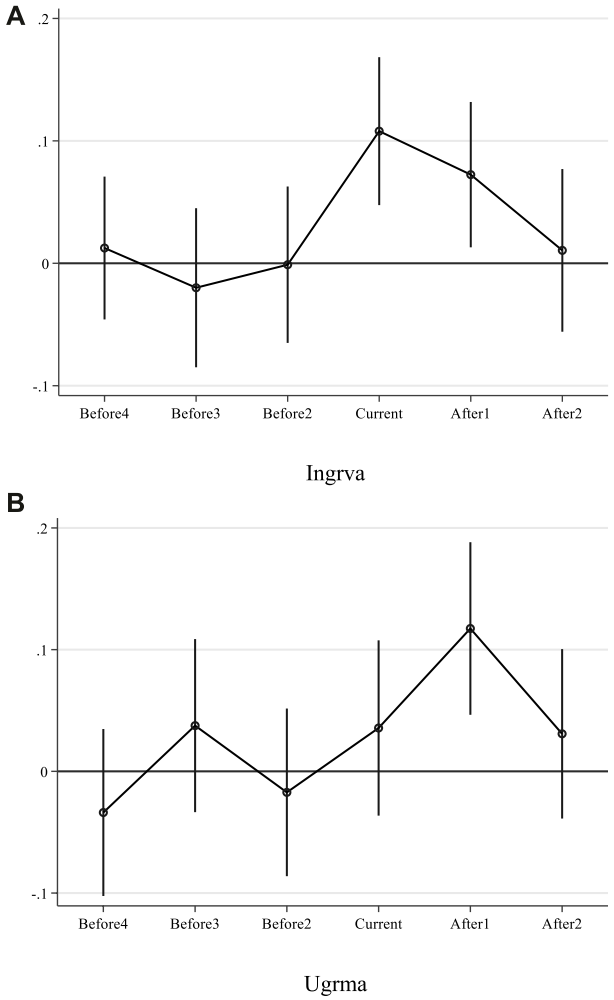

FIGURE 1 | Graphical representation of the results of the parallel trend test.

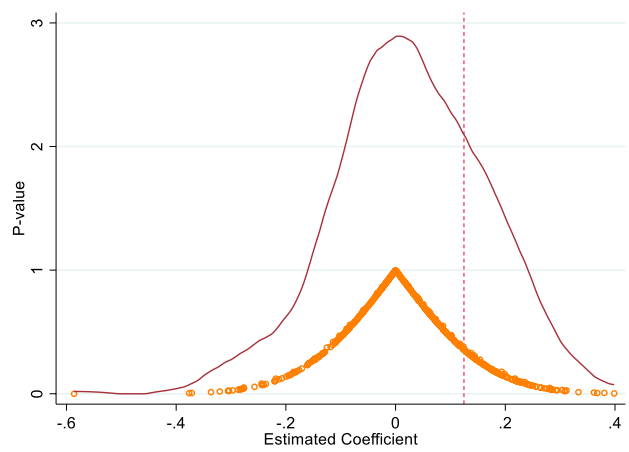

FIGURE 2 | Placebo test result.

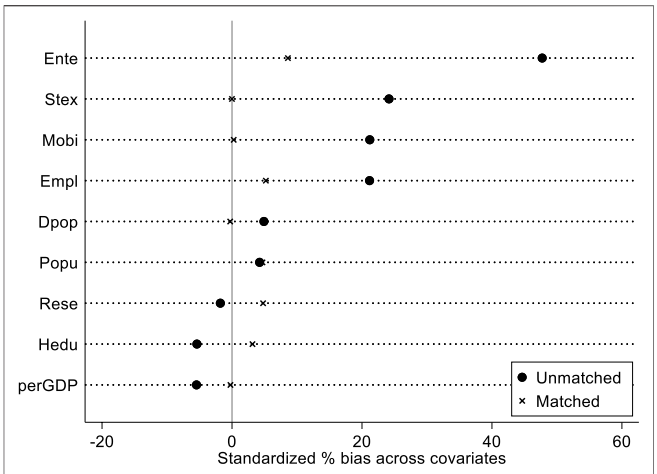

FIGURE 3 | Matching Chart for 2017.

Therefore, the above considerations led to selecting nine control variables, as shown in **Table 4**.

4 EMPIRICAL RESULTS

4.1 Baseline Regression Results

According to the benchmark regression model, this section examines the quantitative impact of pilot zones on urban green technology innovation, and the estimated results are shown in **Table 5**.

The regression results in **Table 5** indicate that pilot zones have promoted green technology innovation. According to **Table 5**, the regression coefficients of Treat*Time in columns (3), (5), (7), 8) are 0.303, 0.370, 0.335, and -0.146, respectively, and all of them are significant at different confidence levels. This result indicates that pilot zones have promoted the number of green utility patents obtained, the number of green invention patents applied, and the number of green utility patents applied. However, pilot zones are negative for the percentage of the number of green utility patents to the total number of patents applied. Among the control variables, population size exhibits a significant adverse effect in several models, indicating that regional innovation does not necessarily increase with regional population size. The increase in employees and people engaged in scientific and technical activities leads to regional green innovation, which is also reflected in research expenditures and education levels.

The reasons for the above empirical results may be as follows: on the one hand, since the pilot zone was established in 2017, the data covers from 2010 to 2019, and the sample period is short, which may cause policy effects of the pilot zone cannot be fully demonstrated; on the other hand, according to the Patent Law of the People's Republic of China, an invention patent refers to a new technical solution for a product, method or its improvement; a utility patent refers to a new technical solution for the shape, structure or combination thereof of a product that is suitable for

TABLE 7 | Regression results after PSM-DID.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	lngrvg	**lngrvgrt**	**Ugrmg**	**Ugrmgrt**	**lngrva**	**lngrvart**	**Ugrma**	**Ugrmart**
Treat * Time	0.332**	1.146**	0.953***	0.234	0.868***	0.960**	0.884***	0.107
	(2.567)	(2.552)	(4.746)	(0.458)	(3.662)	(2.238)	(4.831)	(0.222)
Time	0.014	0.044	0.006	0.077***	0.056	−0.027	0.153***	0.052*
	(0.519)	(1.260)	(0.158)	(2.713)	(1.192)	(−0.655)	(3.801)	(1.723)
Treat	−0.868***	−0.544*	−1.122***	−0.716*	−1.069***	−0.418	−0.835***	−0.725*
	(−12.177)	(−1.701)	(−9.278)	(−1.693)	(−8.263)	(−1.105)	(−4.598)	(−1.791)
Popu	−0.137***	−0.083	−0.230***	−0.318***	−0.143***	0.030	−0.135**	−0.203**
	(−2.747)	(−1.053)	(−3.880)	(−3.501)	(−2.887)	(0.339)	(−2.323)	(−2.523)
Empl	0.829***	0.010	1.112***	0.274**	0.178	0.111	−0.050	0.155
	(3.602)	(0.103)	(4.234)	(2.526)	(0.882)	(1.021)	(−0.207)	(1.604)
Rese	−0.132	0.076	−0.358*	0.106	−0.308***	0.063	−0.222	0.040
	(−0.582)	(0.797)	(−1.761)	(0.687)	(−2.793)	(0.662)	(−-0.961)	(0.329)
Dpop	−0.041*	0.049	−0.068*	−0.057	−0.099*	0.029	−0.073	−0.044
	(−1.793)	(0.619)	(−1.747)	(−1.203)	(−1.790)	(0.360)	(−1.075)	(−1.092)
perGDP	0.019	0.484***	0.149	−0.134	0.307**	0.382**	0.348***	0.086
	(0.272)	(2.952)	(1.126)	(−0.735)	(2.037)	(2.157)	(2.602)	(0.405)
Ente	0.029	−0.082	0.177	0.029	0.206**	−0.147*	0.037	0.027
	(0.206)	(−1.177)	(0.902)	(0.529)	(2.220)	(−1.921)	(0.644)	(0.485)
Stex	−0.006	−0.034	−0.147	−0.194***	0.117	−0.190**	0.313**	−0.115*
	(−0.086)	(−0.648)	(−1.178)	(−2.604)	(0.904)	(−2.349)	(2.011)	(−1.674)
Hedu	0.018	0.019	0.118	0.151**	0.523**	0.080	0.519	0.122**
	(0.206)	(0.355)	(0.707)	(2.367)	(2.112)	(0.859)	(1.602)	(2.163)
Mobi	0.008	0.061	0.009	−0.007	0.013	0.041***	0.010	0.007
	(0.879)	(0.998)	(0.848)	(−0.623)	(0.916)	(4.881)	(0.858)	(0.513)
Cons	0.098***	−0.000	0.140***	−0.025	0.075	0.015	0.022	−0.008
	(3.712)	(−0.011)	(4.138)	(−1.470)	(1.505)	(0.775)	(0.573)	(−0.508)

, **, and * indicate that the statistical value is significant at the 10%, 5%, and 1% levels, respectively.*

practical use. From the above explanation, the level of inventiveness of a green utility patent is lower than that of a green invention patent. Therefore, the incentive effect of the policy is firstly reflected in the application and acquisition of green utility patents and then, over time, in the number of green inventions patents. In addition, since the technical field of invention patents is broader, their examination period is generally more than one and a half years. In contrast, the examination period of a utility patent is generally half a year, and the difference in time may also be one of the reasons for the insignificant effect on the number of green inventions patents obtained.

4.2 Robustness Tests

4.2.1 Changing the Explanatory Variable Measure

To check the robustness of the previous results, we treat the time variable differently here. Since the pilot zones were set up in June 2017, i.e., the middle of the year, assigning 1 to 2017 may amplify the policy effect of the pilot zone. Because of this, the time variable is reassigned to 0.5. The rest of the years are assigned the same value as the baseline regression equation, i.e., 0 before 2017 and 1 after 2017. the regression results after the assignment are shown in **Table 6**. The coefficients of the cross-multiplier term Treat*Time are still significant at different confidence levels, and the positivity and negativity of the impact on different indicators do not change, which is consistent with the results of the baseline regression in **Table 5**.

4.2.2 Parallel Trend Test

The DID model requires that the treatment and control groups satisfy the assumption of parallel trends. **Figure 1** shows the parallel trend test for the two indicators, the number of green utility patents obtained and the number of green invention patent applications. Before 2017, the confidence intervals of the indicators crossed the 0-value line, indicating that they were not significant; after 2017, there were years in which the confidence intervals of the indicators did not cross the 0-value line, i.e., significant status, indicating that the parallel trend test passed.

4.2.3 Placebo Test

To further exclude the influence of other unknown factors on the pilot zones and ensure that the results obtained in this paper are caused by establishing the pilot zones for green finance reform and innovation, we conducted a placebo test. In this paper, 1000 sampling was performed in all 31 provinces, and five provinces were randomly selected as the dummy treatment group in each sampling, while the remaining 26 provinces were used as the control group, and regressions were conducted according to the model 1). **Figure 2** shows the regression results for the explanatory variable Ugrmart. The regression results are normally distributed, the distribution deviates from the baseline regression, and the *p*-value is large and insignificant, as shown by the scatter plot, indicating that pilot zones has no significant effect in these 1000 times of random sampling. Therefore, the conclusions obtained in this paper can pass the placebo test, and the impact of the establishment of the pilot zone

TABLE 8 | Moderating effect test results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ingrvg	Ingrvgrt	Ugrmg	Ugrmgrt	Ingrva	Ingrvart	Ugrma	Ugrmart
Treat*Time*Indu	0.334***	−0.109*	0.818***	0.080	0.747**	−0.007	0.433***	0.083
	(3.464)	(−1.861)	(4.559)	(1.336)	(2.437)	(−0.119)	(3.081)	(1.481)
Treat * Time	0.095*	−0.002	0.370**	−0.117	0.365**	−0.044	0.145*	−0.122*
	(1.897)	(−0.024)	(2.358)	(−1.529)	(2.413)	(−0.565)	(1.797)	(−1.719)
Time	0.180***	0.137***	0.308***	0.170***	0.320***	0.323***	0.372***	0.114**
	(3.613)	(3.132)	(4.674)	(3.624)	(3.611)	(6.149)	(4.100)	(2.417)
Treat	0.057	−0.120*	0.031	−0.128*	0.094	−0.112	0.282**	−0.127*
	(1.007)	(−1.844)	(0.393)	(−1.690)	(0.957)	(−1.408)	(2.495)	(−1.853)
Indu	−0.038	−0.028	−0.051	−0.045**	−0.161**	−0.007	−0.081*	−0.048**
	(−1.543)	(−1.530)	(−1.383)	(−2.137)	(−2.521)	(−0.348)	(−1.662)	(−2.551)
Popu	−0.001	0.000	−0.052	−0.061***	−0.065	0.024	−0.154***	−0.024*
	(−0.062)	(0.005)	(−1.505)	(−3.381)	(−1.345)	(1.267)	(−2.781)	(−1.661)
Empl	0.087	0.015	0.496***	−0.035	0.402	−0.075**	0.523	−0.021
	(0.809)	(0.513)	(4.732)	(−0.822)	(1.610)	(−2.037)	(1.610)	(−0.514)
Rese	0.997***	−0.022	0.351***	0.076***	−0.357	0.019	−0.516**	−0.027
	(6.388)	(−1.238)	(4.269)	(2.785)	(−1.580)	(0.572)	(−2.465)	(−0.993)
Dpop	−0.007	0.003	−0.000	−0.004	0.010	0.012	0.022	−0.004
	(−0.870)	(0.131)	(−0.016)	(−0.239)	(0.369)	(0.357)	(0.668)	(−0.242)
perGDP	0.008	0.010	0.015	−0.005*	0.015	−0.004	0.015	0.000
	(0.920)	(1.403)	(0.975)	(−1.751)	(0.857)	(−1.500)	(0.833)	(0.041)
Ente	−0.058	−0.034***	0.137*	−0.007	0.034	−0.011	−0.024	−0.007
	(−0.913)	(−2.751)	(1.944)	(−0.313)	(0.714)	(−0.852)	(−0.495)	(−0.364)
Stex	0.123***	0.026	0.064	−0.018	0.320**	0.008	0.365**	0.009
	(3.030)	(1.154)	(0.644)	(−0.861)	(2.098)	(0.296)	(2.328)	(0.507)
Hedu	−0.061	0.049*	0.038	0.144***	0.417***	0.082**	0.338**	0.142***
	(−0.736)	(1.669)	(0.518)	(4.638)	(2.638)	(2.365)	(2.433)	(5.097)
Mobi	0.002**	−0.003	0.002	−0.014	−0.000	0.039	−0.007	0.007
	(2.176)	(−0.921)	(0.905)	(−0.967)	(−0.093)	(1.347)	(−0.956)	(0.307)
Cons	−0.025	−0.008	−0.043	−-0.038	−0.062	−0.040	−0.094***	−0.026
	(−0.846)	(−0.204)	(−1.564)	(−1.108)	(−1.588)	(−0.883)	(−2.987)	(−0.887)

*, **, and *** indicate that the statistical value is significant at the 10%, 5%, and 1% levels, respectively.

on green technology innovation has little relationship with other unknown factors.

4.2.4 PSM-DID Test

The treatment and control groups contain cities from different provinces, and since it is not possible to ensure that the treatment and control groups have the same regional characteristics before the policy is implemented, propensity score matching (PSM) is used to match the cities in the treatment and control groups. **Figure 3** shows the matching results for 2017. The results show that after matching, the indicators fall within the interval of (−20%,20%) on the horizontal axis, indicating that the matching results are good enough for the subsequent DID regression.

Table 7 shows the results after PSM-DID. The regression coefficients of the cross-multiplier term Treat*Time for six explanatory variables are significantly positive at the 5% confidence level, and the regression coefficients of the cross-multiplier term of all eight items are positive. After excluding the regional differences between the treatment and control groups, the pilot regions promoted the application and acquisition of regional green patents. The effects on the six indicators were statistically significant, further verifying the robustness of the conclusions in the benchmark regression.

4.2.5 Moderating Effect Test

We use the comprehensive utilization rate of industrial solid waste (*Indu*) as a moderating variable to refer to the moderating effect of environmental regulations. The moderating effect test model is show in **Eq. 2** and the results are shown in **Table 8**. In columns (3) (5) (7) of **Table 8**, the coefficients of cross-multiplier term between explanatory variable and moderating variable are significant, indicating that environmental regulation has played a positive moderating role in the process of green financial policies affecting green innovation. The strengthening of regulation will help improve the impact of green financial policies on the level of green innovation in the region.

$$Tgreen_{it} = \beta_0 + \beta_1 Treat_r * Time_t + \beta_2 Treat_r * Time_t * Indu_{it} + \beta_3 Indu_{it} + \beta_4 Treat_r + \beta_5 Time_t + \rho X_{it} + \delta_r + \gamma_t + \varepsilon_{irt} \quad (2)$$

5 CONCLUSIONS AND POLICY RECOMMENDATIONS

Green technology innovation is a vital force for achieving sustainable economic and environmental development in

China. This paper examines whether the pilot zones can promote regional green technology innovation using a quasi-natural experiment, with the data of Chinese cities from 2010 to 2019 and the number of green patents applied and obtained.

The results show that the pilot zone can induce the green technology innovation activities of the region to a certain extent. After a series of robustness tests, this conclusion is still robust, providing reliable empirical evidence for the relationship between green financial policies and regional green technology innovation. Among them, a heterogeneous effect is shown in green patent categories. The promotion effect on green utility patents is stronger than that on green invention patents, which provides a reference for the formulation and implementation of differentiated green financial policies.

The administrative announcement of the Green Finance Reform and Innovation Pilot Zone was released in June 2017, but the data sample is only available until 2019 due to availability and completeness, which is a shortcoming of the article. Therefore, in the future study, we hope to obtain regional green patent data more than 5 years after the policy announcement to measure the impact of the pilot zones more accurately on regional green innovation. In addition, through a more detailed classification of green patents, more realistic policy recommendations can be made by analyzing the heterogeneous impact of policy regional green innovation.

Therefore, this paper puts forward the following policy recommendations based on the above research findings.

First, the pilot zones should explore replicable experiences and promote them on a larger scale. The pilot zones for green financial reform and innovation are an important practical exploration of China's use of financial regulation and other market-based instruments for environmental governance. The policy allows pilot regions to build distinctive pilot zones based on the institutional environment and economic situation, which can help induce regional green technology innovation and promote high-quality economic development. Therefore, policymakers can contribute to the realization of high-quality economic development by refining pilot experiences and forming typical cases to promote the construction of pilot zones on a larger scale. For example, the government can select the junction of major economic zones such as the Yangtze River Delta, the Guangdong-Hong Kong-Macao Greater Bay Area, the Beijing-Tianjin-Hebei region, and the Chengdu-Chongqing region, and support them to carry out cross-regional pilots of green financial reform and innovation to promote more innovation.

Secondly, the government needs to develop clear guidance programs for different types of green innovation to stimulate independent innovation in pilot areas. Since in the process of patent inventiveness examination, invention patents need to have "outstanding substantive features and significant progress," while utility patents only need to have "substantive features and progress," and utility patents cannot be directly used in patent infringement lawsuits. Therefore, the economic benefits that green invention patents can bring to enterprises and regions are significantly higher than those of utility patents, and the incentive mechanism for green invention patents should be strengthened. A more precise technical transformation plan should be formulated with regional characteristics to help regional industries transform and upgrade. In addition, local governments can also introduce fast-track examination channels for green invention patents, compressing the approval time from patent application to acquisition.

Third, a government-led development model managed by the market is needed to stimulate more social capital to invest in green innovation. On the one hand, the lack of profitability of green finance alone has dramatically reduced the motivation of institutional participation, and the development of green finance in China is still in its infancy. It cannot be separated from government support. On the other hand, to achieve China's goal of reaching carbon peaking and carbon neutrality, it is expected that trillions of *yuan* of green investment will be needed every year, which cannot rely on government investment alone, but will also require private capital inflows, as suggested by a study on another country (Taghizadeh-Hesary & Yoshino, 2019). Therefore, the government should innovate the green financial system, guide, and stimulate more social capital to flow to the green industry, provide financial support for its technological innovation, and form a government-led and market-managed model. The government should improve the incentive mechanism, adopt some more effective incentives to increase market participation, and implement preferential policies such as financial subsidies, tax breaks, and financial incentives as soon as possible.

Due to the paper being limited by data availability, it can be enhanced in two aspects in the future. On the one hand, the pilot zone has a differentiated impact on different types of patents. The subsequent study can conduct more detailed research for more subdivided green patent categories according to WIPO's "Green List of International Patent Classification". On the other hand, several domestic provinces introduced relevant environmental policies during the sample period, and it is difficult to completely exclude the interference of relevant policies in the robustness test. In addition, the pilot zone for green finance reform and innovation is still in the process of exploration and promotion, which can be evaluated more precisely and expanded in more dimensions in the future.

DATA AVAILABILITY STATEMENT

The datasets can be obtained from the Chinese Research Data Services Platform (CNRDS) and China City Statistical Yearbook.

AUTHOR CONTRIBUTIONS

CZ: conceptualization, methodology, writing, validation. XC: software, data, visualization, writing—Review and Editing. YM: data, method.

FUNDING

This research is supported by Social Science Fund, Nanjing University of Posts and Telecommunications (no. NYY219004).

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