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Can the Special Economic Zones Promote the Green Technology Innovation of Enterprises? An Evidence From China

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Addressing global climate change is the responsibility of all mankind, and original green technology innovation is the key to achieving the goal of "carbon neutrality". Under the target of "carbon neutrality", it remains to be seen whether China's special economic zones can promote the green technology innovation of enterprises, which is very important for achieving green and high-quality development. This study examines the impact of special economic zones (SEZs) on enterprises' green technology innovation by constructing a quasi-natural experiment using data of Chinese listed companies (collected from 2000 to 2017) and green patent applications. The empirical results showed that the SEZ program significantly promoted the green technology innovation of enterprises. The number of green patent applications of enterprises in zones has increased by 17.02%. The promotion effect was more significant on enterprises in provincial development zones, those that are owned by the central state, and those in central and eastern regions. In the short term, the green innovation promotion effect is mainly derived from the effect of preferential policy subsidies, while in the long run, the role of the agglomeration effect gradually emerged. This study provides empirical evidence for green and high-quality development. This study also provides a new policy reference for achieving a win–win situation between industrial agglomeration and ecological environment.

Keywords: special economic zones, green technology innovation, agglomeration effect, preferential policy subsidies, green development

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1 INTRODUCTION

Although the economy of China has grown rapidly, energy consumption and environmental pollution restrict the sustainability of economic development (Gu et al., 2019; Gu et al., 2020a; Gu et al., 2020b; Zhao et al., 2020; Zhao et al., 2021; Zhou et al., 2021). According to the report of the 19th CPC National Congress, China's economy has moved from a stage of high-speed growth to a stage of high-quality development. It means that the extensive development model relying on energy consumption can no longer promote the high-quality and sustainable growth of the economy of China (Sui, 2017; Zhang et al., 2018; Peng et al., 2020a; Zhang et al., 2020). At the same time, the emission restrictions and energy constraints under the "carbon neutrality" target have put forward higher requirements for economic growth (Shen et al., 2019; Sheng et al., 2019; Tu et al., 2020). Therefore, green and intensive development has become the key to ensure high-quality economic development (Wang, 2020; Elahi et al., 2022a; Elahi et al., 2022b). Adoption of green technology innovation leads to high-quality development in the agriculture and industrial sectors (Elahi et al., 2019a; Elahi et al., 2019b; Elahi et al., 2021a). Enterprises are the principal body and actual implementation of technological innovation, and patents are important carriers of enterprises' technology. Promoting enterprise green technology innovation is of great significance to high-quality economic development (Odhiambo et al., 2020; Peng et al., 2021; Wang et al., 2021).

China's special economic zones (SEZs) have been introduced nearly 40 years ago. As a typical place-based policy, it is widely used in many countries. In practice, since the implementation of SEZs, the main economic indicators, such as the productivity, innovation level, and scale of enterprises in SEZs, have been greatly improved (Alder et al., 2016; Lu et al., 2019), which has become an important driving force for China to promote economic growth (Peng et al., 2018a; Peng et al., 2019a; Wang Q. et al., 2019). However, whether SEZs balance economic construction and environmental protection is an urgent question to be answered—for example, during the COVID-19 pandemic in 2021, a large number of enterprises in special economic zones were restricted by the policy of power rationing and shutdown due to the rise in coal prices. Promoting green development and upgrading of enterprises have become the key for SEZs to promote sustainable economic development in China. At the same time, in the process of promoting the economic development of special economic zones, air pollution, environmental damage, and other problems that are not conducive to sustainable development have gradually emerged, and environmental constraints have become an important factor hindering the further development of China's economy (Peng et al., 2019b; Peng et al., 2020b; Zhong et al., 2020; Peng et al., 2022b). Therefore, SEZs more and more tend to promote enterprise green and intensive development. Among them, the green development policy in SEZs mainly includes pollution supervision and green development encouragement policies for enterprises in the zone, such as the policy of sewage treatment, the strict supervision policy on pollution discharge of chemical industry, and the policy of encouraging enterprises to save energy and reduce environmental emissions (Elahi et al., 2017a; Elahi et al., 2017b; Elahi et al., 2018b; Zhong et al., 2021). These policies will promote enterprises to enhance their awareness of green development and promote green technology innovation to reduce pollution emissions (Peng et al., 2018b; Wu B. et al., 2021; Peng et al., 2022a). Therefore, it was found that, in the enterprise's green technology innovation, a large number of green inventions and utility model patents are used to reduce the discharge of wastewater and energy consumption (Peng et al., 2019c; Tu et al., 2019; Huang et al., 2021).

Based on the "China SEZ Audit Announcement List" and the panel data of listed companies and corporate green patent application data from 2000 to 2017, this paper empirically determines the causal relationship between the SEZ program and corporate green technology innovation using the method of staggered differences-in-differences (DID). Moreover, this paper analyzes the heterogeneity of the policy effects from the types of the SEZ program, the regional level, and the enterprise ownership. Finally, from the perspective of policy subsidy mechanism and agglomeration effect mechanism, the study estimates the intermediary mechanism of the SEZ program to promote green technology innovation of enterprises.

The study has three main contributions. Firstly, this study examines the impact of the SEZ program on corporate green technology innovation, which expands the existing academic literature on factors affecting green and high-quality development. Secondly, it evaluates the policy effect and mechanism of the SEZ program in the context of China and provides empirical evidence for further improvement and promotion of the SEZ program. Thirdly, it is the first study that focuses on the long-term effect of agglomeration in the SEZ program, which provides a reference for the sustainable development of the SEZ program.

2 INSTITUTIONAL BACKGROUND AND RESEARCH HYPOTHESES

2.1 Institutional Background

The central government of China implemented a series of economic policies to promote regional economic growth (Neumark and Simpson, 2015). In particular, SEZs are a form of incremental development usually used in developing countries. In 1984, the State Council of China approved the first batch of 14 coastal economic and technological SEZs that established the developing guideline. The main focus was on industrial projects, FDI absorption, and export value, with emphasis on the development of high and new technology. The SEZs effectively drive the economic development of the coastal areas (Wei, 1995). The success of coastal urban SEZs has gradually replicated to inland areas, and all regions have actively built SEZs, which have fully covered 31 provinces. There are several types of special economic zones in which the preferential policies have some different emphases—for example, the National Economic and Technical Development Zones (NETDZ) are approved by the central government, which are more privileged and broad, with a wide range of investors. The National High-Tech Industrial Development Zones (NHIDZ) are aiming to develop high-tech industries and promote technological innovation. Both NETDZ and NHIDZ are state-level SEZs and have some similar functions. Provincial development zones (PDZs) are initiated by the provincial government and usually develop industries that are suited to local comparative advantages. According to the China SEZ Audit Announcement List (revised in 2018), there are 2,543 SEZs at or above the provincial level, including 552 state-level zones (which comprised 219 NETDZs, 156 NHIDZs, and other types) and 1,991 PDZs. These SEZs contribute more than 30% of the whole economy of China. As the economic engine, SEZs have promoted the coordinated and orderly economic development of China (Ren, 2018).

The environmental governance and encouraging green development of enterprises in SEZs are important measures for the sustainable economic development of China. In recent years, the Chinese government issued a series of important documents, such as "Action Plan for the Prevention and Control of Water Pollution", "Industrial Green Development Plan", "Several Opinions on Promoting the Transformation, Upgrading, and Innovation and Development of the National Economic and Technological SEZ", and so on. These put forward the guidance of green development of the SEZs. Accordingly, the local governments have also introduced supporting measures to promote the green development of enterprises in the SEZs. The important path to promote green development is to promote the green technology innovation of enterprises, which can reduce energy consumption and pollution emissions and thus fundamentally achieve green development.

The construction of green development in SEZs is a strategic decision to promote China's economic development, so the concept of "green development" and "low-carbon operation" is put in an important position. Studying the impact of the SEZs on the enterprise green technology innovation is an important issue. Meanwhile, the establishment time of each zone is relatively scattered, which is conducive to separating the impact of policy and the unobservable annual fixed effect. This provides an appropriate quasi-natural experiment for the quantitative evaluation of the impact of the SEZ program on enterprise green technology innovation.

2.2 Research Hypotheses

Previous studies focused on China's SEZ program and explored the policy effects of zone construction from macro, meso, and micro perspectives. From the regional macro level, existing research found the positive economic effects of the SEZ program from the perspectives of regional economic growth (Alder et al., 2016; Brachert et al., 2019), regional innovation (Wu M. et al., 2021), FDI (Wang, 2013), and regional employment (Ham et al., 2011; Busso et al., 2013). From the industrial meso level, starting from the leading industries of the SEZ program, extant literature has studied the integration of policy and the local economy in SEZs from the perspectives of comparative advantages (Chen and Xiong, 2015) and industrial upgrading (Li and Shen, 2015). From the enterprise micro level, the studies found that SEZs promoted firm productivity (Lin et al., 2018) and increased the enterprises' scale generally (Li and Wu, 2018). Most studies indicated that the policy effects of China's SEZs have been positive and effective. However, some studies also highlighted that SEZs rely too much on financial subsidies and lead to efficiency loss (Hanson and Rohlin, 2013).

Previous literature focused on the economic effects of SEZs that have already been concerned with the impact on enterprise innovation. However, to the best of our knowledge, until now, no study examined the impact of SEZs on green technology innovation. Actually, in the construction of SEZs, both state-level and provincial-level SEZ programs regard green development as a necessary condition for high-quality economic development. Therefore, the government provides favorable policy support for enterprise green technology innovation in SEZs, which may enhance the motivation of enterprises for green technology innovation, and significantly promotes the improvement of the green technology innovation level of enterprises in SEZs. In addition, the SEZ programs enhance enterprise clustering in specific geographical areas, and the consequent industrial agglomeration promotes green technology innovation (Li et al., 2021). Based on the above-mentioned analysis, we propose the following hypothesis:

Hypothesis 1: Special economic zones could promote green technology innovation of enterprises.

The micro influence of the SEZs establishment on enterprise green technology innovation is mainly reflected in two aspects: First, the government provides more tax incentives and financial subsidies to enterprises and thus directly or indirectly broadens the financing channels of enterprises in SEZs, namely, the preferential policy effect. Second, the establishment of SEZs helps to strengthen the formation of industrial agglomeration and improve the availability of enterprise innovation resources in the zone, namely, the agglomeration effect.

2.2.1 The Preferential Policy Effect of SEZs

Preferential policies for enterprises in SEZs mainly include government financial subsidies and tax incentives. Government subsidies were facilitated as a gratuitous transfer of funds. Its original intention is to influence the innovation decision-making of enterprises by increasing the number of funds owned by enterprises to improve the willingness of enterprises to invest in innovation. Moderate financial subsidies are conducive to making up for market failures in the innovation process, driving innovation investment at the enterprise level, and promoting enterprise technological innovation activities (Görg and Strobl, 2007; Lee, 2011). However, government subsidies may fail to have the expected positive effect. It cannot be ruled out that companies are more likely inclined to invest subsidies into non-productive investment activities than innovation and upgrading activities in the face of high government financial subsidies. In addition, the information asymmetry between the government and enterprises can easily lead to problems, such as reverse selection before enterprises apply for subsidies. Tax incentives help to ease the tax burden of micro-market subjects and reduce the marginal cost of enterprise innovation activities, thus improving the expected income of enterprise innovation investment. It has been demonstrated that tax incentives can promote enterprises to increase R&D investment and innovation output (Bloom et al., 2002; Beck et al., 2016). However, some studies found that tax has a significant incentive effect on enterprise R&D investment, but not obviously on innovation output (Yuan et al., 2016). The previous literature has not found a relationship between financial subsidies and enterprise innovation. Therefore, this paper proposes the following research hypotheses:

Hypothesis 2a: Special economic zones can facilitate green technology innovation of enterprises by the preferential policy effect.

Hypothesis 2b: The preferential policies of special economic zones could not influence green technology innovation of enterprises.

2.2.2 The Agglomeration Effect of SEZs

Governments at all levels attract companies to SEZs with preferential policies and convenient services to promote the formation of industrial clusters (Wang, 2013). The concentration of economic activities helps to reduce transaction costs, transportation costs, equipment usage costs, and labor costs, enabling enterprises to obtain higher economic returns and devote more resources to developing new products and technologies (Andersson et al., 2007). The SEZs, like many place-based programs, attempt to foster agglomeration economies by building clusters (Combes et al., 2011). The essence of an agglomeration economy is the high concentration of factors in a specific geographic area to generate an external economy, and the circular cumulative process of innovative activities and economy of scale plays a role in the formation of agglomeration economy (Xu, 2006). The SEZ achieves self-improvement and sustainable development through the "positive feedback" process of "circular accumulation" of agglomeration effect. The strong agglomeration effect helps enterprises in the zone to obtain external resources more easily and improve the efficiency of using existing resources (Duranton and Puga, 2004). In the meantime, the continuous growth of enterprises in SEZs enhances the overall industrial agglomeration of the zone, further strengthening the effect of economies of scale and external economies. In addition, from the perspective of knowledge generation, the SEZ triggers the spatial reconfiguration of production factors, such as human resources, financial resources, and scientific research resources, among which professional labor and financial resources are fundamental elements for enterprises to engage with technological innovation (Sun et al., 2018; Zulfiqar et al., 2020a; Zulfiqar and Hussain, 2020; Zulfiqar et al., 2021). Enterprises in the development area can share production factors associated with R&D innovation activities, such as R&D personnel, R&D infrastructure, and R&D knowledge (Zulfiqar et al., 2020b), which, in turn, stimulate them to engage in green technology innovation (Carlino and Kerr, 2015). Lastly, knowledge and technology spillover is the most fundamental factor for industrial agglomeration to promote green technology innovation of enterprises. Industrial agglomeration creates conditions for cognitive proximity, social proximity, institutional proximity, and organizational proximity among innovation subjects. It helps promote the division of labor and collaboration among enterprises and leverage knowledge and technology spillover effects (Mariotti et al., 2010). It should be noted that the agglomeration effect needs to be accumulated over a long time period. Therefore, this paper argues that there may be a lag in the agglomeration effect of SEZs on enterprises' green technology innovation. We proposed the following hypotheses.:

Hypothesis 3a: Special economic zones can facilitate green technology innovation of enterprises by the agglomeration effect.

Hypothesis 3b: The agglomeration effect of special economic zones could not influence green technology innovation of enterprises.

3 MATERIALS AND METHODS

3.1 Source of Data

The database used in this study consists of three parts: SEZ data, enterprise green patent data, and enterprise characteristics and financial data. SEZ data was obtained from the China SEZ Audit Announcement List (Revised in 2018). This list included the characteristics of China's existing SEZs by 2018, establishment time, geographic boundary information, and the type of SEZs. Enterprise green patent application data was obtained from the State Intellectual Property Office of China. Enterprise characteristics and financial data were obtained from the China Stock Market & Accounting Research Database. The number of SEZs established before 2000 accounted for a small proportion, and they are located in coastal cities with a high level of economic development. After 2000, SEZs sprang up rapidly in all regions of China. Consequently, the study period is from 2000 to 2017.

3.2 Outlier Processing

We eliminated special treatment, particular transfer, and financial enterprises (*e.g.*, banks, insurance, and security companies) because they generally have special properties that may lead to biased results. After that, we excluded enterprises listed for less than 1 year to reduce the bias caused by the impact of IPO events. Then, we eliminated the sample of areas where no SEZs were established in the research period. Therefore, the impact of the regional effect was removed. Moreover, to avoid extreme values, the main continuous variables are winsorized by 1%.

3.3 Identification of Enterprises in SEZs

To identify whether the enterprise is in SEZs, precise geographical information about enterprises' locations (specific coordinates) is needed. For this purpose, processing was carried out using various steps:

Step 1: We used Baidu Map's geocoding Application Programming Interface and the detailed address of the enterprises to obtain the geographical coordinates of each enterprise. The detailed Chinese address of each enterprise was used with Baidu Map to get a map with the specific location of the address; then, the latitude and longitude of the enterprise were extracted.

Step 2: We mapped the SEZs according to the boundary address of each zone. ArcGIS software was used to merge and intersect the longitude and latitude of enterprises with the map of the SEZ.

This process allows determining whether the enterprise is in SEZs.

Step 3: To avoid systematic errors in localization resolution, we further verified and identified the type of SEZs where the enterprise is located through the special vocabulary contained in the address. The addresses of enterprises in SEZs have some common characteristics—for instance, "158 Jinghai 4th Road, Beijing Economic and Technological Development Zone, Beijing" contains the words "economic and technological development zone"; it is a listed company in NETDZ. Therefore, we identified the enterprises whose address contains the "economic and technological development zone" as being in the NETDZ. Similarly, the enterprises whose address contained "high-tech industrial development zone" were identified as being in the NHIDZ, and the enterprises whose address contained "industrial development zone" or "industrial park" were identified as being in the PDZ.

After the above-mentioned processing, the final dataset of this paper has a total observation value of 28,625 and 1,795 enterprises. Among them, there were 796 enterprises in the state-level SEZs (44.35%), 268 enterprises in the NETDZs (14.93%), 235 enterprises in the NHIDZs (13.09%), and 293 enterprises in the PDZs (16.32%).

4 EMPIRICAL MODEL AND SELECTION OF VARIABLES

Since the establishment of SEZs was carried out in batches, this means that the timing and the location of the SEZs in the sample are different. Thus, this paper takes the establishment of the SEZs as a quasi-experiment to evaluate the net effect of the establishment of SEZs on the green technology innovation of enterprises by constructing a time-varying DID model. As a major tool in evaluation methods of policy effects, the use of a DID model has been preferred because it can avoid the endogeneity problem. Moreover, the use of fixed effects estimation alleviates the omitted variable bias problem to a certain extent. Its basic idea is to construct a double difference statistic reflecting the effect of the policy by comparing the difference between the control and the treatment groups before and after the implementation of the policy. However, an important potential threat of this identification method is that the empirical results may be confounded by regional factors. Therefore, in this paper, enterprises inside and outside the SEZs in the same city are set as the treatment and control groups, respectively. The regression function can be written as follows:

$$\boldsymbol{GreenInnov_{it}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 Policy}_{\mathrm{it}} + \varnothing \boldsymbol{control_{it}} + \boldsymbol{\gamma_t} + \boldsymbol{\mu_i} + \boldsymbol{\epsilon_{it}} \quad (1)$$

where the subscript i and t represent the individual and the year, respectively. The dependent variable $\mathrm{GreenInnov}_{\mathrm{it}}$ represents the green technology innovation of enterprise i in year t. The independent variable $\mathrm{Policy}_{\mathrm{it}}$ is the key variable, which indicates whether the enterprise is affected by the SEZs. If enterprise i becomes an enterprise in the SEZs in year t, the value of the current year and subsequent years is 1; otherwise, it is 0. Similarly, $\mathrm{control}_{\mathrm{it}}$ is a set of control variables that affect enterprise green technology innovation: γ_t is the year fixed effect, μ_i is the individual fixed effects, and ϵ_{it} is the random disturbance term which is assumed to be normally distributed with zero mean value and constant variance (Elahi et al., 2018a; Abid et al., 2019; Elahi et al., 2019c; Elahi et al., 2020; Elahi et al., 2021b).

4.1 Dependent Variables

This paper analyzes the green technology innovation of enterprise in three dimensions: innovation output, innovation efficiency, and innovation input. We used the number of green patent applications (Gpatent) to indicate green technology innovation (Wang Y. et al., 2019). It is the indicator that most represents the green technology innovation level of enterprises, which can be further decomposed into the number of green invention patent applications (Gpatent_i) and the number of green utility model patent applications (Gpatent_u). Innovation efficiency is represented by the green technology innovation efficiency (GIE), which refers specifically to the number of patents produced per unit of R&D input. R&D is used to denote innovation input.

4.2 Control Variables

Following He and Tian (2013), Kafouros et al. (2015), and Liu (2021), the enterprise characteristic variables were selected to control the factors affecting enterprise innovation: enterprise assets (ASSET), enterprise profitability (ROA), enterprise liability ratio (LEV), firm liquidity (LIQ), and firm fixed assets per capita (CLR).

5 RESULTS AND DISCUSSION

5.1 Descriptive Statistics

The specific measurement and descriptive statistics of the variables are shown in **Table 1**. The results found that the average number of green patents was 0.2107, of which the average number of green invention patents was 0.0679, and the average number of green utility model patents was 0.1767 (**Table 1**). The main patent types in green patents were utility model patents. In addition, the green invention patents ranged from 0 to 3.0445, which indicated that there are great differences in the green invention patents among different enterprises in China.

The average number of patent applications of enterprises in SEZs has increased from 0.0373 in 2000 to 2.3123 in 2017. **Figure 1** illustrates the kernel density curves of the green patent application. The line of the green patent application of enterprises in SEZs is skewed to the right, indicating that the enterprises in SEZs have a higher level in green patent application than enterprises not in SEZs. Similarly, the picture on the right side of **Figure 1** illustrates

TABLE 1 | Summary of descriptive statistics.

Variables	Measurement index	Mean	Minimum	Maximum	Standard deviation
Gpatent	Ln (the number of green patents)	0.2107	0	3.0445	0.5849
Gpatent_i	Ln (the number of green invention patents)	0.0679	0	1.7918	0.2801
Gpatent_u	Ln (the number of green utility model patents)	0.1767	0	2.7726	0.5226
GIE	(the number of green invention patents) / R&D	0.1032	0	1.3431	0.1556
R&D	Ln (research and development expenses)	7.8000	0	23.1268	8.5673
ASSET	Ln (total assets)	21.7722	20.8295	22.5730	0.6020
ROA	Return on assets	8.2724	4.3596	12.2408	2.5440
LEV	Asset–liability ratio	50.7045	40.8721	64.2506	7.9901
LIQ	Current assets / current liabilities	1.0195	0.7150	1.7200	0.2832
CLR	Total fixed assets / number of employees	0.9636	0.3469	6.4872	1.1229

*The t-values are given in parentheses. ***, **, and * represent the level of significance of parameters at 1% (p < 0.01), 5% (p < 0.05), and 10% (p < 0.1), respectively.*

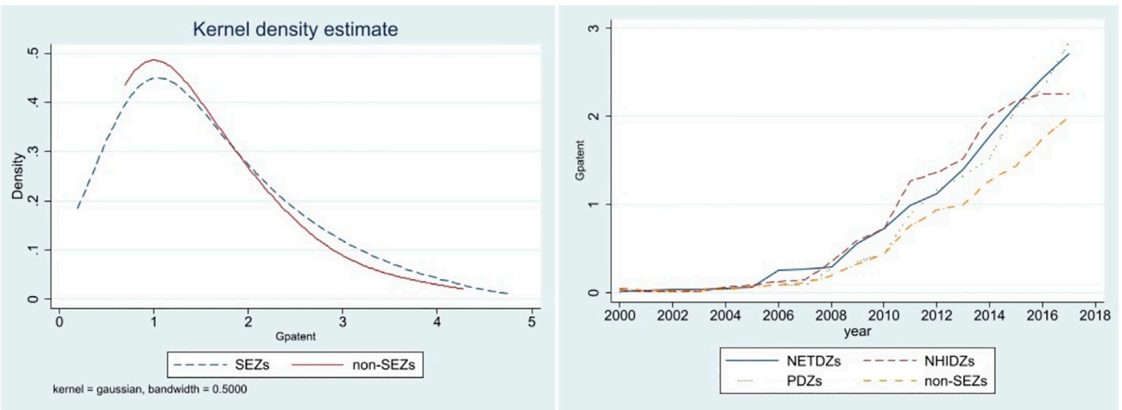

FIGURE 1 | Static and dynamic advantages of green technology innovation of enterprises in special economic zones (SEZs). The left side of the picture shows the kernel density distribution map of the green patent application, and the right side of the picture shows the dynamic evolution of the green patent application of enterprises in every kind of SEZs and non-SEZs.

TABLE 2 | Baseline regression results.

	(1)	(2)	(3)	(4)	(5)
	Gpatent	GIE	Gpatent_i	Gpatent_u	R&D
Policy	0.1702*** (6.87)	0.0140* (1.93)	0.0611*** (4.00)	0.1568*** (6.70)	0.0792*** (16.38)
ASSET	0.1368*** (15.13)	−0.0087*** (−3.76)	−0.0142*** (−2.95)	0.1483*** (16.61)	−0.2725*** (−14.29)
ROA	0.0253*** (12.36)	−0.0019*** (−3.58)	0.0061*** (5.00)	0.0224*** (11.87)	0.0352*** (80.04)
LEV	−0.0056*** (−8.05)	−0.0053*** (−15.24)	−0.0055*** (−11.54)	−0.0041*** (−6.65)	−0.1066*** (−57.94)
LIQ	−0.3936*** (−17.96)	0.0305*** (5.49)	−0.0139 (−1.35)	−0.3920*** (−18.42)	0.2760*** (55.85)
CLR	−0.0470*** (20.45)	0.0065*** (11.39)	−0.0142*** (−11.86)	−0.0421*** (−18.58)	0.0971*** (26.92)
Year FE	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included
N	28,625	28,625	28,625	28,625	28,625
R^2	0.125	0.084	0.045	0.112	0.966

*The t-values are given in parentheses. ***, **, and * represent the level of significance of parameters at 1% (p < 0.01), 5% (p < 0.05), and 10% (p < 0.1), respectively.*

the dynamic evolution of the green patent application of enterprises in every kind of SEZs and non-SEZs. The line of non-SEZs is at the bottom, and the gap with lines of SEZs is getting bigger, which indicates the advantage in green innovation of enterprises in SEZs, especially those in NHIDZs, which is relatively obvious compared to enterprises not in SEZs.

5.2 Baseline Regression Results

Column 1 of **Table 2** shows the effect of the policy of the SEZs on enterprises' green technology innovation. The SEZs can significantly promote the green technology innovation of enterprises in the zone. The coefficient of $Policy_{it}$ is 0.1702, which is statistically significant at 1%. This implies that, on

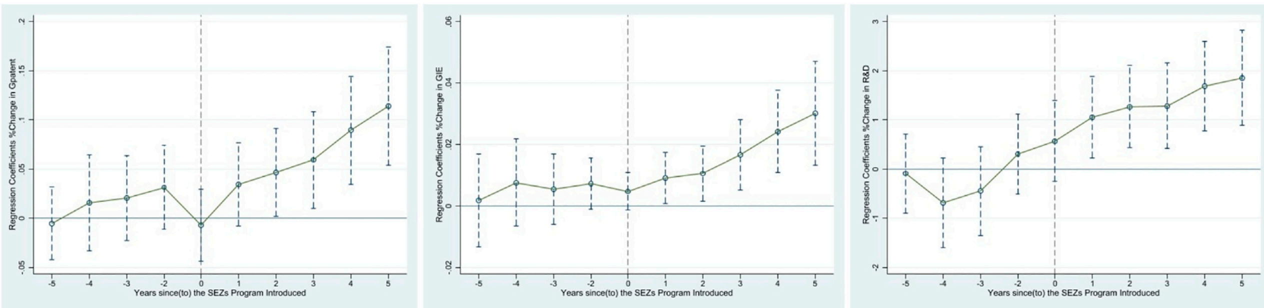

FIGURE 2 | Results of the parallel trend test.

average, compared with the enterprises not in SEZs, the number of green patent applications of enterprises in SEZs has increased by 17.02%. Columns 3 and 4 show that the SEZs boosted 6.11% of green invention patent applications and 15.68% of green utility model patent applications of enterprises in the zone, respectively. It indicated that the promotion of green utility model patents by the SEZs was higher than that of green invention patents. Column 2 of **Table 2** represented the impact of SEZs on the enterprises' green technology innovation efficiency. It can be found that SEZs have a positive effect to promote the innovation efficiency of the enterprises in the area, but the level of significance is not very strong (10%). Meanwhile, column 5 of **Table 2** shows that the SEZs significantly promote enterprises' R&D expenditure. The results revealed that the SEZs significantly promoted enterprises' green technology innovation. Although there is a positive effect on innovation efficiency, the significance is not strong, indicating that the SEZs have promoted enterprises' investment into green technology innovation, but the conversion rate of this innovation input still needs to be improved.

5.3 Test of Robustness

5.3.1 Parallel Trend Test

An important assumption for the assessment of the SEZs using the DID method is that the explained variables satisfy the parallel trend assumption between the treatment and the control groups. It means that the explained variables would have the same trend in both groups in the absence of the policy intervention. In other words, if there are no SEZs, the green technology innovation of the treatment group and the control group will not change significantly over time. Following Beck et al. (2010) and Wang (2013), this study uses the event to conduct a parallel trend test, which also allows for dynamic effects analysis to examine whether there are time lags and decay in the policy effects. The specific regression function can be written as follows:

$$\boldsymbol{y_{it}} = \boldsymbol{\alpha_i} + \boldsymbol{\beta_1 policy_{it}^{-5}} + \boldsymbol{\beta_2 policy_{it}^{-4}} + \ldots + \boldsymbol{\beta_9 policy_{it}^{4}} + \boldsymbol{\beta_{10} policy_{it}^{5}} + \boldsymbol{\gamma control_{it}} + \boldsymbol{\mu_{it}} + \boldsymbol{\delta_{it}} + \boldsymbol{\varepsilon_{it}} \tag{2}$$

where the explained variable y_{it} includes the green patent applications (Gpatent), the GIE, and the R&D expenses (R&D) in the benchmark regression. The $policy_{it}^{-j}$ denotes year t is the j-th year before firm i enters the SEZ, and the $policy_{it}^{j}$ denotes year t is the j-th year after firm i enters the SEZ. The dummy $policy_{it}^{-1}$ is omitted to avoid collinearity problems. Therefore, the parameter β identifies the causal effect of the SEZ program, assuming that setting up a SEZ affects outcomes up to 5 years before the program. Furthermore, α_i is a fixed effect that captures permanent differences and unobserved characteristics that might influence the explained variable. **Figure 2** illustrates the results of the parallel trend test. We found no significant difference between the treatment and the control groups; thus, the parallel trend test is passed. From an overall perspective, the green patent applications after the implementation of the SEZs are increasing year on year and are being influenced progressively by the policy.

5.3.2 Placebo Test

This paper further conducted a placebo test by constructing a pseudo-treatment group and a control group to rule out differences in green technology innovation between enterprises in SEZs and non-SEZs. From the overall sample of 1,795 enterprises, 796 enterprises were randomly selected as the treatment group, and other enterprises were used as the control group. Afterward, we make a regression analysis by adding control variables. The random sample was repeated 500 times to get precise results. **Figure 3** illustrates the distribution of the estimated coefficients of the 500 "pseudo-policy dummy variables" and the corresponding p-values, where the X-axis represents the magnitude of the estimated coefficients of the "pseudo-policy dummy variables", and the Y-axis represents the density values and p-values. The curve in **Figure 3** is the kernel density distribution of the estimated coefficients. The dots are the p-values corresponding to the estimated coefficients, and the vertical dashed line shows a true estimate (0.1702) of the time-varying DID model. Furthermore, it was found that the estimated coefficients obtained by 500 random processing are distributed nearly 0, and all p-values >0.1. It indicates that the effect of a placebo on dependent variables is not statistically significant. The

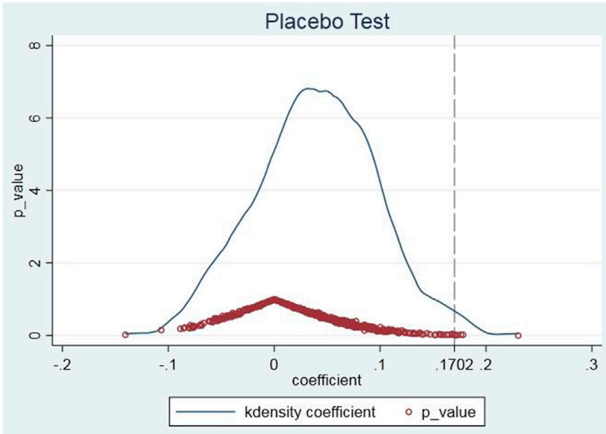

FIGURE 3 | Results of the placebo test.

results of the real DID regression analysis are reliable, and the robustness of the regression results is verified.

5.3.3 Heterogeneity Analysis

It was found that the SEZs can significantly promote the green technology innovation of enterprises, but the impact of the results on different types of SEZs, different regional types, and enterprise attributes needs to be further tested. To identify the heterogeneity of the policy effect of the SEZ construction, we have considered the following tests.

5.3.3.1 Differences in SEZ Type

Since different types of SEZs adopt different policy measures, the impact on enterprises' green technology innovation also differs to a certain extent. Therefore, we further distinguish the types of SEZs to estimate the differentiated impact of SEZs on enterprise innovation. Columns 1 and 2 of **Table 3** represent the results of an empirical analysis of the NETDZ. It was found that the establishment of NETDZ can promote the number of enterprise green patent applications that increased by 11.58% and also has a significantly positive impact on the innovation efficiency of enterprises. Columns 3 and 4 of **Table 3** shows the empirical analysis results of the NHIDZ and PDZs. It was found that the SEZs can significantly improve the green technology innovation level and innovation efficiency of enterprises in the zone, but there are differences to a certain extent. First, the number of green patent applications in PDZs has increased the most, which is higher than those of NHIDZs and NETDZs. Compared with national-level SEZs, provincial-level SEZs are the "main battlefield zone" for provincial-level governments to attract investment, and local governments attach great importance to them. At the same time, considering environmental pressures, local governments have higher environmental requirements for enterprises in provincial-level SEZs. Second, provincial-level SEZs have a significant contribution to the efficiency of green innovation. The reason might be that the level of R&D expenditure in PDZs is far lower than those of NHIDZs and NETDZs. According to the measurement method of innovation efficiency, the innovation efficiency of PDZs is higher and more significant.

5.3.3.2 Differences in Geographical Areas

Regional economic disparities are common in China. Since the reform and opening-up, the eastern and central regions have achieved rapid economic development, while other regions are comparatively slow to economic development. In general, China's economic development level decreases from east to west, with the south being higher than the north. On June 13, 2011, the National Bureau of Statistics divided China's economic regions into four regions, namely: Northeast, East, Central, and West. Specifically, the East region includes the 10 provinces and cities of Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The Central region includes the six provinces of Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The West region includes the 12 provinces and cities of Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The Northeast region includes three provinces, particularly Liaoning, Jilin, and Heilongjiang. Such economic differences can also affect the effectiveness of the implementation of SEZs. To better study the regional heterogeneity of SEZs, this study conducts a regression analysis of Gpatent on sub-samples. The results are given in **Table 4**. It was found that the SEZs have a heterogeneous impact on the enterprise green technology innovation of different regions. SEZs can significantly promote enterprise green technology innovation in the eastern and central regions. Specifically, the coefficients of policy (in columns 2 and 3 of **Table 4**) are positively and statistically significant. It indicates that SEZs can promote the green patent applications of enterprises in the eastern region and central region, which significantly increased by 17.49 and 21.99%, while the corresponding coefficients (in columns 1 and 4 of **Table 4**) are not statistically significant. This implies that, after controlling for other regional factors, the SEZs can significantly reduce the energy intensity in eastern regions but has no significant impact on the energy intensity in the central and western regions. The great differences in the economic development level in different regions make the subsidies and various preferential policies obtained by enterprises in the SEZs in different regions greatly different, which, in turn, lead to differences in the motivation of enterprises for green technology innovation.

5.3.3.3 Differences in Enterprise Ownership

There are differences in the types of ownership of enterprises in SEZs, including central state-owned, local state-owned, and private enterprises. There are significant differences in the policies and measures of the SEZs for enterprises with different ownership, and there are also differences in the responses of various enterprises to the policies of SEZs. Therefore, in this study, we estimate differences in the effects of the SEZs on

TABLE 3 | Test of heterogeneity.

	(1)	(2)	(3)	(4)	(5)	(6)
	Gpatent	GIE	Gpatent	GIE	Gpatent	GIE
	NETDZs		NHIDZs		PDZs	
Policy	0.1158***	0.0249**	0.1643***	0.0303*	0.1721***	0.0334***
	(2.71)	(1.98)	(2.63)	(1.87)	(5.86)	(3.93)
ASSET	0.1539***	0.0270***	0.1400***	0.0212***	0.1302***	0.0231***
	(12.63)	(8.93)	(9.36)	(6.60)	(12.43)	(8.53)
ROA	0.0319***	0.0052***	0.0304***	0.0043***	0.0225***	0.0035***
	(11.83)	(7.42)	(9.45)	(6.16)	(9.12)	(5.10)
LEV	0.0038***	−0.0010***	−0.0054***	−0.0013***	−0.0060***	−0.0015***
	(−4.26)	(−4.92)	(−5.06)	(−5.80)	(−7.22)	(−7.20)
LIQ	−0.4215***	−0.0687***	−0.3823***	−0.0533***	−0.3817***	−0.0636***
	(−14.39)	(−8.79)	(−11.69)	(−7.76)	(−15.03)	(−9.36)
CLR	−0.0515***	−0.0080***	−0.0488***	−0.0066***	−0.0455***	−0.0072***
	(−16.41)	(−9.61)	(−13.62)	(−7.85)	(−17.18)	(−9.80)
Year FE	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included
N	15,147	15,147	10,444	10,444	21,041	21,041
R^2	0.122	0.064	0.126	0.069	0.122	0.063

The t*-values are given in parentheses. ***, **, and * represent the level of significance of parameters at 1%* ($p < 0.01$)*, 5%* ($p < 0.05$)*, and 10%* ($p < 0.1$)*, respectively.*

TABLE 4 | Results of the regional heterogeneity analysis.

	(1)	(2)	(3)	(4)
	Northeast region	Eastern region	Central region	Western region
Policy	0.0070	0.1749***	0.2199***	0.1221
	(0.10)	(5.83)	(3.59)	(1.58)
ASSET	0.1760***	0.1281***	0.1265***	0.1688***
	(4.94)	(11.77)	(5.11)	(6.80)
ROA	0.0388***	0.0211***	0.0265***	0.0355***
	(4.19)	(8.63)	(4.63)	(6.38)
LEV	−0.0010	−0.0053***	−0.0081***	−0.0056***
	(−0.36)	(−5.94)	(−4.94)	(−3.18)
LIQ	−0.4418***	−0.3679***	−0.4340***	−0.4400***
	(−4.67)	(−13.35)	(−7.90)	(−8.02)
CLR	−0.0480***	−0.0427***	−0.0592***	−0.0515***
	(−5.11)	(−15.15)	(−10.46)	(−8.12)
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
N	1,518	18,105	5,101	3,901
R^2	0.101	0.117	0.157	0.133

The t*-values are given in parentheses. ***, **, and * represent the level of significance of parameters at 1%* ($p < 0.01$)*, 5%* ($p < 0.05$)*, and 10%* ($p < 0.1$)*, respectively.*

enterprises with different ownership; particularly, we focus on the green patent applications.

The results shown in **Table 5** depict that the SEZs significantly improved the green technology innovation level of all three types of enterprises. Specifically, the SEZs increase the green patent applications of central state-owned enterprises, local state-owned enterprises, and private enterprises to 30.95, 15.62, and 16.40%, respectively. Therefore, the SEZs have the highest impact on central state-owned enterprises, followed by private enterprises, and finally state-owned enterprises. Moreover, this study distinguishes the types of patent applications as green invention patents and green utility model patents. For central state-owned enterprises, the SEZs increase the number of green invention patent applications by 20.78% and the number of green utility model patent applications by 20.49%. For local state-owned enterprises, the SEZs increase the number of green utility model patent applications by 15.98%. For private enterprises, the SEZs increase the number of green invention patent applications by 5.70% and the number of green utility model patent applications by 15.53%. Unlike central state-owned enterprises, local state-owned enterprises and private enterprises accounted for a larger proportion of the total number of green utility model patents. It is easier to apply for green utility model patents than green invention patents. It can be inferred that local state-owned enterprises and private enterprises in SEZs might seek subsidies with more low-quality inventions.

TABLE 5 | Results of the heterogeneity of enterprise ownership.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Gpatent	Gpatent_i	Gpatent_u	Gpatent	Gpatent_i	Gpatent_u	Gpatent	Gpatent_i	Gpatent_u
	Central state-owned enterprises			Local state-owned enterprise			Private enterprise		
Policy	0.3095***	0.2078**	0.2049**	0.1562***	0.0275	0.1598***	0.1640***	0.0570***	0.1553***
	(2.70)	(2.50)	(2.27)	(2.79)	(1.07)	(2.88)	(6.12)	(3.38)	(5.88)
ASSET	0.1697***	−0.0372	0.1966***	0.1653***	−0.0090	0.1713***	0.1169***	−0.0152***	0.1296***
	(4.32)	(−1.63)	(5.26)	(8.20)	(−0.81)	(8.66)	(11.89)	(−3.02)	(13.14)
ROA	0.0508***	0.0141**	0.0461***	0.0365***	0.0112***	0.0312***	0.0165***	0.0025**	0.0150***
	(5.66)	(2.43)	(5.63)	(8.13)	(4.17)	(7.56)	(7.54)	(2.01)	(7.34)
LEV	−0.0100***	−0.0093***	−0.0080***	−0.0063***	−0.0059***	−0.0048***	−0.0050***	−0.0049***	−0.0035***
	(−3.23)	(−4.37)	(−3.09)	(−4.73)	(−5.45)	(−3.91)	(−6.27)	(−9.84)	(−4.92)
LIQ	−0.6083***	−0.0472	−0.5848***	−0.4051***	−0.0207	−0.3876***	−0.3474***	−0.0019	−0.3581***
	(−6.77)	(−0.94)	(−6.79)	(−9.00)	(−0.91)	(−8.93)	(−13.97)	(−0.18)	(−14.66)
CLR	−0.0819***	−0.0240***	−0.0750***	−0.0502***	−0.0170***	−0.0431***	−0.0388***	−0.0106***	−0.0354***
	(−9.16)	(−4.82)	(−8.85)	(−10.52)	(−7.37)	(−9.22)	(−15.18)	(−7.67)	(−13.78)
Year FE	Included	Included	Included	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included	Included	Included	Included
N	2,813	2,813	2,813	7,005	7,005	7,005	18,807	18,807	18,807
R^2	0.197	0.095	0.175	0.128	0.050	0.116	0.117	0.037	0.104

The t*-values are given in parentheses. ***, **, and * represent the level of significance of parameters at 1% (*p *< 0.01), 5% (*p *< 0.05), and 10% (*p *< 0.1), respectively.*

5.4 Mechanism of Preferential Policy and Agglomeration Effect

In this article, we further explored the impact mechanism of SEZs based on two perspectives, particularly, the preferential policy effect and the agglomeration effect using the regression function as follows:

$$\boldsymbol{GreenInnov_{it}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 Policy_{it}} + \boldsymbol{\delta Policy_{it} * Mech_{it}} + \boldsymbol{\varnothing control_{it}} + \boldsymbol{\gamma_t} + \boldsymbol{\mu_i} + \boldsymbol{\varepsilon_{it}} \tag{3}$$

where Mech_{it} represents the proxy variables of mechanisms; the definitions of other variables are already provided in **Eq. 1**. The preferential policy effect is represented by subsidy and taxp; particularly, subsidy denotes government subsidies received directly by the enterprise, and taxp denotes the tax preference for enterprises in SEZs. Following Liu (2016), it can be estimated as taxp = tax rebates/(tax rebates + taxes paid).

The realization of the agglomeration effect requires not only an increase in the number of enterprises but also an expansion of the scale of the industry. Following Lin et al. (2018), the agglomeration effect can be represented by firm_cluster and ind_agglom, where firm_cluster denotes the number of enterprises clustered in SEZs, and ind_agglom denotes the industrial agglomeration caused by clustering of enterprises within the same industry.

The results are given in **Table 6**. For the policy effect, it was found that the coefficients of Policy * subsidy and Policy * taxp are positive and statistically significant. Meanwhile, for the agglomeration effect, the coefficients of Policy * firm_cluster and Policy * ind_agglom are not significant. The results indicate that SEZs promote the green innovation of enterprises by the preferential policy effect, while the agglomeration effect has no significant role in the promotion of green innovation.

5.5 Analysis of the Lagging Effect of the Agglomeration Effect

It was found that the agglomeration effect is not statistically significant to promote green innovation in the short term (**Table 6**). Therefore, we further focused on the lagging effect of the agglomeration effect by incorporating the lagged terms of the explanatory variables into the regression function (**Eq. 3**). The superscript indicates the number of lag terms, *e.g.*, Policy $^{*}\text{firm\_cluster}^{1}$ denotes the Lag of Policy * firm_cluster by one period.

The results of **Table 7** found that the agglomeration effect of the SEZs has an obvious lag effect. Compared with the agglomeration effect represented by the industry association of enterprises, the agglomeration effect represented by the entry of enterprises is consistent with our intuition because, after the establishment of the SEZs, the policy of attracting investment will attract a large number of enterprises to settle in. The number of enterprises will increase rapidly, but there is no guarantee that these enterprises are in the same industry. Therefore, the industry association of enterprises will play a strong agglomeration effect after the three-phase lag. For different types of SEZs, the conclusions are consistent with the results of the overall analysis, but there are also differences, mainly reflected in the time differences in the agglomeration effect. Moreover, the results confirmed that there is a lag in the agglomeration effect of SEZs. Therefore, in the process of giving play to the role of SEZs in promoting green technology innovation, we should not only pay attention to the short-term effects brought about by subsidy policies but

TABLE 6 | Analysis of mechanism: the preferential policy and the agglomeration effect.

	(1)	(2)	(3)	(4)
	Gpatent	Gpatent	Gpatent	Gpatent
	The preferential policy effect		The agglomeration effect	
Policy	0.0753***	0.1448***	0.1191**	0.1590***
	(3.33)	(6.00)	(2.53)	(5.98)
Policy* subsidy	0.0140***			
	(9.67)			
Policy* taxp		0.2378***		
		(3.45)		
Policy * firm_cluster			0.0292	
			(1.37)	
Policy *ind_agglom				0.0125
				(1.30)
control	Included	Included	Included	Included
Year FE	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included
N	28,625	28,625	28,625	28,625
R^2	0.127	0.127	0.125	0.125

The t-*values are given in parentheses. *** and ** represent the level of significance of parameters at 1%* (p *< 0.01) and 5%* (p *< 0.05), respectively.*

TABLE 7 | The lagging effect of agglomeration effect in promoting enterprise green technology innovation.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SEZs		NETDZs		NHIDZs		PDZs	
Policy*firm_cluster^1	0.0279***		−0.0287		0.1316**		0.0188*	
	(3.44)		(−1.31)		(2.42)		(1.94)	
Policy*firm_cluster^2	0.0406***		0.0257		0.1376**		0.0299***	
	(4.78)		(0.96)		(2.56)		(2.78)	
Policy*firm_cluster^3	0.0238**		0.0597*		0.1629**		0.0372***	
	(2.47)		(1.90)		(2.55)		(3.26)	
Policy*firm_cluster^4	0.0560***		0.1121***		0.2120***		0.0552***	
	(5.09)		(3.37)		(3.25)		(3.92)	
Policy*firm_cluster^5	0.0931***		0.1766***		0.3794***		0.1723***	
	(7.75)		(4.99)		(5.82)		(10.49)	
Policy*ind_agglom^1		0.0115*		0.0720*		0.0119		0.0188**
		(1.81)		(1.79)		(0.33)		(2.15)
Policy*ind_agglom^2		0.0130*		0.0885*		−0.0198		0.0230**
		(1.73)		(1.90)		(−0.69)		(2.24)
Policy*ind_agglom^3		0.0139**		0.1558**		−0.1166***		−0.0009
		(2.01)		(2.16)		(−2.70)		(−0.09)
Policy*ind_agglom^4		0.0217**		0.1841***		0.0213		0.0020
		(2.30)		(2.74)		(0.32)		(0.17)
Policy*ind_agglom^5		0.0854***		0.2973***		0.1658**		0.0489***
		(7.23)		(3.50)		(2.57)		(3.51)
control	Included	Included	Included	Included	Included	Included	Included	Included
Year FE	Included	Included	Included	Included	Included	Included	Included	Included
Firm FE	Included	Included	Included	Included	Included	Included	Included	Included
N	28,625	28,625	15,147	15,147	10,444	10,444	21,041	21,041
R^2	0.130	0.012	0.131	0.008	0.028	0.108	0.035	0.105

The t-*values are given in parentheses. *** and ** represent the level of significance of parameters at 1%* (p *< 0.01) and 5%* (p *< 0.05), respectively.*

also pay attention to the long-term effects of the agglomeration effects of SEZs.

6 CONCLUSION

To assess the green development promotion effect of the SEZs, this study adopted a quasi-natural experiment method to empirically investigate the impact of the SEZs on the green technology innovation of enterprises based on the microdata of Chinese listed companies and green patent application data. The results relieved the following conclusions:

The SEZs significantly promoted the green technology innovation of enterprises. Overall, the number of green patent applications of enterprises in the zone has increased by 17.02%. In terms of classification, the number of invention patent applications has increased by 6.11%, and the number of utility model patent applications has increased by 15.68%.

From the perspective of the types of SEZs, both the establishment of NETDZs and NHIDZs promoted the improvement of the level of green technology innovation.

From a regional perspective, the green innovation promotion effect was mainly reflected in the central and eastern regions.

From the perspective of enterprise ownership, the SEZs have increased the green patent applications of central state-owned enterprises by 30.95%, while the improvement of local state-owned enterprises and private enterprises is relatively lower.

Moreover, in the short term, the green innovation promotion effect of the SEZs mainly derived from the preferential policy effect rather than the agglomeration effect. The agglomeration effect has a certain lag, but in the long run, the promoting effect of green technology innovation will become more significant.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

XL contributed to conceptualization, methodology, formal analysis, and writing—original draft and editing. JZ contributed to investigation, data curation, methodology, and software. TL contributed to conceptualization, project administration, funding acquisition, and writing—review and editing. XZ contributed to supervision, validation, and visualization. All authors contributed to manuscript revision and approved the submitted version.

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