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Achieving carbon neutrality: How does the construction of national high-tech zones affect the green innovation of enterprises? Based on quasi-natural experiments in pilot areas in China

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From the standpoint of green patents, verifying the influence of the construction of national high-tech zones on the degree of green innovation of enterprises is of enormous theoretical and practical importance. We construct a multi-period two-difference model to assess the influence of the national high-tech zone policy's implementation on enterprises' levels of green innovation. The outcomes of the study show that: first, the establishment of national high-tech zones greatly increases the level of green innovation among enterprises. While the effect on green and practical patents is average, the effect on green invention patents is more obvious. Second, how enterprises in national high-tech zones promote green innovation varies significantly. Promotional effects are more prominent in Tier 1 and Tier 2 regions, non-state firms, and high-tech industries with significant economic development. State-owned enterprises, non-high-tech industries, and third-tier and lower-tier regions, on the other hand, fared brilliantly. Third, additional action mechanisms show that the establishment of national high-tech zones can contribute to the institutional environmental effects of enterprises and the concentration of green innovation elements, thereby realizing regional green innovation development. Thus, our research provides an empirical foundation for stimulating the formation of national high-tech zones, increasing firms' ability to innovate on their own, and nurturing the long-term growth of national high-tech zones and associated businesses.

KEYWORDS

carbon neutrality, national high-tech zone, corporate green innovation, double difference model, government policies

1. Introduction

China's economy has grown continuously and steadily, resulting in the awareness of green development becoming an important concept that influences contemporary social and economic development (Su and Fan, 2022; Wang and He, 2022). The green industry has become a major development trend with the continuous integration of green concepts into the development of the industry (Midttun et al., 2022). The national high-tech zone, which serves as a pilot zone to encourage technological innovation and green development, is a vital technical support for green development. To promote green development, scientific and technological innovation must be coupled (Xie et al., 2018; Lu et al., 2020). They complement each other, are mutually advantageous, are coupled and facilitated, and promote high-quality economic development together (Li et al., 2021; Wu et al., 2022).

The goal of green innovation differs from other forms of innovation in that it emphasizes resource allocation and organizational innovation. Besides the spillover effects of innovation activities themselves (such as technology spillovers and knowledge externalities), green innovation is also characterized by environmental benefits that distinguish it from general innovation. Externalities caused by external environmental costs are also referred to as externalities (Chava, 2014; Qiao et al., 2019). Green innovation outcomes meet the criteria of environmental, economic, and social performance, which has a dual externality (Wang et al., 2022). They have an impact not only on how successfully enterprises perform but also on how severely the environment is impacted (Takalo and Tooranloo, 2021). Furthermore, this may potentially have a positive effect on society, which would benefit everyone.

China's carbon neutrality target provides more effective impetus and support for green innovation and development. The national high-tech zone's resources for scientific and technological innovation serve to improve the environment and provide a solid support for fostering green growth. Given the development of the new normal, the study of how to use national high-tech construction as an important carrier for innovation-driven, and then enhance the green operation level and green competitiveness of local enterprises, is of considerable theoretical and practical value (Ding H. et al., 2022). This article begins by looking at enterprise green patents to see if the construction of national high-tech zones may improve the degree and role of green innovation in businesses in the process of boosting the implementation of innovative development strategies. This analysis is significant in terms of reference and illumination for further understanding the future development direction and positioning of national high-tech zone building.

2. Literature review

Several research findings on the connection between the growth of national high-tech zones and enterprise green innovation can be found throughout the body of current literature, with the following elements gaining the most attention.

First, a study of the impact of national high-tech zone development on implementation. Academics both domestically and abroad have studied the establishment of the national high-tech zone as an important step for the enhancement of the national innovation development and the promotion of regional economic transformation. The first step is to investigate the significance and purpose of the location. As an example, Hu et al. (2021) analyzed the influence of land use change at different stages of the life cycle. According to some scholars, allotting resources efficiently and improving innovation ability can be significantly improved by establishing high-tech industrial zones (Xi and Mei, 2022). From the perspective of urban innovation, the establishment of national high-tech zones is a choice that conforms to the times and has an important impact on improving the development of urban innovation system (Luo and Shen, 2022). The second step is to assess the impact on its development. Some scholars classified and expanded on the concept, status, authority, and functions of China's administrative management system for high-tech zones, and they recognized the path of innovation (Zheng and Li, 2020). We should build a scientific evaluation index system to support the growth of national high-tech zones, to develop a world-class science park (Xie et al., 2018). Last but not least, academics have performed substantial research on the construction effect. One example is the employment of a method based on dynamic network relaxation assessment to assess the performance of China's national high-tech businesses (Bai et al., 2015). From the aspect of industrial structure, the construction of national high-tech zones will have a substantial influence on the modernization and transformation of regional industrial structure, and this impact will have a varied growth cycle. Relevant academics' discussions of the influence of high-tech zones on the degree of urban innovation, enterprise innovation performance, and regional green economic growth improved relevant analysis on the establishment of national high-tech zones (Shafique, 2013; Kong et al., 2021; Zhao et al., 2022).

Second, research on the measurement and influencing factors of enterprise green innovation. Green innovation can also be achieved by emphasizing technological innovation, which is most intuitively reflected in improved enterprise productivity, which can be measured by enterprise production efficiency. In addition, enterprises' innovation activities differ in terms of input and generation of innovation due to their diversity. Researchers construct theoretical models to analyze the interaction between environmental regulation and corporate green innovation. At the same time, the number of enterprise green patents and green invention patents is used to reflect the strength of enterprises' green innovation capabilities. Through research, it has been found that environmental regulations can effectively play a role in promoting it (Qiao et al., 2022; Xie and Teo, 2022). Some scholars have studied the relationship between environmental regulation, enterprise green technology innovation and green management innovation from the perspective of strategic flexibility and regional differences, and have confirmed that the impact of different variables is also different (Zhou, 2006). Some scholars, however, take a breakthrough or progressive approach to innovation, which not only emphasizes the importance of breaking through existing products, technologies, and services to develop enterprises but also pays attention to the transformation of products and technologies (Lian et al., 2022). According to relevant scholars, enterprise green innovation is affected primarily by factors such as the market, environmental policy, government, and environmental regulation (Du et al., 2022; Su et al., 2022). A targeted analysis of enterprise green innovation development and solutions was conducted by Weng et al. (2022).

According to the research literature currently available, relevant research on the construction of national high-tech zones and enterprise green innovation is relatively fruitful, and some scholars look into how the creation of national high-tech zones affects the effectiveness of urban green innovation at the local level (Park and Lee, 2004). Few authors have looked at the effects of national high-tech zone policies on green transformation and enterprise innovation development from the perspective of green development, though some scholars have studied the effects of national high-tech zone establishment on enterprise innovation performance. The twofold difference approach is utilized to assess its impact on enterprise green innovation levels, and its mechanism of action to improve enterprise green innovation is examined. Consequently, utilizing panel data from China's A-share listed businesses and prefecture-level cities from 2005 to 2019, this research focuses on the green growth effect caused by the establishment of national high-tech zones.

Some of the potential contributions of this paper include: (1) Taking the pilot construction of the national high-tech zone as a quasi-natural experiment, starting from the perspective of green development and change, the impact of the national high-tech zone on the green innovation of enterprises is mainly considered, so as to enrich the relevant research work of micro-enterprises. (2) Enterprise green patent data is used to reflect the amount of green innovation in enterprises. For analysis, green patents are subdivided into enterprise utility model patents and green invention patents to illustrate the differences between different innovation outputs and inputs. (3) Make an effort to consider the innovation-driven influence of high-tech zone creation on business growth, and investigate how it influences enterprise green innovation from the standpoints of factor agglomeration, innovation-driven capability, and the impact of transaction costs imposed by the institutional environment. (4) In addition to an examination of the influence of various influencing factors on the growth of enterprise green innovation development, several effects of the establishment of national high-tech zones are examined.

3. Theoretical mechanisms and research assumptions

The creation of pilot national high-tech zones is crucial for fostering the adoption of creative development strategies and attaining high-quality regional development. It is a crucial component of the central development location-oriented policy. Enterprise innovation activities are inextricably linked to the promotion of regional high-tech development. Therefore, the creation of the national high-tech zone has improved the ability of businesses to innovate independently by creating a good innovation environment for them. It is also useful for expanding green production technology and carrying out innovative activities with the twin goals of economic and environmental benefits, to achieve low-carbon development in the area, as a result of utilizing creative technologies and methods (Petrescu et al., 2016; Wang and Zhi, 2016). The formation of high-tech zones, according to theory, can enable the flow of innovation factor resources between regions, have effects on enterprise development that are driven by innovation, and be managed at the institutional level, as indicated in the following parts (Wang et al., 2022).

3.1. Factor agglomeration and enterprise green innovation

The establishment of national high-tech zones may increase green innovation in enterprises by improving the agglomeration effect. The establishment of high-tech zones can provide regulatory benefits to high-tech enterprises, attract the necessary talent, capital, and other resources to construct a certain scale of agglomeration, and ultimately boost the rate of regional technological growth (Ding J. et al., 2022a,b). While high-tech zones are being developed, encouraging the growth of local green innovation by focusing on increasing human capital and information sharing is a more straightforward approach. The construction of the national high-tech zones can create an advantageous condition for the growth of both high-tech and non-high-tech industries, ensure the normal flow of resources between various business types, and boost the area's human capital stock while achieving the rational allocation of resources in various industries, thereby resolving the issue of the region's lack of stamina for enterprise development (Jiang et al., 2023). On the other hand, it helps to increase the efficiency with which enterprises use their resources, as well as to realize gains in talent development and labor quality by raising business levels of high technology and high knowledge. Finally, these zones contribute to the aggregation of elements and the exhibition of diverse industrial parks, which increases the level of technical advancement of firms (Liu et al., 2022).

As factor endowment rises, the influence of environmental regulation on company innovation efficiency will diminish. At the moment, China's misallocation of scientific and technology resources is most visible in three areas: first, a severe lack of investment in basic research, a low proportion of investment in enterprises, and insufficient investment in traditional sectors (Kuang et al., 2022). Second, despite China's overall abundant liquidity, the misallocation of financial resources makes it difficult and costly for small businesses to obtain capital (Morazzoni and

Sy, 2022). The financial sector does not efficiently support the capital required for the transformation and upgrading of old businesses, as well as the creation and expansion of emergent industries, making real-economy development challenging. Finally, the misallocation of human resources manifests itself in the phenomena of overinvestment in the financial and virtual economy industries. Pilot construction policy construction of high-tech zones effectively addresses the issue of low efficiency caused by factor mismatch, consequently improving company green innovation efficiency (Zhang et al., 2023).H1:The factor agglomeration effect generated by the construction of the national high-tech zone promotes the green innovation of enterprises.

3.2. Institutional environment and enterprise green innovation

The establishment of national high-tech zones may raise the amount of green innovation in enterprises by establishing institutional environmental implications. The foundation for the construction of the national high-tech zone, an industrial agglomeration park, was laid by the government's industrial policy, which is increasingly impacted by policy assistance (Liu et al., 2022). To function, develop, and compete in the market, related businesses must have accurate market information, and the resulting transaction costs will increase unproductive spending. The high-tech zone policy can stimulate the improvement and growth of the regional institutional environment, as well as an improvement in innovation efficiency and collaborative invention development, resulting in lower business transaction costs and production costs (Zhou et al., 2021). The creation of high-tech zones has boosted the competitiveness of high-tech enterprises and encouraged commercial potential for green innovation. However, to promote the influence of the institutional environment and achieve green innovation and development across the entire region, non-high-tech industries must continue to fully exploit the policy dividends provided by the high-tech zone policy (Lu et al., 2022).

Only endogenous independent innovation, according to the notion of innovation-driven economic growth, is the major driver of technological advancement and economic prosperity. Exogenous technology introduction and imitation cannot become a long-term stable driver driving economic growth (Qiao et al., 2022). To address China's severe resource and environmental issues, high-tech zones were established as an institutional guarantee of the country's autonomous innovation and to assist in the greening of the economy more quickly and cheaply. The creation of the national high-tech zone has significantly increased China's green technology and industry's international competitiveness with the aid of a steadily improving green innovation guarantee system and supporting policy system. Green innovation is the integration of the two development concepts of green and innovation. Furthermore, by developing high-tech zones, a strong government can effectively mitigate the consequences of market demand and return rate uncertainty, while also increasing company enthusiasm for green innovation (Xie et al., 2022). This is primarily because establishing high-tech zones reduces the cost of enterprise end-to-end governance and production legality, as well as the environmental impact of manufacturing. Furthermore, fewer resources are used at the source, immediately reducing the number of pollutants discharged.H2:Optimizing the high-tech zone's institutional environment promotes enterprises' green innovation.

3.3. Economic development and enterprise green innovation

Green innovation has a public attribute due to its stronger emphasis on the characteristic of resource allocation than other firm innovation activities (Hu et al., 2021). This is accomplished by emulating a strategic sense of corporate social responsibility and principles. Economic development will unavoidably have an influence on company green innovation because it is the primary component of economic activity. While manufacturing generates huge wealth, the traditional economic development model also presents several difficulties such as resource depletion, environmental degradation, and the greenhouse effect (Li et al., 2022). Carbon emissions are principally caused by the use of energy and materials at each stage. As a result, under the normal economic development model, enterprises' efforts to innovate in a greener manner will be hampered (Wang et al., 2022).

In some ways, China's economic development success comes at the expense of the environment, resource scarcity, and environmental pollution, exacerbating concerns with fragile environments, lengthy economic growth models, and environmental oversight during the Chinese economic development process. As a result, the disparity between resource and environmental constraints and economic expansion has grown more pronounced (Zhang et al., 2020). Green manufacturing through corporate green innovation is a significant goal and development paradigm for achieving sustainable and high-quality development. Green manufacturing practices are used to ensure a product's functioning, quality, and cost, as well as its overall environmental effect and resource efficiency. Finally, ensure that the product's entire life cycle produces no pollution or produces as little as possible (Lin and Ma, 2022). The National High-tech Zone has achieved high-quality innovation-driven economic development, promoting the establishment of innovative firms, through a variety of governmental supports and a comprehensive infrastructure. In addition to stimulating and promoting environmental protection production technology in enterprises, the establishment of high-tech zones can provide new opportunities for green transformation and business development, as well as achieve coordinated development of economic and environmental benefits in the process of ongoing innovation and development.H3:The positive correlation between the construction of national high-tech zones and the level of green innovation of enterprises gradually increases with economic development.

The specific research logic of this paper is shown in Figure 1.

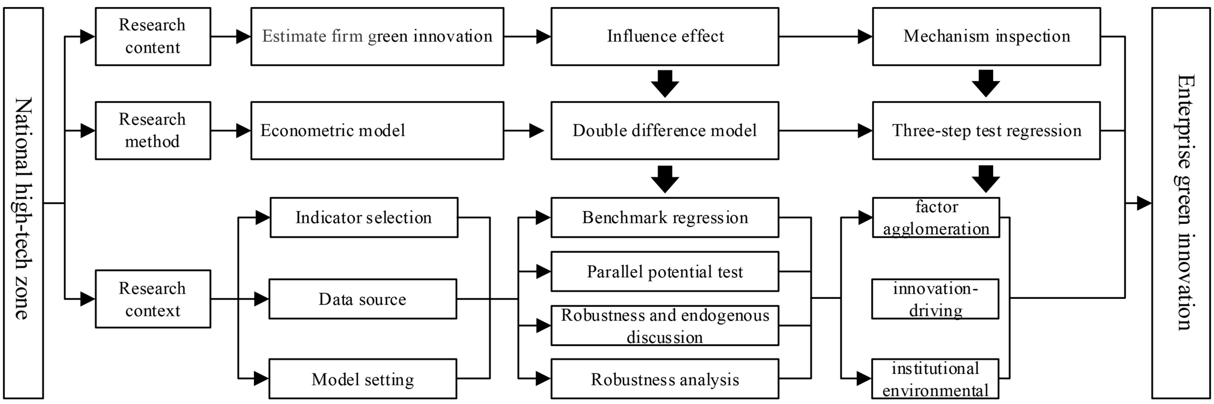

FIGURE 1
The research logic of this article.

4. Research design

4.1. Two-difference model

To assess the influence of policy implementation on company green innovation, this study employs a double difference model based on establishing national high-tech zones. The experimental and control groups were formed using the criterion "if the policy is implemented, "and the policy's implementation was treated as a dummy variable. Because the national high-tech zone pilot is built in batches, using a single time point twofold difference model may result in incorrect experimental results. Using predecessors' research approaches, a multi-period twofold difference model is developed for in-depth examination (Beck et al., 2010). Here is the precise model:

$$\ln \text{patent}_{it} = \alpha_0 + \alpha_1 du \times dt + \alpha_2 \text{Control}_{it} + \mu_{it} + \lambda_{it} + \varepsilon_{it} \quad (1)$$

where i and t reflect the corresponding enterprise and year, patent_{it} reflects the company green innovation, and $du \times dt$ is a dummy variable for policy implementatio. Control_{it} reflects control variables that affect the variable being explained, $\propto$ and λ represent individual and year fixed effects and ε represents random error terms.

Furthermore, there is no direct comparison between established and unestablished areas of the national high-tech zone. To avoid the estimation error caused by the use of the double difference model and to enhance the comparability of the two, the establishment of a national high-tech zone in the location of the enterprise and the location of the enterprise without the establishment of a national high-tech zone are thus matched using the double differential tendency score matching method. This work refers to previous research methodologies to set the PSM-DID regression model (Holtz, 2012; Zhang et al., 2022).

$$\ln \text{patent}_{it}^{PSM} = \beta_0 + \beta_1 du \times dt + \beta_2 \text{Control}_{it} + \mu_{it} + \lambda_{it} + \varepsilon_{it} \quad (2)$$

4.2. Description of the relevant variable

Explanatory variable: Corporate Green Innovation (*pat*). This study refers to the International Patent Commission's (IPC) classification of environmentally friendly patented technology and draws on forerunners' research tactics to reflect the firms' level of green innovation. Improving enterprise green innovation can lower the amount of input created by polluting intermediates (Zhou and Qi, 2022). It is further subdivided for study into green utility model patents (*pat-ut*) and green invention patents (*pat-in*).

Core explanatory variables: policy dummy variables ($du \times dt$). The policy dummy variable in this study is the location of pilot areas, the experimental group is businesses in the high-tech zone, and the corresponding dummy variable is 1; businesses in non-high-tech zones are employed as control groups, and their corresponding dummy variables are 0. This conforms to the standards of national policy papers. To reflect the entire impact of policy implementation, the policy dummy variable interaction items are generated concurrently following the national high-tech zone's establishment time.

Control variables: This article chooses variables that have a strong link with enterprise green innovation to minimize the influence of missing variables on model regression findings. (1) The company's size as assessed by total assets in the most recent fiscal year. (2) Return on net assets (*roe*), calculated by dividing the current fiscal year's total net assets by the after-tax earnings. (3) The asset-liability ratio is calculated by dividing the company's total liabilities by its total assets for the current fiscal year (*lev*). (4) The company's age, as evidenced by its formation date. (5) The enterprise's intensity of R&D investment (*rd*) is defined by the proportion of R&D spending in total operating income in the current year.

4.3. Data source

Given the difficulty in getting micro-enterprise data, this research draws its sample from Chinese A-share listed enterprises from 2005 to 2019. The relevant data for listed firms is primarily sourced from the Guotai An (CSMAR) database, while the patent data is derived from the State Intellectual Property Office's patent databases and the China Urban Statistical Yearbook, among other sources, and is manually collected. Simultaneously, the listed enterprise registration location information is matched with the regional information involved in the establishment of the national high-tech zone to get correct sample matching data. During the sample data processing, the relevant data of ST, *ST listed firms, and financial institutions were eliminated, and some of the sample data with missing financial information and research variables were excluded, yielding a total of 32,505 sample observations. Furthermore, for the sake of research, the sample data in 2005 were treated at constant valence, and all data were logarithmized to lessen the volatility of the regression results.

5. Analysis of empirical results

5.1. Benchmark regression analysis

The double difference approach is used in this study to empirically examine the net effect of the implementation of the pilot policy before employing the strategy of gradually adding control variables to perform regression. Table 1 displays the regression results under the theoretical analysis and empirical model development discussed previously.

The two-difference model's fundamental regression findings are shown in Table 1, The regression coefficient of the policy dummy variable is initially importantly positive regardless of whether the control variable is included in the regression model, and it rises with the addition of the control variable, showing that the creation of the national high-tech zone plays a role in fostering regional green growth and thereby enhancing enterprise levels of green innovation. Green patents are further divided into green invention patents and green utility model patents to explicitly investigate the impact of the establishment of national high-tech zones on firms' capacity for green innovation. While the implementation of the national high-tech zone policy is significantly beneficial for green utility model patents at the 10% level, it is not significantly beneficial for green invention patents at the 5% level, demonstrating that the influence of national high-tech zone creation on internal enterprise green innovation is not uniform. This could be because the current system emphasizes the volume and intensity of innovation input while allowing little room for the transfer of innovation input from theory to practice. Furthermore, this indicates how invention-based patent innovation can be used to stimulate corporate innovation and growth more efficiently.

The firm's scale and return on net assets are two crucial control variables that have a substantial influence on how innovatively green an enterprise is. This means that as a company's development scale grows, so do its productive benefits and labor force profitability, ensuring that the company has the resources it needs to engage in innovative activities. Corporate R&D investment is also an important factor in supporting corporate green innovation, green utility model patents, and green invention patents. This emphasizes the need of investing in innovation. The asset-liability ratio and enterprise age both harm corporate green innovation.

5.2. PSM-DID-based inspection

Given that there may be variances in the sample data due to changes in regional conditions during the execution of the national high-tech zone program. It is critical to compare the experimental and control groups' sample data, compute the required propensity score value using the Logit regression model,

TABLE 1 Regression results of the baseline model.

Variable	*pat*		*pat-in*		*pat-ut*	
	(1)	(2)	(3)	(4)	(5)	(6)
du × *dt*	0.143*** (2.68)	0.112*** (3.31)	0.191** (1.99)	0.225** (2.05)	0.526* (1.75)	0.048* (1.83)
lnsize		0.258** (2.35)		0.148*** (2.88)		0.089** (2.18)
lnroe		1.248** (2.40)		0.948* (1.80)		1.496** (2.30)
lnlev		−0.585*** (−3.36)		−0.080*** (−2.63)		−0.108** (−2.18)
lnage		−0.325* (−1.82)		−0.093** (−2.37)		−0.175** (−2.07)
lnrd		0.105** (1.98)		0.148* (1.78)		0.082** (2.42)
Time	YES	YES	YES	YES	YES	YES
Individuals	YES	YES	YES	YES	YES	YES
N	32,505	32,505	32,505	32,505	32,505	32,505
R^2	0.692	0.718	0.725	0.705	0.882	0.792

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

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and run the related balance test with the covariate. From Table 2, the overall findings of the sample data after matching suit the balancing assumption, and the lack of substantial disparities between the matched variables further supports the accuracy of the matching results. As can be shown after matching the sample data, the execution of the national high-tech zone policy has a considerable influence on raising the degree of green innovation among firms. The significant coefficient is likewise noticeably higher, and the promotion effect on green invention patents is stronger than the promotion effect on green utility model patents. This supports the veracity of the previous findings.

5.3. Robustness test and endogeneity discussion

Various strategies are used to measure robustness to corroborate the veracity of previous empirical results. The percentage of enterprise green patents in total patent numbers is used as a substitution variable to quantify enterprise green innovation, which allows the influence of major explanatory variables on the numerator and denominator to be separated. This substitution variable method is first used, based on predecessors' research concepts (Popp, 2006). The regression test results are shown in column (1) of Table 3, and it reflects that even after adjusting for substitution variables, the implementation of the national high-tech zone policy still has a high promotion influence on the level of green innovation of enterprises, confirming the rationality of variable selection. As a result, the explanatory variables will be treated with a lag period and regressed again. The test results are shown in column (2) of Table 3, and the regression results demonstrate that the coefficient between the lagging period of the national high-tech zone policy's dummy variables and the green innovation level of enterprises is positive. Finally, regression is performed using the Tobit model, and analysis is performed using the approach of substituting the econometric model. The regression data is shown in column (3) of Table 3, demonstrating that the research results are still credible. The study's findings were determined to be trustworthy.

The issue of missing data and the reverse causal link between variables are the two main points of controversy regarding the model's endogeneity. As a result, the model's endogeneity is further assessed using the two-stage least squares method (2SLS). Lagging panel data can be used to process tool variable choices. The lag periods of the national high-tech zone policy's dummy variables and two lag period data are chosen as the paper's tool variables. The regression results of the model are shown in column (4) of Table 3, and both the LM and F statistics show significant findings. Furthermore, the results of Hasen's test illustrate the utility of the instrumental variables, overcoming the model's endogeneity problem.

TABLE 2 Regression test results of PSM-DID.

Variable	*pat*	*pat-in*	*pat-ut*
$du \times dt$	0.412*** (3.48)	0.247** (2.23)	0.178* (1.94)
Control variables	YES	YES	YES
Fixed time	YES	YES	YES
Fixed individuals	YES	YES	YES
N	32,086	32,086	32,086
R^2	0.869	0.789	0.825

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

TABLE 3 Robustness test and endogenous regression results.

Variable	Enterprise green innovation			
	(1)	(2)	(3)	(4)
$du \times dt$	0.312*** (2.59)	0.258*** (2.92)	0.418** (2.05)	0.104** (2.17)
LM statistics				6.705* (1.88)
F statistic				40.361*** (15.01)
Hasen				20.125*** (10.23)
Control variables	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES
Fixed individuals	YES	YES	YES	YES
N	32,505	32,505	32,505	32,505
R^2	0.728	0.826	0.792	0.814

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

TABLE 4 Test results of heterogeneity of economic development strength.

Variable	First- and second-tier cities			Third-tier and below cities		
	pat	*pat-in*	*pat-ut*	*pat*	*pat-in*	*pat-ut*
	(1)	(2)	(3)	(4)	(5)	(6)
$du \times dt$	1.125*** (3.67)	0.751*** (2.85)	1.245** (1.99)	0.471* (1.9)	1.027* (1.75)	1.042 (1.53)
Control variables	YES	YES	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES	YES	YES
Fixed individuals	YES	YES	YES	YES	YES	YES
N	21,525	21,525	21,525	10,980	10,980	10,980
R^2	0.826	0.847	0.853	0.782	0.794	0.804

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

5.4. Further heterogeneity analyzes

Due to disparities in economic development strength, geographic location, and enterprise type across regions, it is vital to focus on high-tech zone implementation in the subsequent research of the influence of national high-tech zone establishment on green innovation of firms. This is because high-tech zone laws vary based on the type of firm. As a result, this heterogeneous effect is further discussed below.

5.4.1. Heterogeneity of economic development strength

Because of the variance in economic growth strength between areas, this study divides the sample data into first- and second-tier cities, third-tier cities, and below, and divides the associated enterprise samples accordingly. Individual regression results are shown in Table 4.

Table 4 columns (1)–(3) shows the regression findings for first- and second-tier cities, and columns (4)–(6) provide the regression results for third-tier and below cities. It has been discovered that the establishment of pilot areas plays a vital role in boosting the improvement of companies' green innovation levels in first- and second-tier cities, as well as third-tier cities and below. While the national high-tech zone policy's implementation plays a stronger role in enhancing both first- and second-tier cities when it comes to green invention patents and green utility model patents, the impact on businesses in developed cities is greater. The positive significance level for third-tier cities and below is not high, and among them, the regression coefficient of green utility model patents is not obvious. The creation of pilot areas will encourage companies to enhance their level of technological innovation and continuously innovate the production process department to improve industrial competitiveness in those developed regions due to geographic location, infrastructure construction, technological capital, and other resource advantages. However, the undeveloped regions' economic development strength is weak, and there is a lack of financial assistance and factor resource flow. In the short term, the formation of pilot areas has minimal influence on the degree of green innovation of connected firms, and it is important to raise awareness of independent innovation and increase the region's innovation capability.

5.4.2. Heterogeneity of enterprise ownership

The extent to which an enterprise's level of green innovation improves will be determined by the type of enterprise as well as the strength of the area's economic development. Direct government management or intervention is the hallmark of state-owned enterprises, and the location of the business must take into account the government's strategic objectives and development plans. Non-state-owned enterprises are more cognizant of market developments. To that end, this study evaluates the levels of green innovation and examines the consequences of creating pilot areas on enterprises with diverse ownership structures. Although it is not immediately evident from the regression findings in Table 5, there is an important positive promotion effect on non-state-owned firms from the execution of the national high-tech zone plan on state-owned enterprises' development of green innovation. On the one hand, whether or not national high-tech zones are developed, state-owned businesses have a relatively solid infrastructure basis and it is very easy for them to obtain money and favorable regulations. Therefore, it is uncertain how the construction of the pilot areas would affect the linked enterprises' ability to innovate more sustainably. On the other hand, non-state-owned businesses urgently need to draw in foreign investment through the creation of national high-tech zones and create a favorable business climate, so that the impact of pilot areas on green innovation is more apparent.

5.4.3. Industry heterogeneity

The varied effects of the construction of pilot areas on enterprise green innovation were investigated from the perspectives of economic development strength and firm ownership heterogeneity. The establishment of high-tech zones will be focused on the growth of high-tech industries, and the direction and pace of development of different industry types will affect the enhancement of local green innovation. As a result, this paper leans on the preceding classification of high-tech businesses to divide the sample data into high-tech and non-high-tech industries, and the specific regression results are provided in Table 6. It reflects that the execution of the pilot areas policy plays a larger role in promoting the level of green innovation in high-tech sectors. This also demonstrates the efficacy of policy execution. It demonstrates that the creation of the pilot areas has obvious industrial variations in the improvement of firms' green innovation level.

5.5. Mechanism of action analysis

According to the empirical data, the pilot building of the pilot areas has a significant influence on encouraging enterprises to increase their level of green innovation. But how exactly does this promotion work? The approach of establishing national high-tech zones to encourage enterprise green innovation needs to be investigated further to provide solutions to the concerns stated above. The implementation of the high-tech zone policy drives the factor agglomeration effect, innovation-driven effect, and institutional environment effect in the process of promoting the level of green innovation in enterprises, to better improve the level of regional low-carbon development. Hence, two more models are added to the model (1), and then the mediation effect model is built for in-depth investigation, and the specific model development technique is as follows:

$$\text{Mediation}_{it} = \theta_0 + \theta_1 du \times dt + \theta_2 \text{Control}_{it} + \mu_{it} + \lambda_{it} + \mu_{it} \quad (3)$$

$$\ln \text{patent}_{it} = \varphi_0 + \varphi_1 du \times dt + \varphi_2 \text{Mediation}_{it} + \varphi_3 \text{Control}_{it} + \mu_{it} + \lambda_{it} + \varepsilon_{it} \quad (4)$$

In the formula, mediation is a collection of mediating variables. The OP approach is used to estimate the factor agglomeration effect (*fac*) by determining the total factor productivity of firms (Ren et al., 2022). The Innovation Index of publicly traded companies is used as a proxy variable for measuring the innovation-driving effect (*inv*; Hao et al., 2022). The institutional transaction cost in firm transaction costs is used as a proxy variable in this study to quantify the institutional environmental effect (*env*; Fan et al., 2019). In addition, when performing the mediation effect test, it is necessary to ensure that the regression coefficients α_1 , θ_1 , and φ_1 in the policy dummy variables in the model (1), (3), and (4) all meet the significance level. Simultaneously, when the coefficient φ_1 in equation (4) is not significant, it is indicated that the intermediary variable plays a complete mediating role of the explanatory variable affecting the explanatory variable. When the coefficient φ_1 is less than α_1 , it indicates that the intermediary variable plays a partial mediating role in promoting it, and the specific influence mechanism is shown in Table 7 through the corresponding model regression test.

TABLE 5 Results of the heterogeneity test of enterprise ownership.

Variable	State-owned enterprises			Non-state-owned enterprises		
	pat	*pat-in*	*pat-ut*	*pat*	*pat-in*	*pat-ut*
	(1)	(2)	(3)	(4)	(5)	(6)
$du \times dt$	1.205* (1.67)	1.014 (1.45)	0.275 (1.39)	0.782*** (2.66)	1.147** (2.30)	0.082* (1.75)
Control variables	YES	YES	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES	YES	YES
Fixed individuals	YES	YES	YES	YES	YES	YES
N	11,985	11,985	11,985	20,520	20,520	20,520
R^2	0.71	0.642	0.628	0.802	0.814	0.852

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

TABLE 6 Heterogeneity test results of different industries.

Variable	High-tech industries			Non-high-tech industries		
	pat	*pat-in*	*pat-ut*	*pat*	*pat-in*	*pat-ut*
	(1)	(2)	(3)	(4)	(5)	(6)
$du \times dt$	1.105*** (3.02)	1.045*** (2.9)	1.042** (2.06)	0.893** (2.35)	0.127* (1.88)	0.422* (1.89)
Control variables	YES	YES	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES	YES	YES
Fixed individuals	YES	YES	YES	YES	YES	YES
N	9,060	9,060	9,060	23,445	23,445	23,445
R^2	0.817	0.804	0.882	0.824	0.739	0.756

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

TABLE 7 Test results of the influence mechanism of mediation effect.

Variable	*fac*	*lnpatent*	*inv*	*lnpatent*	*env*	*lnpatent*
$du \times dt$	0.109** (2.18)	1.247*** (2.81)	0.042*** (2.62)	0.858*** (3.18)	0.188* (1.89)	0.362*** (2.81)
fac		0.241*** (3.60)				
inv				0.217*** (3.28)		
env						0.205** (2.37)
Control variables	YES	YES	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES	YES	YES
Fixed individuals	YES	YES	YES	YES	YES	YES
N	32,505	32,505	32,505	32,505	32,505	32,505
R^2	0.807	0.854	0.79	0.745	0.71	0.893

***, **, and * indicate passing the significance test of 1, 5, and 10%, respectively, and the *t*-value in parentheses is the *t*-value.

Table 7 shows that the formation of the pilot areas has a significant intermediate role in driving the augmentation of businesses' green innovation levels because of the factor agglomeration impact, innovation-driven effect, and institutional environment effect. The adoption of a national high-tech zone strategy can first foster collaboration and the sharing of factor resources, which can enhance firms' production technology level. The contribution of the pilot areas to innovation is mostly due to the information exchange and knowledge transfer that it encourages among various innovation subjects, which results in the progress of manufacturing technology. The construction of the national high-tech zone will allow high-tech industries and surrounding linked firms to benefit from preferential policies, institutional guarantees, and so on, which will be more conducive to increasing enterprises' innovative potential. As a result of the enterprise's operation, the institutional environment effect will generate a variety of transaction costs. The three major effects of factor agglomeration, innovation drive, and institutional environment generated during the construction of the pilot areas are simultaneously found to importantly enhance the enterprises' green innovation level, and the significance coefficient gradually increases, confirming the validity of the previous research hypothesis. This is because all three effects were included in the regression model.

6. Conclusion and revelations

6.1. Research conclusion

This paper develops a multi-period double difference model based on micro-enterprise panel data from A-share listed companies in China, from 2005 to 2019 to validate the influence and mechanism of the national high-tech zone policy implementation on green innovation of enterprises. The implementation of the high-tech zone policy, in particular, has a more obvious promotion influence on companies' green invention patents, although the promotion effect of enterprises utilizing utility model patents is broad. (1) The establishment of the pilot areas plays a significant role in increasing the level of green innovation among firms. (2) The heterogeneity study results show that the formation of national high-tech zones has a greater influence on green innovation in first- and second-tier cities, whereas the significance level of the regression coefficient in third- and lower-tier cities is low. This is because of the disparity in economic development strength. The adoption of the national high-tech zone strategy favors non-state-owned enterprises more in terms of increasing their level of green innovation while having little impact on state-owned businesses. The establishment of national high-tech zones has a bigger impact on green innovation than on non-high-tech industries. (3) The mechanism of action analysis demonstrates that pilot areas implementation essentially increases the degree of green innovation of businesses by fully utilizing the effects of factor agglomeration, innovation-driven effect, and institutional environment.

6.2. Policy recommendations

Based on the preceding conclusions, the following policy recommendations are offered in this study:

To encourage the potential for green innovation among businesses, actively encourage the creation of national high-tech zones, develop innovative methods and mechanisms, and better utilize the leading role of high-tech zones in innovation. In this paper, we further demonstrate from the perspective of green development through empirical research that the implementation of high-tech zone policies will have a positive influence on the level of green innovation of enterprises. On the one hand, a large number of research results show that the construction of national high-tech zones has a significant role in promoting the innovation and development of enterprises. Therefore, it is essential to encourage the creation of pilot areas logically. To ensure long-term innovation and development in the area, it is necessary to establish and enhance the intellectual property protection and R&D management system in the national high-tech zone, raise enterprise awareness and level of R&D investment, and attach importance to the quality of innovation for patent applications. Improve high-tech zone enterprises' ability to innovate autonomously, use innovation as a long-term company growth engine, and design the national high-tech zone's construction to best serve the interests of green business innovation. To improve the flow of factor resources, the government has raised the level of green technology in high-tech firms by passing environmental regulatory measures such as harsher penalties and higher technical standards. On the other hand, it has spurred corporations to invest more in green development. Reduce the negative impact of technical barriers on corporate green innovation by communicating and sharing information. On the other hand, to reduce corporate transaction costs, it is critical to establish an environment that stimulates innovation and to implement preferential policies such as policy subsidies and tax exemptions. To support the long-term development of pilot areas, it is also necessary to fully capitalize on the motivating power of high-tech enterprises on park development and to raise enterprise understanding of and accountability for attaining the aim of carbon-neutral development.

Plan the establishment of pilot areas logically, taking into account all important factors such as the nature of firms and other regional variances. To construct high-tech zones that accomplish overall high-quality development while leaving a tiny footprint, it is critical to carefully analyze the economic development potential of various locations, the nature of enterprises, and whether or not they fall under the scope of high-tech industries. In addition, we should create a green innovation structure for firms that is adaptable to local situations.

6.3. Limitation and future research

This article, which starts with the notion of creating pilot areas for the development of green businesses, offers recommendations and references for the implementation of high-tech zone policies to support the level of green innovation of businesses through empirical testing and analysis. After careful research and analysis, it was determined that there are still some areas that could be expanded upon and further investigated. These include: (1) Because the pilot areas are being developed from a global standpoint, businesses in the surrounding areas may be affected by interaction. Future research can now focus on the effects of the pilot areas policy's implementation on spatial spillover effects. (2) Several factors could have an influence on the expansion of enterprise green innovation. Consequently, future research might focus on developing a more thorough system of assessment elements to analyze how enterprises can develop their green innovation. (3) Regarding the influencing factors of green innovation, the influencing role of the implementation of other industrial policies can also be considered.

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

XJ, ZL, JX, and PZ performed the material preparation, data collection, and analysis. BL wrote the first draft of the manuscript. All authors contributed to the study conception and design, commented on previous versions of the manuscript, and read and approved the final manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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