frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 04 April 2024
DOI 10.3389/fenvs.2024.1369433

OPEN ACCESS

EDITED BY
Oscar Alfranca,
Universitat Politecnica de Catalunya, Spain

REVIEWED BY
Yang Wang,
Yunnan Normal University, China
Yaojun Fan,
Dhurakij Pundit University, Thailand

*CORRESPONDENCE
Yu Jia,
jiayu210@outlook.com

RECEIVED 12 January 2024
ACCEPTED 15 March 2024
PUBLISHED 04 April 2024

CITATION
Cao W, Jia Y and Tan B (2024), Impact of industrial policy on urban green innovation: empirical evidence of China's national high-tech zones based on double machine learning. *Front. Environ. Sci.* 12:1369433.
doi: 10.3389/fenvs.2024.1369433

Impact of industrial policy on urban green innovation: empirical evidence of China's national high-tech zones based on double machine learning

Wei Cao, Yu Jia* and Benwei Tan

College of Economics and Management, Taiyuan University of Technology, Taiyuan, China

Effective industrial policies need to be implemented, particularly aligning with environmental protection goals to drive the high-quality growth of China's economy in the new era. Setting up national high-tech zones falls under the purview of both regional and industrial policies. Using panel data from 163 prefecture-level cities in China from 2007 to 2019, this paper empirically analyzes the impact of national high-tech zones on the level of urban green innovation and its underlying mechanisms. It utilizes the national high-tech zones as a quasi-natural experiment and employs a double machine learning model. The study findings reveal that the policy for national high-tech zones greatly enhances urban green innovation. This conclusion remains consistent even after adjusting the measurement method, empirical samples, and controlling for other policy interferences. The findings from the heterogeneity analysis reveal that the impact of the national high-tech zone policy on green innovation exhibits significant regional heterogeneity, with a particularly significant effect in the central and western regions. Among cities, there is a notable push for green innovation levels in second-tier, third-tier, and fourth-tier cities. The moderating effect results indicate that, at the current stage of development, transportation infrastructure primarily exerts a negative moderating effect on how the national high-tech zone policy impacts the level of urban green innovation. This research provides robust empirical evidence for informing the optimization of the industrial policy of China and the establishment of a future ecological civilization system.

KEYWORDS

national high-tech zone, industrial policy, green innovation, heterogeneity analysis, moderating effect, double machine learning

1 Introduction

The Chinese economy currently focuses on high-quality development rather than quick growth. The traditional demographic and resource advantages gradually diminish, making the earlier crude development model reliant on excessive resource input and consumption unsustainable. Simultaneously, resource impoverishment, environmental pollution, and carbon emissions are growing more severe (Wang F. et al., 2022). Consequently, pursuing a mutually beneficial equilibrium between the economy and the environment has emerged as a critical concern in China's economic growth. Green innovation, the integration of innovation with sustainability development ideas, is progressively gaining significance within the framework of reshaping China's economic development strategy and addressing the challenges associated with resource and environmental limitations. In light of the present circumstances, and with the objectives outlined in the "3060 Plan" for carbon peak and carbon neutral, the pursuit of a green and innovative development trajectory, emphasizing heightened innovation alongside environ-mental preservation, has emerged as a pivotal concern within the context of China's contemporary economic progress.

Industrial policy is pivotal in government intervention within market-driven resource allocation and correcting structural disparities. The government orchestrates this initiative to bolster industrial expansion and operational effectiveness. In contrast to Western industrial policies, those in China are predominantly crafted within the administrative framework and promulgated through administrative regulations. Over an extended period, numerous industrial policies have been devised in response to regional disparities in industrial development. These policies aim to identify new growth opportunities in diverse regions, focusing on optimizing and upgrading industrial structures. These strategies have been implemented at various administrative levels, from the central government to local authorities (Sun and Sun, 2015). As a distinctive regional economic policy in China, the national high-tech zone represents one of the foremost supportive measures a city can acquire at the national level. Its crucial role involves facilitating the dissemination and advancement of regional economic growth. Over more than three decades, it has evolved into the primary platform through which China executes its strategy of concentrating on high-tech industries and fostering development driven by innovation. Concurrently, the national high-tech zone, operating as a geographically focused policy customized for a specific region (Cao, 2019), enhances the precision of policy support for the industries under its purview, covering a more limited range of municipalities, counties, and regions. Contrasting with conventional regional industrial policies, the industry-focused policy within national high-tech zones prioritizes comprehensive resource allocation advice and economic foundations to maximize synergy and promote the long-term sustainable growth of the regional economy, and this represents a significant paradigm shift in location-based policies within the framework of carrying out the new development idea. Its inception embodies a combination of central authorization, high-level strategic planning, local grassroots decision-making, and innovative system development. In recent years, driven by the objective of dual carbon, national high-tech have proactively promoted environmentally friendly innovation. Nevertheless, given the proliferation of new industrial policies and the escalating complexity of the policy framework, has the setting up of national high-tech zones genuinely elevated the level of urban green innovation in contrast to conventional regional industrial policies? What are the underlying mechanisms? Simultaneously, concerning the variations among different cities, have the industrial policy tools within the national high-tech zones been employed judiciously and adaptable? What are the concrete practical outcomes? Investigating these matters has emerged as a significant subject requiring resolution by government, industry and academia.

2 Literature review and research hypothesis

2.1 Literature review

When considering industrial policy, the setting up national high-tech zones embodies the intersection of regional and industrial policies. Domestic and international academic research concerning setting up national high-tech zones primarily centers on economic activities and innovation. Notably, the economic impact of national high-tech zones encompasses a wide range of factors, including their influence on total factor productivity (Tan and Zhang, 2018; Wang and Liu, 2023), foreign trade (Alder et al., 2016), industrial structure upgrades (Yuan and Zhu, 2018), and economic growth (Liu and Zhao, 2015; Huang and Fernández-Maldonado, 2016; Wang Z. et al., 2022). Regarding innovation, numerous researchers have confirmed the positive effects of national high-tech zones on company innovation (Vásquez-Urriago et al., 2014; Díez-Vial and Fernández-Olmos, 2017; Wang and Xu, 2020); Nevertheless, a few scholars have disagreed on this matter (Hong et al., 2016; Sosnovskikh, 2017). In general, the consensus among scholars is that setting up high-tech national zones fosters regional innovation significantly. This consensus is supported by various aspects of innovation, including innovation efficiency (Park and Lee, 2004; Chandrashekar and Bala Subrahmanya, 2017), agglomeration effect (De Beule and Van Beveren, 2012), innovation capability (Yang and Guo, 2020), among other relevant dimensions. The existing literature predominantly delves into the correlation between the setting up of national high-tech zones, innovation, and economic significance. However, the rise of digital economic developments, notably industrial digitization, has accentuated the limitations of the traditional innovation paradigm. These shortcomings, such as the inadequate exploration of the social importance and sustainability of innovation, have become apparent in recent years. As the primary driver of sustainable development, green innovation represents a potent avenue for achieving economic benefits and environmental value (Weber et al., 2014). Its distinctiveness from other innovation forms lies in its potential to facilitate the transformation of development modes, reshape economic structures, and address pollution prevention and control challenges. However, in the context of green innovation, based on the double-difference approach, Wang et al. (2020) has pointed out that national high-tech zones enhance the effectiveness of urban green innovation, but this is only significant in the eastern region.

Furthermore, scholars have also explored the mechanisms underlying the innovation effects of national high-tech. For example, Cattapan et al. (2012) focused on science parks in Italy. They found that green innovation represents a potent avenue for achieving economic benefits as the primary driver of sustainable development, and environmental value technology transfer services positively influence product innovation. Albahari et al. (2017) confirmed that higher education institutions' involvement in advancing corporate innovation within technology and science parks has a beneficial moderating effect. Using the moderating effect of spatial agglomeration as a basis, Li WH. et al. (2022) found that industrial agglomeration has a significantly unfavorable moderating influence on the effectiveness of performance transformation in national high-tech zones. Multiple studies have examined the national high-tech zone industrial policy's regulatory framework and urban innovation. However, in the age of rapidly expanding new infrastructure, infrastructure construction is concentrated on information technologies like blockchain, big data, cloud computing, artificial intelligence, and the Internet; Further research is needed to explore whether traditional infrastructure, particularly transportation infrastructure, can promote urban green innovation. Transportation infrastructure has consistently been vital in fostering economic expansion, integrating regional resources, and facilitating coordinated development (Behrens et al., 2007; Zhang et al., 2018; Pokharel et al., 2021). Therefore, it is necessary to investigate whether transportation infrastructure can continue encouraging innovative urban green practices in the digital economy.

In summary, the existing literature has extensively examined the influence of national high-tech zones on economic growth and innovation from various levels and perspectives, establishing a solid foundation and offering valuable research insights for this study. Nonetheless, previous studies frequently overlooked the impact of national high-tech zones on urban green innovation levels, and a subsequent series of work in this paper aims to address this issue. Further exploration and expansion are needed to understand the industrial policy framework's strategy for relating national high-tech zones to urban green innovation. Furthermore, there is a need for further improvement and refinement of the research model and methodology. Based on these, this paper aims to discuss the industrial policy effects of national high-tech zones from the perspective of urban green innovation to enrich and expand the existing research.

In contrast to earlier research, the marginal contribution of this paper is organized into three dimensions: 1) Most scholars have primarily focused on the effects of national high-tech zones on economic activity and innovation, with less emphasis on green innovation and rare studies according to the level of green innovation perspective. The study on national high-tech zones as an industrial policy that has already been done is enhanced by this work. 2) Regarding the research methodology, the Double Machine Learning (DML) approach is used to evaluate the policy effects of national high-tech zones, leveraging the advantages of machine learning algorithms for high-dimensional and non-parametric prediction. This approach circumvents the problems of model setting bias and the "curse of dimensionality" encountered in traditional econometric models (Chernozhukov et al., 2018), enhancing the credibility of the research findings. 3) By introducing transportation infrastructure as a moderator variable, this study investigates the underlying mechanism of national high-tech zones on urban green innovation, offering suggestions for maximizing the influence of these zones on policy.

2.2 Theoretical analysis and hypotheses

2.2.1 National high-tech zones' industrial policies and urban green innovation

As one of the ways to land industrial policies at the national level, national high-tech zones serve as effective driving forces for enhancing China's ability to innovate regionally and its contribution to economic growth (Xu et al., 2022). Green innovation is a novel form of innovation activity that harmoniously balances the competing goals of environmental preservation and technological advancement, facilitating the superior expansion of the economy by alleviating the strain on resources and the environment (Li, 2015). National high-tech zones mainly impact urban green innovation through three main aspects. Firstly, based on innovation compensation effects, national high-tech zones, established based on the government's strategic planning, receive special treatment in areas such as land, taxation, financing, credit, and more, serving as pioneering special zones and experimental fields established by the government to promote high-quality regional development. When the government offers R&D subsidies to enterprises engaged in green innovation activities within the zones, enterprises are inclined to respond positively to the government's policy support and enhance their level of green innovation as a means of seeking external legitimacy (Fang et al., 2021), thereby contributing to the advancement of urban green innovation. Secondly, based on the industrial restructuring effect, strict regulation of businesses with high emissions, high energy consumption, and high pollution levels is another aspect of implementing the national high-tech zone program. Consequently, businesses with significant emissions and energy consumption are required to optimize their industrial structure to access various benefits within the park, resulting in the gradual transformation and upgrading of high-energy-consumption industries towards green practices, thereby further contributing to regional green innovation. Based on Porter's hypothesis, the green and low-carbon requirements of the park policy increase the production costs for polluting industries, prompting polluting enterprises to upgrade their existing technology and adopt green innovation practices. Lastly, based on the theory of industrial agglomeration, the national high-tech zones' industrial policy facilitates the concentration of innovative talents to a certain extent, resulting in intensified competition in the green innovation market. Increased competition fosters the sharing of knowledge, technology, and talent, stimulating a market environment where the survival of the fittest prevails (Melitz and Ottaviano, 2008). These increase the effectiveness of urban green innovation, helping to propel urban green innovation forward. Furthermore, the infrastructure development within the national high-tech zones establishes a favorable physical environment for enterprises to engage in creative endeavors. Also, it enables the influx of high-quality innovation capital from foreign sources, complementing the inherent characteristics of national high-tech zones that attract such capital and concentrate green innovation resources, ultimately resulting in both environmental and economic benefits. Based on the above analysis, Hypothesis 1 is proposed:

Hypothesis 1. Implementing industrial policies in national high-tech zones enhances levels of urban green innovation.

2.2.2 Heterogeneity analysis

Given the variations in economic foundations, industrial statuses, and population distributions across different regions, development strategies in different regions are also influenced by these variations (Chen and Zheng, 2008). Theoretically, when using administrative boundaries or geographic locations as benchmarks, the impact of national high-tech zone industrial policy on urban green innovation should be achieved through strategies like aligning with the region's existing industrial structure. Compared to the western and central regions, the eastern region exhibits more incredible innovation and dynamism due to advantages such as a developed economy, good infrastructure, advanced management concepts, and technologies, combined with a relatively high initial level of green innovation factor endowment. Considering the diminishing marginal effect principle of green innovation, the industrial policy implementation in national high-tech zones favors an "icing on the cake" approach in the eastern region, contrasting with a "send carbon in the snow" approach in the central and western regions. In other words, the economic benefits of national high-tech zones for promoting urban green innovation may need to be more robust than their impact on the central and western regions. Literature confirms that establishing national high-tech zones yields a more beneficial technology agglomeration effect in the less developed central and western regions (Liu and Zhao, 2015), leading to a more substantial impact on enhancing the level of urban green innovation.

Moreover, local governments consider economic development, industrial structure, and infrastructure levels when establishing national high-tech zones. These factors serve as the foundation for regional classification to address variations in regional quality and to compensate for gaps in theoretical research on the link between national high-tech zone industrial policy implementation and urban green innovation. Consequently, the execution of industrial policies in national high-tech zones relies on other vital factors influencing urban green innovation. Significant variations exist in economic development and infrastructure levels among cities of different grades (Luo and Wang, 2023). Generally, cities with higher rankings exhibit strong economic growth and infrastructure, contrasting those with lower rankings. Consequently, the effect of establishing a national high-tech zone on green innovation may vary across different city grades. Thus, considering the disparities across city rankings, we delve deeper into identifying the underlying reasons for regional diversity in the green innovation outcomes of industrial policies implemented in national high-tech zones based on city grades. Based on the above analysis, Hypothesis 2 is proposed:

Hypothesis 2. There is regional heterogeneity and city-level heterogeneity in the impact of national high-tech zone policies on the level of urban green innovation.

2.2.3 The moderating effect of transportation infrastructure

Implementing industrial policies and facilitating the flow of innovation factors are closely intertwined with the role of transport infrastructure as carriers and linkages. Generally, enhanced transportation infrastructure facilitates the absorption of local factors and improves resource allocation efficiency, thereby influencing the spatial redistribution of production factors like labor, resources, and technology across cities. Enhanced transportation infrastructure fosters the development of more robust and advanced innovation networks (Fritsch and Slavtchev, 2011). Banister and Berechman (2001) highlighted that transportation infrastructure exhibits network properties that are fundamental to its agglomeration or diffusion effects. From this perspective, robust infrastructure impacts various economic activities, including interregional labor mobility, factor agglomeration, and knowledge exchange among firms, thereby expediting the spillover effects of green technological innovations (Yu et al., 2013). In turn, this could positively moderate the influence of national hi-tech zone policies on green innovation. On the other hand, while transportation infrastructure facilitates the growth of national high-tech zone policies, it also brings negative impacts, including high pollution, emissions, and ecological landscape fragmentation. Improving transportation infrastructure can also lead to the "relative congestion effect" in national high-tech zones. This phenomenon, observed in specific regions, refers to the excessive concentration of similar enterprises across different links of the same industrial chain, which exacerbates the competition for innovation resources among enterprises, making it challenging for enterprises in the region to allocate their limited innovation resources to technological research and development activities (Li et al., 2015). As a result, there needs to be a higher green innovation level. Therefore, the impact of transportation infrastructure in the current stage of development will be more complex. When the level of transport infrastructure is moderate, adequate transport infrastructure supports the promotion of urban green innovation through national high-tech zone policies. However, the impact of transport infrastructure regulation may be harmful. Based on the above analysis, Hypothesis 3 is proposed:

Hypothesis 3. Transportation infrastructure moderates the relationship between national high-tech zones and levels of urban green invention.

3 Research design

3.1 Model setting

This research explores the impact of industrial policies of national high-tech zones on the level of urban green innovation. Many related studies utilize traditional causal inference models to assess the impact of these policies. However, these models have several limitations in their application. For instance, the commonly used double-difference model in the parallel trend test has stringent requirements for the sample data. Although the synthetic control approach can create a virtual control group that meets parallel trends' needs, it is limited to addressing the 'one-to-many' problem and requires excluding groups with extreme values. The selection of matching variables in propensity score matching is subjective, among other limitations (Zhang and Li, 2023). To address the limitations of conventional causal inference models, scholars have started to explore applying machine learning to infer causality (Chernozhukov et al., 2018; Knittel and Stolper, 2021). Machine learning algorithms excel at an impartial assessment of the effect on the intended target variable for making accurate predictions.

In contrast to traditional machine learning algorithms, the formal proposal of DML was made in 2018 (Chernozhukov et al., 2018). This approach offers a more robust approach to causal inference by mitigating bias through the incorporation of residual modeling. Currently, some scholars utilize DML to assess causality in economic phenomena. For instance, Hull and

Grodecka-Messi (2022) examined the effects of local taxation, crime, education, and public services on migration using DML in the context of Swedish cities between 2010 and 2016. These existing research findings serve as valuable references for this study. Compared to traditional causal inference models, DML offers distinct advantages in variable selection and model estimation (Zhang and Li, 2023). However, in promoting urban green innovation in China, there is a high probability of non-linear relationships between variables, and the traditional linear regression model may lead to bias and errors. Moreover, the double machine learning model can effectively avoid problems such as setting bias. Based on this, the present study employs a DML model to evaluate the policy implications of establishing a national high-tech zone.

3.1.1 Double machine learning framework

Prior to applying the DML algorithm, this paper refers to the practice of Chernozhukov et al. (2018) to construct a partially linear DML model, as depicted in Eq. 1 below:

$$\boldsymbol{\ln GI_{it} = \theta_0 Zone_{it} + g(X_{it}) + U_{it}, E(U_{it}|Zone_{it}, X_{it}) = 0} \quad (1)$$

where i represents the city, t represents the year, and $lnGI_{it}$ represents the explained variable, which in this paper is the green innovation level of the city. $Zone_{it}$ represents the disposition variable, which in this case is a national high-tech zone's policy variable. It takes a value of 1 after the implementation of the pilot and 0 otherwise. θ_0 is the disposal factor that is the focus of this paper. X_{it} represents the set of high-dimensional control variables. Machine learning algorithms are utilized to estimate the specific form of $\hat{g}(X_{it})$, whereas U_{it}, which has a conditional mean of 0, stands for the error term. n represents the sample size. Direct estimation of Eq. 1 provides an estimate for the coefficient of dispositions.

$$\boldsymbol{\hat{\theta}_0 = \left(\frac{1}{n}\sum_{i\in I,t\in T} Zone_{it}{}^2\right)^{-1} \frac{1}{n}\sum_{i\in I,t\in T} Zone_{it}\left(lnGI_{it} - \hat{g}(X_{it})\right)} \quad (2)$$

We can further explore the estimation bias by combining Eqs 1, 2as depicted in Eq. (3) below:

$$\boldsymbol{\sqrt{n}\left(\hat{\theta}_0 - \theta_0\right) = \left(\frac{1}{n}\sum_{i\subset I,t\subset T} Zone_{it}{}^2\right)^{-1} \frac{1}{\sqrt{n}}\sum_{i\subset I,t\subset T} Zone_{it}U_{it} + \left(\frac{1}{n}\sum_{i\in I,t\in T} Zone_{it}{}^2\right)^{-1} \frac{1}{\sqrt{n}}\sum_{i\in I,t\in T} Zone_{it}\left[g(X_{it}) - \hat{g}(X_{it})\right]} \quad (3)$$

where $\boldsymbol{a = (\frac{1}{n}\sum_{i\in I,t\in T} Zone_{it}{}^2)^{-1}\frac{1}{\sqrt{n}}\sum_{i\in I,t\in T} Zone_{it}U_{it}}$, by a normal distribution having 0 as the mean, $\boldsymbol{b = (\frac{1}{n}\sum_{i\in I,t\in T} Zone_{it}{}^2)^{-1}\frac{1}{\sqrt{n}}\sum_{i\in I,t\in T} Zone_{it}[g(X_{it}) - \hat{g}(X_{it})]}$. It is important to note that DML utilizes machine learning and a regularization algorithm to estimate a specific functional form $\hat{g}(X_{it})$. The introduction of "canonical bias" is inevitable as it prevents the estimates from having excessive variance while maintaining their unbiasedness. Specifically, the convergence of $\hat{g}(X_{it})$ to $g(X_{it})$, $n^{-\varphi g} > n^{-1/2}$, as n tends to infinity, b also tends to infinity, $\hat{\theta}_0$ is difficult to converge to θ_0. To expedite convergence and ensure unbiasedness of the disposal coefficient estimates with small samples, an auxiliary regression is constructed as follows:

$$\boldsymbol{Zone_{it} = m(X_{it}) + V_{it}, E(V_{it}|X_{it}) = 0} \quad (4)$$

where $m(X_{it})$ represents the disposition variable's regression function on the high-dimensional control variable, this function also requires estimation using a machine learning algorithm in the specific form of $\hat{m}(X_{it})$. Additionally, V_{it} represents the error term with a 0 conditional mean.

3.1.2 The test of the mediating effect within the DML framework

This study investigates how the national high-tech zone industrial policy influences the urban green innovation. It incorporates moderating variables within the DML framework, drawing on the testing procedure outlined by Jiang (2022), and integrates it with the practice of He et al. (2022), as outlined below:

$$\boldsymbol{lnGI_{it} = \theta_1 Zone_{it} * lntra_{it} + g(X_{it}) + U_{it}, E(U_{it}|Zone_{it} * lntra_{it}, X_{it}) = 0} \quad (5)$$

$$\boldsymbol{Zone_{it} * lntra_{it} = m(X_{it}) + V_{it}, E(V_{it}|X_{it}) = 0} \quad (6)$$

Equation 5 is based on Eq. 1 with the addition of variables $lntra_{it}$ and $Zone_{it}$*$lntra_{it}$.Where $lntra_{it}$ represents the moderating variable, which in this paper is the transportation infrastructure. $Zone_{it}$*$lntra_{it}$ represents the interaction term of the moderating variable and the disposition variable. The variables $lntra_{it}$ and $Zone_{it}$ are added to the high-dimensional control variables X_{it}, and the rest of the variables in Eq. 5 are identical to Eq. 1. θ_1 represents the disposal factor to focus on.

3.2 Variable selection

3.2.1 Dependent variable: level of urban green innovation (lnGI)

Nowadays, many academics use indicators like the number of applications for patents or authorizations to assess the degree of urban innovation. To be more precise, the quantity of patent applications is a measure of technological innovation effort, while the number of patents authorized undergoes strict auditing and can provide a more direct reflection of the achievements and capacity of scientific and technological innovation. Thus, this paper refers to the studies of Zhou and Shen (2020) and Li X. et al. (2022) to utilize the count of authorized green invention patents in each prefecture-level city to indicate the level of green innovation. For the empirical study, the count of authorized green patents plus 1 is transformed using logarithm.

3.2.2 Disposal variable: dummy variables for national high-tech zones (Zone)

The national high-tech zone dummy variable's value correlates with the city in which it is located and the list of national high-tech zones released by China's Ministry of Science and Technology. If a national high-tech zone was established in the city by 2017, the value is set to 1 for the year the high-tech zone is established and subsequent years. Otherwise, it is set to 0.

3.2.3 Moderating variable: transportation infrastructure (lntra)

Previous studies have shown that China's highway freight transport comprises 75% of the total freight transport (Li and Tang, 2015). Highway transportation infrastructure has a significant influence on the evolution of the Chinese economy. The development and improvement of highway infrastructure are crucial for modern transportation. This paper uses the research methods of Wu (2019) and uses the roadway mileage (measured in kilometers) to population as a measure of the quality of the transportation system.

3.2.4 Control variables

(1) Foreign direct investment (lnfdi): There is general agreement among academics that foreign direct investment (FDI) significantly influences urban green innovation, as FDI provides expertise in management, human resources, and cutting-edge industrial technology (Luo et al., 2021). Thus, it is necessary to consider and control the level of FDI. This paper uses the ratio of foreign investment to the local GDP in a million yuan.
(2) Financial development level (lnfd): Innovation in science and technology is greatly aided by finance. For the green innovation-driven strategy to advance, it is imperative that funding for science and technology innovation be strengthened. The amount of capital raised for innovation is strongly impacted by the state of urban financial development (Zhou and Du, 2021). Thus, this paper uses the loan balance to GDP ratio as an indicator.
(3) Human capital (lnhum): Highly skilled human capital is essential for cities to drive green innovation. Generally, highly qualified human capital significantly boosts green innovation (Ansaris et al., 2016). Therefore, a measure was employed: the proportion of people in the city who had completed their bachelor's degree or above.
(4) Industrial structure (lnind): Generally, the secondary industry in China is the primary source of pollution, and there is a significant impact of industrial structure on green innovation (Qiu et al., 2023). The metric used in this paper is the secondary industry-to-GDP ratio for the area.
(5) Regional economic development level (lnagdp): A region's level of economic growth is indicative of the material foundation for urban green innovation and in-fluences the growth of green innovation in the region (Bo et al., 2020). This research uses the annual gross domestic product *per capita* as a measurement.

3.3 Data source

By 2017, China had developed 157 national high-tech zones in total. In conjunction with the study's objectives, this study performs sample adjustments and a screening process. The study's sample period spans from 2007 to 2019. 57 national high-tech zones that were created prior to 2000 are omitted to lessen the impact on the test results of towns having high-tech zones founded before 2007. Due to the limitations of high-tech areas in cities at the county level in promoting urban green innovation, 8 high-tech zones located in county-level cities are excluded. And 4 high-tech zones with missing severe data are excluded. Among the list of established national high-tech zones, 88 high-tech zones are distributed across 83 prefecture-level cities due to multiple districts within a single city. As a result, 83 cities are selected as the experimental group for this study. Additionally, a control group of 80 cities was selected from among those that did not have high-tech zones by the end of 2019, resulting in a final sample size of 163 cities. This paper collects green patent data for each city from the China Green Patent Statistical Report published by the State Intellectual Property Office. The author compiled the list of national high-tech zones and the starting year of their establishment on the official government website. In addition, the remaining data in this paper primarily originated from the China Urban Statistical Yearbook (2007–2019), the EPS database, and the official websites of the respective city's Bureau of Statistics. Missing values were addressed through linear interpolation. To address heteroskedasticity in the model, the study logarithmically transforms the variables, excluding the disposal variable. Table 1 shows the descriptive analysis of the variables.

TABLE 1 Descriptive analysis.

Var. Name	Obs	Mean	Std. Dev.	Min	Max
lnGI	2,119	2.183	1.413	0.000	6.286
zone	2,119	0.285	0.452	0.000	1.000
lnfdi	2,119	−4.790	1.393	−12.400	−1.648
lnfd	2,119	0.654	0.364	−0.428	3.059
lnhum	2,119	−4.810	0.892	−8.574	−2.140
lnind	2,119	3.591	0.238	2.149	4.229
lnagdp	2,119	10.401	0.654	8.131	12.579

4 Empirical analysis

4.1 National high-tech zones' policy effects on urban green innovation

This study utilizes the DML model to estimate the impact of industrial policies implemented in national high-tech zones at the level of urban green innovation. Following the approach of Zhang and Li (2023), the sample is split in a ratio of 1:4, and the random forest algorithm is used to perform predictions and combine Eq. (1) with Eq. (4) for the regression. Table 2 presents the results with and without controlling for time and city effects. The results indicate that the treatment effect sizes for these four columns are 0.376, 0.293, 0.396, and 0.268, correspondingly, each of which was significant at a 1% level. Thus, Hypothesis 1 is supported.

4.2 Robustness tests

4.2.1 Eliminate the influence of extreme values

To reduce the impact of extreme values on the estimation outcomes, all variables on the benchmark regression, excluding

TABLE 2 Benchmark regression results.

Variant	lnGI			
Zone	0.376*** (6.90)	0.293*** (4.68)	0.396*** (7.11)	0.268*** (4.37)
Controls	Yes	Yes	Yes	Yes
Time fixed effects	Yes	No	No	Yes
Urban fixed effects	No	Yes	No	Yes
Observations	2,119	2,119	2,119	2,119

Notes: ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively; robust z-statistics are shown in parentheses; same below.

TABLE 3 Extreme values removal results.

Variant	lnGI	
	(1) Variable 1% indentation	(2) Variable 5% indentation
Zone	0.269*** (4.37)	0.272*** (4.46)
Controls	Yes	Yes
Time fixed effects	Yes	Yes
Urban fixed effects	Yes	Yes
Observations	2,119	2,119

TABLE 4 The addition of province and time fixed effects interaction terms.

Variant	lnGI
Zone	0.234*** (4.02)
Controls	Yes
Time fixed effects	Yes
Urban fixed effects	Yes
Province-time interaction fixed effects	Yes
Observations	2,119

the disposal variable, undergo a shrinkage process based on the upper and lower 1% and 5% quantiles. Values lower than the lowest and higher than the highest quantile are replaced accordingly. Regression analyses are conducted. Table 3 demonstrates that removing outliers did not substantially alter the findings of this study.

4.2.2 Considering province-time interaction fixed effects

Since provinces are critical administrative units in the governance system of the Chinese government, cities within the same province often share similarities in policy environment and location characteristics. Therefore, to account for the influence of temporal changes across different provinces, this study incorporates province-time interaction fixed effects based on the benchmark regression. Table 4 presents the individual regression results. Based on the regression results, after accounting for the correlation between different city characteristics within the same province, national high-tech zone policies continue to significantly influence urban green innovation, even at the 1% level.

TABLE 5 Results of removing the impact of parallel policies.

Variant	lnGI
Zone	0.245*** (3.31)
Controls	Yes
Time fixed effects	Yes
Urban fixed effects	Yes
Observations	1,790

4.2.3 Excluding other policy disturbances

When analyzing how national high-tech zones affect strategy for urban green innovation, it is susceptible to the influence of concurrent policies. This study accounts for other comparable policies during the same period to ensure an accurate estimation of the policy effect. Since 2007, national high-tech zone policies have been successively implemented, including the development of "smart cities." Therefore, this study incorporates a policy dummy variable for "smart cities" in the benchmark regression. The specific regression findings are shown in Table 5. After controlling for the impact of concurrent policies, the importance of national high-tech zones' policy impact remains consistent.

4.2.4 Resetting the DML model

To mitigate the potential bias introduced by the settings in the DML model on the conclusions, the purpose of this study is to assess the conclusions' robustness using the following methods. First, the sample split ratio of the DML model is adjusted from 1:4 to 1:2 to examine the potential impact of the sample split ratio on the conclusions of this study. Second, the machine learning algorithm is substituted, replacing the random forest algorithm, which has been utilized as a prediction algorithm, with lasso regression, gradient boosting, and neural networks to investigate the potential influence of prediction algorithms on the conclusions of this study. Third, regarding benchmark regression, additional linear models were constructed and analyzed using DML, which involves subjective decisions regarding model form selection. Therefore, DML was employed to construct more comprehensive interactive models, aiming to assess the influence of model settings on the conclusions of this study. The main and auxiliary regressions utilized for the analysis were modified as follows:

$$\boldsymbol{lnGI_{it}} = \boldsymbol{g}(\boldsymbol{Zone_{it}}, \boldsymbol{X_{it}}) + \boldsymbol{U_{it}} \tag{7}$$

10.3389/fenvs.2024.1369433

$$Zone_{it} = m(X_{it}) + V_{it} \tag{8}$$

Combining Eqs (7), (8) for the regression, the interactive model yielded estimated coefficients for the disposition effect:

$$\check{\theta}_1 = E[g(Zone_{it} = 1, X_{it}) - g(Zone_{it} = 0, X_{it})] \tag{9}$$

The results of Eq. (9) are shown in column (5) of Table 6. And all the regression results obtained from the modified DML model are presented in Table 6.

The findings indicate that the sample split ratio in the DML model, the prediction algorithm used, or the model estimation approach does not impact the conclusion that the national high-tech zone policy raises urban areas' level of green innovation. These factors only modify the magnitude of the policy effect to some degree.

4.3 Heterogeneity analysis

4.3.1 Regional heterogeneity

The sample cities were further divided into the east, central, and west regions based on the three major economic subregions to examine regional variations in national high-tech zone policies ' effects on urban green innovation, with the results presented in Table 7. National high-tech zone policies do not statistically significantly affect urban green innovation in the eastern region. However, they have a considerable beneficial influence in the central and western areas. The lack of statistical significance may be explained by the possibility that the setting up of national high-tech zones in the eastern region will provide obstacles to the growth of urban green innovation, such as resource strain and environmental pollution. Given the central and western regions' relatively underdeveloped economic status and industrial structure, coupled with the preceding theoretical analysis, establishing national high-tech zones is a crucial catalyst, significantly boosting urban green innovation levels. Furthermore, the central government emphasizes that setting high-tech national zones should consider regional resource endowments and local conditions, implementing tailored policies. The central and western regions possess unique geographic locations and natural conditions that make them well-suited for developing solar energy, wind energy, and other forms of green energy. Compared to the central region, the national high-tech zone initiative has a more pronounced impact on promoting urban green innovation in the western region. While further optimization is needed for the western region's urban innovation environment, the policy on national high-tech zones has a more substantial incentive effect in this region due to its more significant development potential, positive transformation of industrial structure, and increased policy support from the state, including the development strategy for the western region.

4.3.2 Urban hierarchical heterogeneity

The New Tier 1 Cities Institute's '2020 City Business Charm Ranking' is the basis for this study, with the sample cities categorized into Tier 1 (New Tier 1), Tier 2, Tier 3, Tier 4, and Tier 5. Table 8 presents the regression findings for each of the groups.

The results in Table 8 reveal significant heterogeneity at the city level regarding national high-tech zones' effects on urban green innovation, confirming Hypothesis 2. In particular, the coefficients for the first-tier cities are not statistically significant due to the small sample size, and the same applies to the fifth-tier cities. This could be attributed to the relatively weak economy and infrastructure development issues in the fifth-tier cities. Additionally, due to their limited level of development, the fifth-tier cities may have a relatively homogeneous industrial structure, with a dominance of traditional industries or agriculture and a need for a more diversified industrial layout. National high-tech zones have not

TABLE 6 Results of resetting the DML model.

Variant	lnGI				
	(1) Sample 1: 2	(2) Lasso regression	(3) Gradient promotion	(4) Neural networks	(5) Interactive model
Zone	0.227***(3.60)	0.236***(5.30)	0.331***(6.37)	0.236**(2.71)	0.64***(19.88)
Controls	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Urban fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2,119	2,119	2,119	2,119	2,119

TABLE 7 Heterogeneity test results for different regions.

Variant	lnGI		
	(1) Eastern Region	(2) Central Region	(3) Western Region
Zone	0.076 (0.85)	0.333*** (3.28)	0.843*** (3.83)
Controls	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Urban fixed effects	Yes	Yes	Yes
Observations	806	858	455

TABLE 8 Heterogeneity test results for different classes of cities.

Variant	lnGI				
	(1) First-tier city	(2) Second-tier city	(3) Third-tier city	(4) Fourth-tier city	(5) Fifth-tier city
Zone	0.402 (0.5)	0.307* (1.99)	0.229** (2.45)	0.402***(4.28)	−0.056 (−0.47)
Controls	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes
Urban fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	26	143	624	715	598

TABLE 9 Empirical results of moderating effects.

Variant	lnGI
Zone*lntra	−2.223** (−2.11)
Controls	Yes
Time fixed effects	Yes
Urban fixed effects	Yes
Observations	2,119

greatly aided the development of green innovation in these cities. In contrast, national high-tech zone policies in second-tier, third-tier, and fourth-tier cities have a noteworthy favorable impact on green innovation, indicating their favorable influence on enhancing green innovation in these cities. Despite the lower level of economic development in fourth-tier cities compared to second-tier and third-tier cities, the fourth-tier cities' national high-tech zones have the most pronounced impact on promoting green innovation. This could be attributed to the ongoing transformation of industries in fourth-tier cities, which are still in the technology diffusion and imitation stage, allowing these cities' national high-tech zones to maintain a high marginal effect. Thus, Hypothesis 2 is supported.

5 Further analysis

According to the empirical findings, setting high-tech national zones significantly raises the bar for urban green innovation. Therefore, it is essential to understand the underlying factors and mechanisms that contribute to the positive correlation. This paper constructs a moderating effect test model using Eqs 5, 6 and provides a detailed discussion by introducing transportation infrastructure as a moderating variable.

The empirical finding of the moderating impact of transportation infrastructure is shown in Table 9. The dichotomous interaction term Zone*lntra is significantly negative at the 5% level, suggesting that the impact of national high-tech zone policies on the level of urban green innovation is negatively moderated by transportation infrastructure. This result deviates from the general expectation, but it aligns with the complexity of the role played by transportation infrastructure in the context of modern economic development, as discussed in the previous theoretical analysis. This could be attributed to the insufficient green innovation benefits generated by the policy on national high-tech zones at the current stage, which fails to compensate for the adverse effects of excessive resource consumption and environmental pollution caused by the construction of the zone. Furthermore, transportation infrastructure can lead to an excessive concentration of similar enterprises in the high-tech zones. This excessive concentration creates a relative crowding effect, intensifying competition among enterprises. It diminishes their inclination to engage in green innovation collaboration and investment and hinders their effective implementation of technological research and development activities. Moreover, the excessive clustering of similar enterprises implies a need for more diversity in green innovation activities among businesses located in national high-tech zones. This results in duplicated green innovation outputs and hinders the advancement of green innovation. Thus, Hypothesis 3 is supported.

6 Conclusion and policy recommendations

6.1 Conclusion

Based on panel data from 163 prefecture-level cities in China from 2007 to 2019, the net effect of setting national high-tech zones on urban green innovation was analyzed using the double machine learning model. The results found that: firstly, the national high-tech zone policy significantly raises the degree of local green innovation, and these results remain robust even after accounting for various factors that could affect the estimation results. Secondly, in the central and western regions, the level of urban green innovation is positively impacted by the national high-tech zone policy; However, this impact is less significant in the eastern region. In the western region compared to the central region, the national high-tech zone initiative has a stronger impact on increasing the level of urban green innovation. Across different city levels, compared to second-tier and third-tier cities, the high-tech zone policy has a more substantial impact on increasing the level of green innovation in fourth-tier cities. Thirdly, based on the moderating effect mechanism test, the construction of transportation infrastructure weakens the promotional effect of national high-tech zones on urban green innovation.

6.2 Policy recommendations

In order that national high-tech zones can better promote China's high-quality development, this paper proposes the following policy recommendations:

(1) Urban green innovation in China depends on accelerating the setting up of national high-tech zones and creating an atmosphere that supports innovation. Establishing national high-tech zones as testbeds for high-quality development and green innovation has significantly elevated urban green innovation. Thus, cities can efficiently foster urban green innovation by supporting the development of national high-tech zones. Cities that have already established national high-tech zones should further encourage enterprises within these zones to increase their investment in research and development. They should also proceed to foster the leadership of national high-tech zones for urban green innovation, assuming the role of pilot cities as models and leaders. Additionally, it is essential to establish mechanisms for cooperation and synergy between the pilot cities and their neighboring cities to promote collective green development in the region.

(2) Expanding the pilot program and implementing tailored policies based on local conditions are essential. Industrial policies about national high-tech zones have differing effects on urban green innovation. Regions should leverage their comparative advantages, consider urban development's commonalities and unique aspects, and foster a stable and sustainable green innovation ecosystem. The western and central regions should prioritize constructing and enhancing new infrastructure and bolster support for the high-tech green industry. The western region should seize the opportunity presented by national policies that prioritize support, quicken the rate of environmental innovation, and progressively bridge the gap with the eastern and central regions in various aspects. Furthermore, second-tier, third-tier, and fourth-tier cities should enhance the advantages of national high-tech zone policies, further maintaining the high standard of green innovation and keeping green innovation at an elevated level. Regions facing challenges in green innovation, particularly fifth-tier cities, should learn from the development experiences of advanced regions with national high-tech zones to compensate for their deficiencies in green innovation.

(3) Highlighting the importance of transportation regulation and enhancing collaboration in green innovation is crucial. Firstly, transportation infrastructure should be maximized to strengthen coordination and cooperation among regions, facilitate the smooth movement of innovative talents across regions, and facilitate the rational sharing of innovative resources, collectively enhancing green innovation. Additionally, attention ought to be given to the industrial clustering effect of parks to prevent the wastage of resources and inefficiencies resulting from the excessive clustering of similar industries. Efforts should be focused on effectively harnessing the latent potential of crucial transportation infrastructure areas as long-term drivers of development, promptly mitigating the negative impact of transportation infrastructure construction, and gradually achieving the synergistic promotion of the setting up of national high-tech zones and the raising of urban levels of green innovation, among other overarching objectives.

6.3 Limitations and future research

Our study has some limitations because the research in this paper is conducted in the institutional context of China. For example, not all countries are suitable for implementing similar industrial policies to develop the economy while focusing on environmental protection. However, we recognize that this study is interesting and relevant, and it encourages us to focus more intensely on environmental protection from an industrial policy perspective. Moreover, this paper exhibits certain limitations in the research process. Firstly, the urban green innovation measurement index was developed using the quantity of green patent authorizations. Future studies could focus on green innovation processes, such as the quality of green patents granted. Secondly, the paper employs machine learning techniques for causal inference. Subsequent investigations could delve further into the potential applications of machine learning algorithms in environmental sciences to maximize the benefits of innovative research methodologies.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

WC: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing–review and editing. YJ: Conceptualization, Data curation, Formal Analysis, Investigation, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing. BT: Investigation, Project administration, Writing–review and editing.

Funding

The authors declare that financial support was received for the research, authorship, and/or publication of this article. This research was supported by the Youth Fund for Humanities and Social Science research of Ministry of Education (20YJC790004).

Acknowledgments

The authors are grateful to the editors and the reviewers for their insightful comments.

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.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Albahari, A., Pérez-Canto, S., Barge-Gil, A., and Modrego, A. (2017). Technology parks versus science parks: does the university make the difference? *Technol. Forecast. Soc. Change* 116, 13–28. doi:10.1016/j.techfore.2016.11.012

Alder, S., Shao, L., and Zilibotti, F. (2016). Economic reforms and industrial policy in a panel of Chinese cities. *J. Econ. Growth* 21, 305–349. doi:10.1007/s10887-016-9131-x

Ansaris, M., Ashrafi, S., and Jebellie, H. (2016). The impact of human capital on green innovation. *Industrial Manag. J.* 8 (2), 141–162. doi:10.22059/imj.2016.60653

Banister, D., and Berechman, Y. (2001). Transport investment and the promotion of economic growth. *J. Transp. Geogr.* 9 (3), 209–218. doi:10.1016/s0966-6923(01)00013-8

Behrens, K., Lamorgese, A. R., Ottaviano, G. I., and Tabuchi, T. (2007). Changes in transport and non-transport costs: local vs global impacts in a spatial network. *Regional Sci. Urban Econ.* 37 (6), 625–648. doi:10.1016/j.regsciurbeco.2007.08.003

Bo, W., Yongzhong, Z., Lingshan, C., and Xing, Y. (2020). Urban green innovation level and decomposition of its determinants in China. *Sci. Res. Manag.* 41 (8), 123. doi:10.19571/j.cnki.1000-2995.2020.08.013

Cao, Q. F. (2019). The latest researches on place based policy and its implications for the construction of xiong'an national new district. *Sci. Technol. Prog. Policy* 36 (2), 36–43. (in Chinese).

Cattapan, P., Passarelli, M., and Petrone, M. (2012). Brokerage and SME innovation: an analysis of the technology transfer service at area science park, Italy. *Industry High. Educ.* 26 (5), 381–391. doi:10.5367/ihe.2012.0119

Chandrashekar, D., and Bala Subrahmanya, M. H. (2017). Absorptive capacity as a determinant of innovation in SMEs: a study of Bengaluru high-tech manufacturing cluster. *Small Enterp. Res.* 24 (3), 290–315. doi:10.1080/13215906.2017.1396491

Chen, M., and Zheng, Y. (2008). China's regional disparity and its policy responses. *China & World Econ.* 16 (4), 16–32. doi:10.1111/j.1749-124x.2008.00119.x

Chernozhukov, V., Chetverikov, D., Demirer, M., Duflo, E., Hansen, C., Newey, W., et al. (2018). Double/debiased machine learning for treatment and structural parameters. *Econ. J.* 21 (1), C1–C68. doi:10.1111/ectj.12097

De Beule, F., and Van Beveren, I. (2012). Does firm agglomeration drive product innovation and renewal? An application for Belgium. *Tijdschr. Econ. Soc. Geogr.* 103 (4), 457–472. doi:10.1111/j.1467-9663.2012.00715.x

Díez-Vial, I., and Fernández-Olmos, M. (2017). The effect of science and technology parks on firms' performance: how can firms benefit most under economic downturns? *Technol. Analysis Strategic Manag.* 29 (10), 1153–1166. doi:10.1080/09537325.2016.1274390

Fang, Z., Kong, X., Sensoy, A., Cui, X., and Cheng, F. (2021). Government's awareness of environmental protection and corporate green innovation: a natural experiment from the new environmental protection law in China. *Econ. Analysis Policy* 70, 294–312. doi:10.1016/j.eap.2021.03.003

Fritsch, M., and Slavtchev, V. (2011). Determinants of the efficiency of regional innovation systems. *Reg. Stud.* 45 (7), 905–918. doi:10.1080/00343400802251494

He, J. A., Peng, F. P., and Xie, X. Y. (2022). Mixed-ownership reform, political connection and enterprise innovation: based on the double/unbiased machine learning method. *Sci. Technol. Manag. Res.* 42 (11), 116–126. (in Chinese).

Hong, J., Feng, B., Wu, Y., and Wang, L. (2016). Do government grants promote innovation efficiency in China's high-tech industries? *Technovation* 57, 4–13. doi:10.1016/j.technovation.2016.06.001

Huang, W. J., and Fernández-Maldonado, A. M. (2016). High-tech development and spatial planning: comparing The Netherlands and Taiwan from an institutional perspective. *Eur. Plan. Stud.* 24 (9), 1662–1683. doi:10.1080/09654313.2016.1187717

Hull, I., and Grodecka-Messi, A. (2022). *Measuring the impact of taxes and public services on property values: a double machine learning approach*. arXiv preprint arXiv:2203.14751.

Jiang, T. (2022). Mediating effects and moderating effects in causal inference. *China Ind. Econ.* 5, 100–120. doi:10.19581/j.cnki.ciejournal.2022.05.005

Knittel, C. R., and Stolper, S. (2021). Machine learning about treatment effect heterogeneity: the case of household energy use. *Nashv. TN* 37203, 440–444. doi:10.1257/pandp.20211090

Li, H., and Tang, L. (2015). Transportation infrastructure investment, spatial spillover effect and enterprise inventory. *Manag. World* 4, 126–136. doi:10.19744/j.cnki.11-1235/f.2015.04.012

Li, W. H., Liu, F., and Liu, T. S. (2022a). Can national high-tech zones improve the urban innovation efficiency? an empirical test based on the effect of spatial agglomeration regulation. *Manag. Rev.* 34 (5), 93. doi:10.14120/j.cnki.cn11-5057/f.2022.05.007

Li, X. (2015). Analysis and outlook of the related researches on green innovation. *R&D Manag.* 27 (2), 1–11. doi:10.13581/j.cnki.rdm.2015.02.001

Li, X., Shao, X., Chang, T., and Albu, L. L. (2022b). Does digital finance promote the green innovation of China's listed companies? *Energy Econ.* 114, 106254. doi:10.1016/j.eneco.2022.106254

Li, X. P., Li, P., Lu, D. G., and Jiang, F. T. (2015). Economic agglomeration, selection effects and firm productivity. *J. Manag. World* 4, 25–37+51. (in Chinese). doi:10.19744/j.cnki.11-1235/f.2015.04.004

Liu, R. M., and Zhao, R. J. (2015). Does the national high-tech zone promote regional economic development? A verification based on differences-in-differences method. *J. Manag. World* 8, 30–38. doi:10.19744/j.cnki.11-1235/f.2015.08.005

Luo, R., and Wang, Q. M. (2023). Does the construction of national demonstration logistics park produce economic growth effect? *Econ. Surv.* 40 (1), 47–56. doi:10.15931/j.cnki.1006-1096.2023.01.015

Luo, Y., Salman, M., and Lu, Z. (2021). Heterogeneous impacts of environmental regulations and foreign direct investment on green innovation across different regions in China. *Sci. total Environ.* 759, 143744. doi:10.1016/j.scitotenv.2020.143744

Melitz, M. J., and Ottaviano, G. I. (2008). Market size, trade, and productivity. *Rev. Econ. Stud.* 75 (1), 295–316. doi:10.1111/j.1467-937x.2007.00463.x

Park, S. C., and Lee, S. K. (2004). The regional innovation system in Sweden: a study of regional clusters for the development of high technology. *Ai Soc.* 18 (3), 276–292. doi:10.1007/s00146-003-0277-7

Pokharel, R., Bertolini, L., Te Brömmelstroet, M., and Acharya, S. R. (2021). Spatio-temporal evolution of cities and regional economic development in Nepal: does transport infrastructure matter? *J. Transp. Geogr.* 90, 102904. doi:10.1016/j.jtrangeo.2020.102904

Qiu, Y., Wang, H., and Wu, J. (2023). Impact of industrial structure upgrading on green innovation: evidence from Chinese cities. *Environ. Sci. Pollut. Res.* 30 (2), 3887–3900. doi:10.1007/s11356-022-22162-1

Sosnovskikh, S. (2017). Industrial clusters in Russia: the development of special economic zones and industrial parks. *Russ. J. Econ.* 3 (2), 174–199. doi:10.1016/j.ruje.2017.06.004

Sun, Z., and Sun, J. C. (2015). The effect of Chinese industrial policy: industrial upgrading or short-term economic growth. *China Ind. Econ.* 7, 52–67. (in Chinese). doi:10.19581/j.cnki.ciejournal.2015.07.004

Tan, J., and Zhang, J. (2018). Does national high-tech development zones promote the growth of urban total factor productivity? —based on" quasi-natural experiments" of 277 cities. *Res. Econ. Manag.* 39 (9), 75–90. doi:10.13502/j.cnki.issn1000-7636.2018.09.007

Vásquez-Urriago, Á. R., Barge-Gil, A., Rico, A. M., and Paraskevopoulou, E. (2014). The impact of science and technology parks on firms' product innovation: empirical evidence from Spain. *J. Evol. Econ.* 24, 835–873. doi:10.1007/s00191-013-0337-1

Wang, F., Dong, M., Ren, J., Luo, S., Zhao, H., and Liu, J. (2022a). The impact of urban spatial structure on air pollution: empirical evidence from China. *Environ. Dev. Sustain.* 24, 5531–5550. doi:10.1007/s10668-021-01670-z

Wang, M., and Liu, X. (2023). The impact of the establishment of national high-tech zones on total factor productivity of Chinese enterprises. *China Econ.* 18 (3), 68–93. doi:10.19602/j.chinaeconomist.2023.05.04

Wang, Q., She, S., and Zeng, J. (2020). The mechanism and effect identification of the impact of National High-tech Zones on urban green innovation: based on a DID test. *China Popul. Resour. Environ.* 30 (02), 129–137.

Wang, W. S., and Xu, T. S. (2020). A research on the impact of national high-teach zone establishment on enterprise innovation performance. *Econ. Surv.* 37 (6), 76–87. doi:10.15931/j.cnki.1006-1096.20201010.001

Wang, Z., Yang, Y., and Wei, Y. (2022b). Has the construction of national high-tech zones promoted regional economic growth? empirical research from prefecture-level cities in China. *Sustainability* 14 (10), 6349. doi:10.3390/su14106349

Weber, M., Driessen, P. P., and Runhaar, H. A. (2014). Evaluating environmental policy instruments mixes; a methodology illustrated by noise policy in The Netherlands. *J. Environ. Plan. Manag.* 57 (9), 1381–1397. doi:10.1080/09640568.2013.808609

Wu, Y. B. (2019). Does fiscal decentralization promote technological innovation. *Mod. Econ. Sci.* 41, 13–25.

Xu, S. D., Jiang, J., and Zheng, J. (2022). Has the establishment of national high-tech zones promoted industrial Co-Agglomeration? an empirical test based on difference in difference method. *Inq. into Econ. Issues* 11, 113–127. (in Chinese).

Yang, F., and Guo, G. (2020). Fuzzy comprehensive evaluation of innovation capability of Chinese national high-tech zone based on entropy weight—taking the northern coastal comprehensive economic zone as an example. *J. Intelligent Fuzzy Syst.* 38 (6), 7857–7864. doi:10.3233/jifs-179855

Yu, N., De Jong, M., Storm, S., and Mi, J. (2013). Spatial spillover effects of transport infrastructure: evidence from Chinese regions. *J. Transp. Geogr.* 28, 56–66. doi:10.1016/j.jtrangeo.2012.10.009

Yuan, H., and Zhu, C. L. (2018). Do national high-tech zones promote the transformation and upgrading of China's industrial structure. *China Ind. Econ.* 8, 60–77. doi:10.19581/j.cnki.ciejournal.2018.08.004

Zhang, T., Chen, L., and Dong, Z. (2018). Highway construction, firm dynamics and regional economic efficiency. *China Ind. Econ.* 1, 79–99. doi:10.19581/j.cnki.ciejournal.20180115.003

Zhang, T., and Li, J. C. (2023). Network infrastructure, inclusive green growth, and regional inequality: from causal inference based on double machine learning. *J. Quantitative Technol. Econ.* 40 (4), 113–135. doi:10.13653/j.cnki.jqte.20230310.005

Zhou, L., and Shen, K. (2020). National city group construction and green innovation. *China Popul. Resour. Environ.* 30 (8), 92–99.

Zhou, X., and Du, J. (2021). Does environmental regulation induce improved financial development for green technological innovation in China? *J. Environ. Manag.* 300, 113685. doi:10.1016/j.jenvman.2021.113685