National Innovative City and Green Technology Progress: Empirical Evidence from China

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Abstract: In this paper, a quasi-natural experiment of national innovative city pilot policy (NICPP) is carried out to investigate the impact of the NICPP on green technology innovation (GTI) and its intrinsic mechanism with the method of difference-in-difference. It is found that the NICPP significantly enhances GTI, and there is a certain lag and persistence in this effect. Heterogeneity analysis shows that the higher the administrative level and the more the geographical advantages of NICPP, the more obvious the driving effect of GTI. The mechanism test shows that the NICPP has an effect on the GTI through three channels: innovation factor input, agglomeration effect of science and technology talent, and entrepreneurial vitality empowerment. The findings of this study provide policy insights for further optimizing the construction of innovative cities and then promoting GTI development, ultimately realizing green dynamics transformation and high-quality development of China's economy.

Keywords: National innovative cities; Green technology Progress; Agglomeration effect; High-quality development

1 Introduction

In the report of the 20th National Congress of the Communist Party of China, General Secretary Xi Jinping is emphasized that the concept that "lucid water and lush mountains are invaluable assets" should be firmly established and practiced, which requires government to designate the development at the height of harmonious coexistence between human and nature, as well as launching a series of measures to promote high-quality development, such as accelerating the green transformation of development mode, promoting the formation of green and low-carbon production mode and lifestyle, promoting green development and harmonious coexistence between human and nature, and put

forward the long-term goal of socialist modernization in 2035, i.e. fundamentally improving the ecological environment and basically realizing the goal of building the "Beautiful China". In 2021, the State Council issued the *Guiding Opinions on Accelerating the Establishment and Improvement of a Green Low-carbon Circular Development Economic System*, emphasizing the need to accelerate the construction of a market-oriented green technology innovation system. The problem of pollution emissions and ecological damage caused by China's extensive economic growth pattern driven by factor resources in the past is becoming more and more serious, which is contrary to the requirements of the current high-quality economic development, innovation-driven development strategy and "double carbon" goal. Data from China's State Environmental Protection Administration and National Bureau of Statistics show that the national economic loss due to environmental pollution in 2021 was 518.8 billion RMB, accounting for 3.05% of the annual GDP, with serious socio-economic consequences. At the same time, behind the rapid growth of green technology patents in China, there are still problems such as their low proportion of overall patents and the weak overseas layout of green and low-carbon patents. In the international community, green development and environmental protection are also key issues at the heart of the world's development, and the "Stockholm+50" summit once again emphasized that the Earth is still the only inhabitable planet we have, making the cry "There is only one Earth". The threat of environmental pollution and climate extremes has had a serious impact on countries around the world, especially developing countries, causing the displacement and even death of tens of millions of people and trillions of dollars in economic losses. Therefore, it is an urgent task to build an environmentally friendly and technology-intensive sustainable economic development system and promote the coordinated development of economic society and natural environment. It has become the focus of the government and academia all around the world to improve the level of green technology innovation (GTI) to help the green low-carbon circular economy.

Innovation is the decisive factor for a country to maintain strong economic growth and gain international competitive advantage (Kremer, 2020), and GTI, as the key to promote the green development of China's economy and help the construction of a beautiful China, is also the first driver for the transformation of growth drivers from old to new and the green transformation and upgrading of development mode. In order to accelerate the construction of the "Innovative Country" and promote the green transformation of technological innovation, the Chinese government has set up a total of 78 national pilot innovative cities in batches since 2008. The essence of this policy is to break the shackles of high innovation thresholds and excessive costs, improve the independent innovation capacity of cities, strengthen the new model of innovation-driven urban development, and ultimately promote the green low-carbon urban development with green technological innovation. The national innovative city pilot policy (NICPP) is a multi-pronged policy system for systematic innovation and development, which includes agglomeration of innovation subjects, agglomeration of innovation resources, improvement of innovation system and mechanism, optimization of industrial structure and improvement of urban business environment and so on. The

NICPP provides an important reference for developing countries to formulate innovation incentive policies in response to their national conditions and to achieve a "corner overtaking", and also contributes Chinese wisdom and solutions to other developing countries and the international community on how to deal with innovation incentives and low-carbon environmental protection and ultimately achieve green innovative development. Green technology innovation and urban green development are one of the main focuses of the NICPP. Whether the NICPP can effectively promote the level of GTI and how to improve the GTI capability are not only the core issues of building an innovative city and even an innovative country, but also key propositions for China to achieve green transformation of economic development mode, innovative transformation of economic growth drivers and high-quality economic development. It is also a challenge for developing countries and the international community to use green innovation to achieve low carbon and promote the cause of carbon peaking and carbon neutrality, which is the focus of this paper.

The literature related to this study can be roughly divided into two categories, one is the literature related to GTI. The literature on GTI is mainly based on the Porter Hypothesis (Porter & Van der Linde, 1995) and studies the non-market instruments, focusing on the impact of environmental regulation on GTI. From the perspective of enterprise-level research, there is no consensus on the impact of environmental regulation on corporate GTI. Scholars with positive views believe that the implementation of environmental regulation by the government will increase the R&D expenditure of enterprises by increasing cost pressure (Milani, 2017), facilitate the GTI of enterprises and accelerate the process of green production transformation and upgrading of enterprises (Liu & Li, 2022; Du et al., 2022); other scholars have found that different environmental regulation methods will affect the effect of GTI (Requate & Unold, 2001; Wang et al., 2022), and may even have a negative effect on reducing technological innovation efficiency and production efficiency (Van Leeuwen & Mohnen, 2017; Du et al., 2021). From the perspective of urban research, firstly, the improvement of urban institutional environment, innovation environment and market environment will strengthen the input of technological production elements (Gogokhia & Berulava, 2021; Zheng et al., 2021), and the increase of urban wealth will promote the development of technological progress in a green direction (Jerzmanowski & Tamura, 2019; Chen, 2020; Arranz et al., 2019; Nguyen et al., 2020); secondly, with the increase of green consumption demand generated by urban development, enterprises will strengthen green technology innovation and produce environmentally friendly products according to market demand (Arranz et al., 2019; Wang et al., 2021); thirdly, the improvement of the city's market environment, innovation environment and public service infrastructure will provide more employment opportunities, as well as innovation and entrepreneurship opportunities, thus attracting agglomeration of capital, talents and technology (Diamond, 2016), further strengthening the green development appeal of resource agglomeration areas, promoting the level of GTI, and thus promoting the high-quality development of the urban economy (Zhao et al., 2022), forming a virtuous circle of interaction between GTI and urban development.

The other category is the literature on the NICPP. With the increasing distribution range and number of national innovative pilot cities and the emerging effects of the NICPP implementation, scholars have gradually assessed the effects of this policy in depth, and the related literature focuses on the effects of the pilot policy on the technological innovation of enterprises and cities. At the firm level, many scholars have found that the construction of innovative cities has a significant positive effect on improving the quantity and quality of firm innovation (Cao et al., 2022; Li et al., 2022), and the NICPP can drive firm technological innovation by optimizing the innovation environment and strengthening the subsidy effect (Cao et al., 2022); at the city level, many scholars have taken multiple perspectives to analyzing the policy effects of national innovative city construction, Bai et al. (2022) found that the NICPP enhances urban entrepreneurial activity by exerting the agglomeration effects of venture capital, talent and technology.

By browsing the relevant literature, it can be found that the research on green technology innovation mainly focuses on the enterprise level, and there are few studies on the regional level, especially the municipal level. As the basic unit of a country, the city gathers all kinds of production and innovation elements (Smit et al., 2015). The level of urban development plays a non-negligible role in regional and even national economic development. At the same time, most of the research on the construction of innovative cities only focuses on technological innovation in the traditional sense, which fails to meet the requirements of the current green development transformation to go deep into the GTI level. Therefore, it is of great practical significance to study the impact of NICPP on the level of GTI and reveal the internal mechanism of policy effects.

Compared with the existing literature, the marginal contributions of this paper are mainly reflected in the following points: (1) Different from the existing literature on the economic effect of NICPP, this paper explores the GTI effect of NICPP from the perspective of environmental effect. This paper not only examines the static effect of NICPP on GTI, but also identifies its dynamic effect. (2) This paper identifies the influence mechanism of NICPP on green technology innovation as well as the heterogeneity of urban geographic location and administrative level.

The rest of this paper is structured as follows: Part 2 describes the theoretical analysis and research hypothesis; Part 3 analysis the empirical research design; Part 4 displays the empirical validation and result analysis; and Part 5 is the research conclusion and policy implications.

2 Theoretical analysis and research hypothesis

2.1 NICPP and GTI

The NICPP is a pilot policy at the municipal level formulated to achieve the goal of building the "Innovative Country" and implement the innovation-driven development strategy. It has the characteristics of development pillar, model exploration and policy-driven combination. First, the NICPP is an important pillar of building the "Innovative Country". The construction of innovative cities is to absorb and integrate innovative resources such as finance, talents and policies to form a

resource agglomeration effect. By optimizing the allocation of innovative resources, increasing the input of innovative resources, and optimizing the external environment, it promotes technological innovation in various fields (Cao et al., 2022), realizes the transformation and upgrading of urban development to green low-carbon and innovation-driven in traditional industries (Cohendet et al., 2009), and lays a first-mover competitive advantage in strategic emerging industries; secondly, the NICPP is an urgent requirement for exploring new models of urban development. Under the background that the extensive economic growth model with intensive production factors is difficult to sustain, urban development, on the one hand, needs to break through the constraints of population, resources and environment; on the other hand, it needs to solve the environmental problems such as heavy pollution and destructive development of industries. The construction of national innovative cities promotes GTI activities in key areas by increasing R&D and investment in technologies such as environmental protection and information transformation, and ultimately realizes the transformation of the city to a resource-saving and environment-friendly development mode. Finally, the NICPP is an exploration of the multi-dimensional combination of innovation policy tools. The coverage of the NICPP is relatively wide. The pilot cities can formulate corresponding policy tools depending on their own social and economic development status, industrial development advantages and disadvantages, and urban development planning (Bai et al., 2022). The market competition type, administrative order type and voluntary pilot type are combined with each other to formulate green innovation policies with regional characteristics. For example, the pilot cities formulate industry subsidies, fiscal support, green finance, specific tax incentives and special funds according to the situation and stimulate the green innovation vitality of various industries and enterprises in the city through a comprehensive and multi-level policy combination (Huang et al., 2022; Irfan et al., 2022), ultimately enhancing GTI and promoting urban green development transformation.

Hypothesis 1: **The NICPP can effectively promote the level of GTI.**

2.2 Heterogeneity analysis of city characteristics on the effect of NICPP

The above contents have analyzed of the NICPP on the impact of GTI, but have not fully considered the difference of urban characteristics on the policy effect. Established studies have shown that differences in the geographical location and administrative hierarchy of cities can have heterogeneous effects on urban innovation resource concentration, population concentration and socio-economic development, and therefore, their effects on the implementation effects of NICPP can also be influenced to some extent.

From the perspective of the city's geographical location, the construction of innovative cities will be influenced by the city's economic basis, resource endowment and other factors when it plays a driving role in the GTI. Hu Huanyong Line is a population density dividing line starting from Aihun, Heilongjiang Province to Tengchong, Yunnan Province. The northwest side of the line is dominated by grasslands, deserts and plateaus with arid climate and scarce rainfall, while the

southeast side is dominated by plains and hills with humid climate and abundant rainfall, which leads to differences in population and economy between the two sides of the Line (Wang et al., 2022). In terms of population, the northwest part of Hu Huanyong Line has poor geographical and climatic conditions, which makes it inhospitable for population to live, while the southeast part has gentle terrain and pleasant climate. As a result, the average temperature, precipitation, soil quality and topographic conditions on each side of the Line shows great differences, and a large number of people gather in the southeast part of the Line, which is more suitable for living. Cities on the southeast side of Hu Huanyong Line can play the role of population agglomeration to form a larger scale of talent supply and promote GTI and industrial green low-carbon transformation and upgrading. On the economic level, due to geographical and climatic factors, the northwest side of Hu Huanyong Line was dominated by animal husbandry in the past, while the southeast side has a more developed farming economy. Infrastructure construction and urbanization process of cities are also influenced by geographical location, climatic conditions and ethnic culture. Cities on the northwest side face problems such as difficult construction and low economic effects when carrying out infrastructure construction due to the complex geographical situation and harsh weather conditions, then the urbanization level grows slowly due to cultural and infrastructural factors, thus the gap between the economic development levels on both sides of Hu Huanyong Line is relatively wide. The cities located on the southeast side of the Line can take advantage of the population concentration and developed economy to gather more innovative resources as well as scientific and technological talents to help improve the green innovation capacity and better utilize the effect of the NICPP to improve the overall level of the GTI.

From the perspective of the administrative hierarchy of cities, China's provincial capitals, municipalities and special economic zones have better policy implementation foundations. Since the Reform and Opening-up, China has carried out a large number of policies and practices of opening-up and administrative reform. Some of the reforms have been carried out step by step in batches according to the principle of "pilot first and gradual promotion". Therefore, the central government will give special status to some cities to achieve the reform pilot demonstration goals. Provincial capitals, municipalities and special economic zones are the pioneers of such reforms and policy demonstration cities. These cities have a strong economic foundation and government administrative capacity, and also have higher freedom of policy formulation. At the same time, their special status can strengthen their agglomeration of resources such as talents, finance and innovation in the surrounding areas, forming regional central cities or central urban agglomerations (Bai et al., 2022; Cui & Liu, 2022). Therefore, cities with higher administrative levels can give full play to their advantages in economic development, institutional reform and infrastructure, better gather green innovation resources, and better play the green innovation promotion effect of the NICPP to promote the level of GTI. However, the general municipal level cities are relatively weak in terms of economic strength and policy agglomeration compared with the above-mentioned cities, which makes the general municipal level cities weaker than the cities with high administrative levels in

terms of innovation factor agglomeration, financial investment, as well as innovation and entrepreneurship attraction, thus limiting the GTI promotion effect of NICPP to a certain extent.

Hypothesis 2: **Cities with good geographical location and high administrative level can better play the promoting effect of NICPP on GTI.**

2.3 Analysis of the mechanism of the role of NICPP in influencing GTI

The intrinsic mechanism of NICPP influencing GTI is reflected in the following three aspects.

First, in the process of promoting green and low-carbon development, there are problems such as path dependence and severe external financing constraints (Yu et al., 2021). Combined with the cost pressure of emission reduction and pollution control, and the influence of high investment and high risk of green technology innovation R&D, it may reduce the R&D investment of GTI and inhibit the R&D willingness of GTI. It has a crowding out effect on GTI input (Du et al., 2022), so more capital investment is needed to promote GTI to achieve transformational innovation of green development (Huang et al., 2019). And the NICPP can promote the increase of GTI investment in the following two aspects, and then enhance the level of GTI: On the one hand, the government's financial support and guidance is an important grasp for building national innovative cities. In the *Guidelines for Building Innovative Cities*, it is pointed out that the local financial investment in science and technology should be increased, and the government can provide more financial support for each innovation entity according to the pilot work guidelines, and lower the threshold and cost of GTI through the direct support of financial subsidies, so as to stimulate the green innovation vitality of each innovation entity, and finally enhancing the level of GTI. On the other hand, according to signal theory by Spence (1978), the financial subsidies from governments can transmit the quality information of innovation subjects to outside investors to form a certification effect, release favorable policy news to potential investors, and attract private capital and venture capital from society to enter the external financing of GTI, thus alleviating the external financing constraint of green innovation to promote the GTI investment agglomeration of cities (Yang et al., 2022), forming a good situation that official capital drives social capital investment and gathers innovation resources from all parties to jointly promote GTI.

Second, scientific and technological talents are the key subjects to promote GTI and the main force to promote the construction of innovative cities. The NICPP provides a policy basis for the pilot cities to formulate talent policies, creates policy advantages for the pilot cities to establish a highland of talent agglomeration. Pilot cities can build an integrated multi-level talent attraction policy system by improving the talent training system of their own cities, formulating new policies for the introduction of innovative talents and optimizing the development environment of innovative talents. In the process of promoting the construction of innovative cities, each pilot city actively improves the city's talent policy and increases the attraction of talents, such as solving the life problems of scientific and technological talents by providing talent subsidies, housing subsidies and

urban *hukou*; optimizes the working environment of scientific and technological talents by reforming the work evaluation system, improving job promotion incentives and increasing scientific research subsidies. On the one hand, the agglomeration of innovative talents strengthens the stock and density of urban knowledge, promotes the growth of regional knowledge and technology, and provides the basis of talent reserve and knowledge stock for GTI. On the other hand, talent agglomeration can play a knowledge spillover effect, help to reduce the cost of knowledge dissemination, increase the frequency of talent exchange through formal and informal channels, play the function of re-learning and re-cultivating talents, and provide a favorable environment for the rapid learning and diffusion of knowledge and professional skills, thus helping each innovation subject to exchange information and learn skills faster, better collect market information and meet market demand, enhance the GTI ability and innovation vitality of each innovation subject, and ultimately create more GTI results.

Third, as an extension of GTI, entrepreneurship is an important way to transform GTI results on the ground and commercialize the industry (Shane & Venkataraman, 2003). The ultimate goal of the NICPP is to promote the innovation-driven development of the city, therefore, it becomes crucial to exploit the actual economic effects of the GTI results, and the NICPP pays high attention to the activity of entrepreneurial activities and uses entrepreneurship as a measurement and evaluation indicator. From the perspective of willingness to innovate, the construction of national innovative cities motivates the entrepreneurial vitality of various innovative agents in the city, stimulates the research and exploration of niche areas in various industries, creates a technology agglomeration effect, and thus generates more GTI results; from the perspective of administrative factors, cumbersome government administrative procedures and processes create additional transaction costs for innovation and entrepreneurship, and at the same time tend to breed rent-seeking problems and produce negative effects that hinder innovation and entrepreneurship activities. The NICPP puts forward higher requirements on the administrative capacity and efficiency of the pilot cities, which further pushes the government to deepen the reform of government functions to streamline the government, delegate power, and improve government services in the field of science and technology, improve the government management system and mechanism, streamline the administrative process and improve the administrative efficiency, reduce the threshold of urban entrepreneurship and non-productive costs, and thus enhance the entrepreneurial activity of the cities. This will enhance the entrepreneurial activity in the city and provide more opportunities and conditions for GTI activities. From the perspective of industrial agglomeration, the entrepreneurship-driven effect played by the NICPP can promote enterprises and industries to form a union in the region, cause the industrial agglomeration effect and radiation effect, and further promote the integrated development with the green innovation chain by uniting the upstream and downstream of the industrial chain supply chain, so as to promote the market-oriented green innovation guaranteed by the industrial chain supply chain.

Hypothesis 3: **The NICPP can enhance GTI by exerting the agglomeration effect of innovation input.**

Hypothesis 4: **The NICPP can enhance GTI by exerting the agglomeration effect of science and technology talent.**

Hypothesis 5: **The NICPP can enhance GTI by exerting the entrepreneurial vitality empowerment.**

And finally, a total research framework is shown in **Figure 1**.

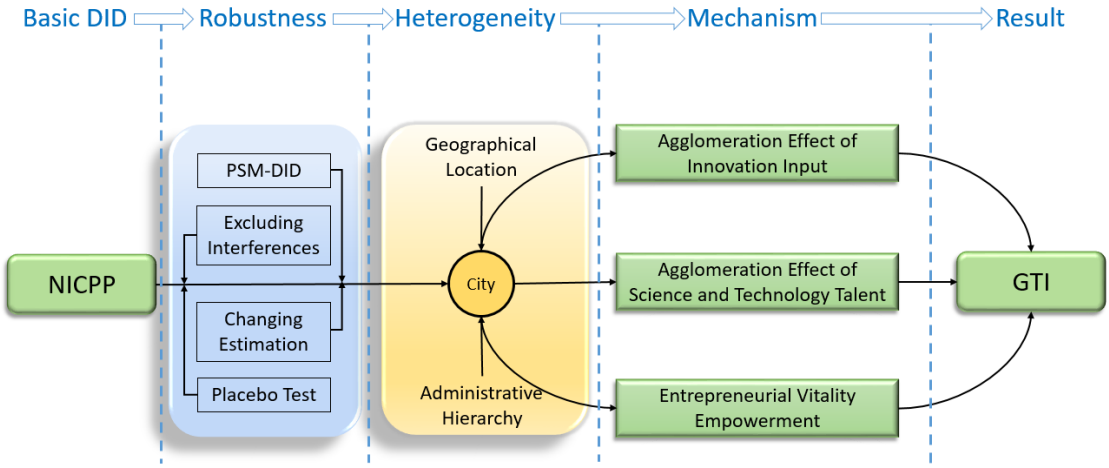

Figure 1. Research framework

3 Empirical research design

3.1 Identification strategy and model setting

The NICPP is a policy shock exogenous to GTI activities. On the one hand, it will lead to the difference between the GTI activities of the national innovative city and the non-national innovative pilot cities during the sample period. On the other hand, it will cause a gap in the GTI level of the pilot cities before and after the implementation of the NICPP. Therefore, it can be regarded as a quasi-natural experiment to promote GTI activities. Considering that the NICPP follows the principle of "pilot first and gradual promotion" to gradually expand the scope of pilot cities in batches, in order to identify the impact of NICPP on GTI activities more scientifically and reasonably, this paper refers to the setting method of Bertrand et al. (2004), and uses multi-period double difference to construct the following econometric model:

$$Gpatent_{i,t} = \alpha + \beta Policy_{i,t} + \gamma Control + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (1)$$

$Gpatent_{i,t}$ represents GTI capability; $Policy_{i,t}$ represents the dummy variable of the NICPP. When a city is approved as a national innovative pilot city, the variable value is 1 in the

current year and the subsequent years, otherwise it is 0. The variable is the cross-multiplication of the treatment group dummy variable $treat$ and the pilot city approved year dummy variable time ; $Control$ is a set of city-level control variables, which will be introduced below; μ_i, λ_t are city and year fixed effects respectively ; $\varepsilon_{i,t}$ is a random error term.

3.2 Variables

3.2.1 Dependent variable

GTI capability ($Gpatent$). The existing literature measures GTI in three main ways: first, by using non-parametric methods such as DEA to measure green total factor productivity and isolate the technical progress term from it; second, by examining process upgrading and new product development; and third, by using the number of green patent applications, acquisitions and citations to measure it. The first method is biased because green input factors cannot be effectively distinguished from green outputs, and the second method is generally applicable at the micro level of enterprises but difficult to be implemented at the city level, so this paper uses the number of green invention patent applications per 10,000 people to measure GTI. According to the green patent classification list and IPC codes of the World Intellectual Property Organization (WIPO), all patent information in the State Intellectual Property Office was searched and classified by setting the patent classification, classification code IPC and address, and finally the green patent data at different city levels were obtained.

3.2.2 Core independent variable

Virtual variable ($Policy$) of NICPP. This paper takes the NICPP as a quasi-natural experiment, and uses the intersection of the pilot city group ($treat$) and the virtual variable ($time$) of the policy pilot approval year to represent the policy effect ($Policy$) of the NICPP pilot city. For the year when a city is approved as a NICPP pilot city and the subsequent years, $Policy$ is set to 1, otherwise 0.

3.2.3 Control variables

Considering that various factors at the city level may have a differential impact on the GTI, several control variables are selected in this paper: (1) industrial structure ($Industry$): measured by the GDP share of the total output value of the secondary industry; (2) financial level ($Finance$): measured by the GDP share of the loan balance of financial institutions at the end of the year in the city; (3) foreign openness ($Open$): measured by the GDP share of the actual foreign direct investment; (4) digitalization level ($Inform$): measured by the GDP share of the total post and telecommunications business; (5) Internet level ($Internet$): measured by the number of domestic Internet users as a share of the total population at the end of the year; In addition, this paper controls for year and city fixed effects.

3.3 Data sources and description statistics

This paper selects the panel data of 289 municipal level cities in China from 2003 to 2019 as the research samples, with a total sample size of 4283. There are 75 cities in the treatment group and 214 cities in the control group. The city-level data involved in this paper are mainly from *China Statistical Yearbook* and *China City Statistical Yearbook*, and the missing values of individual samples are supplemented by the statistical yearbook data of each municipal level city.

Table 1 gives the descriptive statistical results of the main variables. From the results, it can be seen that there is a large gap between the GTI in the two groups of samples of national innovative cities and non-innovative cities, and the number of green invention patent applications in national innovative cities is significantly higher than that in non-national innovative cities. As can be seen from **Figure 2**, the number of green patents in the pilot cities (treated group) experienced a more significant increase after 2010 compared to the non-pilot cities (control group), and the gap between the level of green innovation in the pilot and non-pilot cities gradually widened after 2010, which tentatively indicates that the level of GTI is relatively higher in the cities of NICPP.

Table 1. Descriptive statistics of the main variables

Variable	Unit	All Cities			Treated Group Cities			Control Group Cities		
		Obs	*Mean*	*S.D.*	*Obs*	*Mean*	*S.D.*	*Obs*	*Mean*	*S.D.*
Gpatent	pcs	4878	0.3791	0.9502	1270	1.0438	1.5723	3608	0.1452	0.3752
Policy		5202	0.1263	0.3322	1350	0.4867	0.5000	3852	0	0
Industry	%	4586	47.6296	11.0092	1194	48.6777	9.4168	3392	47.2606	11.496
Finance	%	4836	0.8650	0.4973	1257	1.2261	0.6846	3579	0.7382	0.3284
Open	%	4576	0.0200	0.0209	1239	0.0319	0.0247	3337	0.0156	0.0173
Inform	%	4797	0.0280	0.0175	1242	0.0280	0.0176	3555	0.0279	0.0174
Internet	%	4835	0.1501	0.1565	1255	0.2405	0.2020	3580	0.1184	0.1220
Rdr	%	5167	0.0126	0.0131	1346	0.0219	0.0175	3821	0.0092	0.0091
Tecpeo	%	4560	0.0035	0.005	1186	0.0074	0.0078	3374	0.0021	0.0023
Company	%	5040	2.4448	6.1653	1307	5.7333	10.1704	3733	1.2934	3.1642

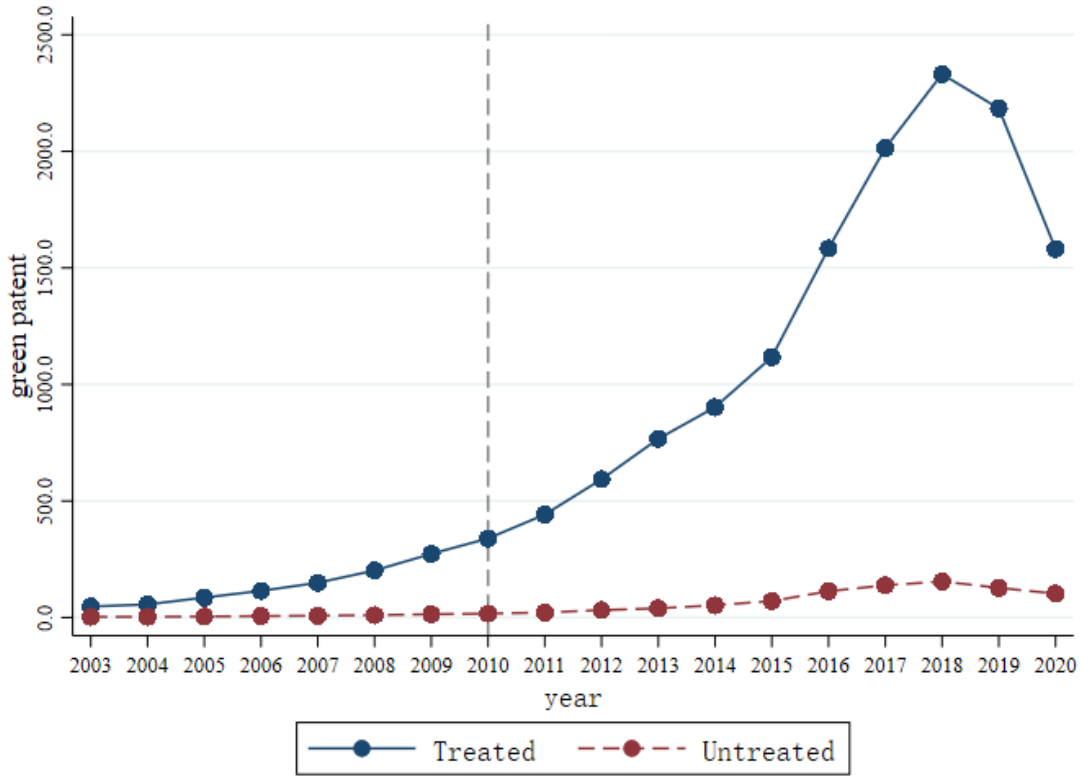

Figure 2. Pre-trend test

4 Empirical tests and analysis of results

4.1 Baseline regression results

In order to test the impact of NICPP on GTI, this paper performs regression analysis on the baseline regression model, and **Table 2** reports the regression results. In column (1), control variables and fixed effects are not added; in column (2), fixed effects of city and year are added on the basis of column (1); in column (3)-(4), regression results of control variables are added on the basis of column (1)-(2) respectively. The regression results show that the coefficients of the regressions are significantly positive with or without the inclusion of control variables and fixed effects, indicating that the NICPP significantly improves the level of GTI, *ceteris paribus*. From the magnitude of the estimated coefficient of $Gpatent$ in column (4), the number of green invention patent applications per 10,000 people in a city will increase by 0.9826 units when a city is qualified as a NICPP pilot city, indicating that the NICPP will stimulate substantial output of GTI, which verifies the Hypothesis 1 that NICPP has a positive impact on GTI.

Table 2. Baseline regression results

Variable	(1)	(2)	(3)	(4)
	Gpatent	*Gpatent*	*Gpatent*	*Gpatent*
Policy	1.7146***	1.2195***	0.9347***	0.9826***
	(50.3068)	(8.5141)	(27.8970)	(8.2676)

Industry			-0.0034***	-0.0083**
			(-3.5634)	(-2.3476)
Finance			0.0118	0.0239
			(0.4899)	(0.3387)
Open			2.0503***	-4.9348***
			(4.5952)	(-2.8585)
Inform			0.7807	0.3304
			(1.4146)	(0.3113)
internet			3.0553***	1.7074***
			(41.1339)	(4.0716)
Constant	0.1749***	0.0230	-0.1102*	0.4179**
	(14.8681)	(0.7824)	(-1.9602)	(2.0073)
Fixed effects	No	Yes	No	Yes
N	4878	4878	4283	4283
Group R^2	0.3417	0.4170	0.5647	0.4791

Note: t-values in brackets, *, **, *** denote 10%, 5%, and 1% significance levels, respectively. Same as below.

4.2 Parallel trend test and dynamic effect test

An important prerequisite for using the multi-period Difference-in-Difference model to evaluate the NICPP is that the core independent variables must meet the parallel trend hypothesis between the experimental group and the control group, i.e., in the absence of external policy shocks, the trend of the core independent variable of both experimental group and control group should be consistent. This paper adopts the event study method to set virtual variables for the actual policy implementation years of different pilot cities, and then tests whether the experimental group and the control group meet the parallel trend test and the dynamic effect of the NICPP. The regression model is set as follows:

$$Gpatent_{i,t} = \alpha + \beta_t \sum_{t=1}^{3} Before_{i,t} + \theta Current_{i,t} + \delta_{i,t} \sum_{t=1}^{10} After_{i,t} + \gamma Control + \mu_i + \lambda_t + \varepsilon_{i,t} \quad (2)$$

The time dummy variables $Before_{i,t}$, $Current_{i,t}$ and $After_{i,t}$ were the observed values of the n years before, the current year and n years after each city became a pilot city, respectively. The values of the above three dummy variables of non-pilot cities are all 0. Since the observation period of this sample is 2003-2019, and the policy implementation year of the first batch of innovative pilot cities is 2008, there are no more than -5 years of sample values in some cities. For this reason, this paper merges the time before period -5 of other cities into period -4 and removes this time dummy

variable to avoid multicollinearity. As shown in **Figure 3**, the coefficients of the relative dummy variables before the policy are not significant and the estimated values are close to 0, indicating that before the policy, the experimental group and the control group do not have significant differences in GTI, which satisfies the parallel trend test. In terms of the dynamic effects of the policy, considering that as of 2019, the first and second batch of NICPP have been implemented for nearly 10 years and the sample size of the pilot cities is large, this paper mainly analyzes the dynamic effects of the 10 period. Although the level of GTI has increased slightly after the implementation of the policy, the effect is not obvious within the three years of the implementation of the policy. After three years of the NICPP, the estimated coefficient of the NICPP is significantly positive and rising, indicating that the NICPP can significantly promote the level of GTI, but the policy effect has a certain lag.

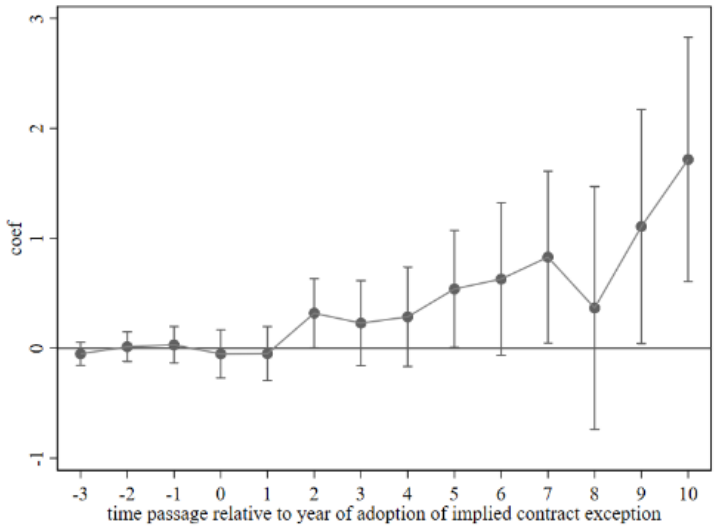

Figure 3. Parallel trend test and dynamic effect test

4.3 Robustness test

In order to verify the robustness and reliability of the baseline regression results in this paper, robustness tests are conducted in several aspects as follows.

4.3.1 Propensity score method matching and multi-period Difference-in-Difference method（PSM-DID）

The NICPP is not a natural experiment in the strict sense, so there may be differences in the characteristics of the city samples in the experimental and control groups, causing the problem of sample selectivity bias and thus leading to biased regression results. To alleviate this problem, this paper first uses propensity score matching to match the experimental group with appropriate control group samples, and then regresses the samples using the baseline regression model to achieve bias correction. The existing literature on the construction of PSM is divided into two main approaches:

one is to construct a cross-sectional PSM, which is to treat the whole panel data as multiple cross-sectional data in matching; the other is the period-by-period matching method, which is to match the most similar control group samples for the experimental group year by year. Therefore, this paper adopts the cross-sectional method and the period-by-period method for propensity score matching, respectively.

Cross-sectional PSM: This method uses the caliper nearest neighbor matching method to match the experimental group with the most suitable control group that satisfies the common support condition, and removes the non-common support parts, then regresses the panel data on the original model after deconstructing the cross-sectional data. The cross-sectional PSM needs to undergo a balance test and analysis of the matching effect, and the results of the balance test are given in **Figure 4**. The standardized mean deviation of all matched variables after matching is significantly smaller than the standard deviation before matching, and all of them are less than 50%, which basically meets the requirement of the balance test of standardized mean deviation less than 10%, proving that the cross-sectional PSM method has the effect of reducing the matching bias. **Figure 5** gives the sample matching situation, and the results show that most of the samples in the experimental and control groups lie within the range of common values, thus the estimation results of the cross-sectional PSM can be used as a certain reference when combined with the above two test results.

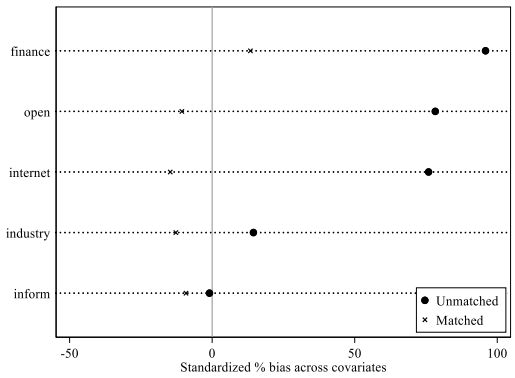

Figure 4. Cross-sectional PSM equilibrium test

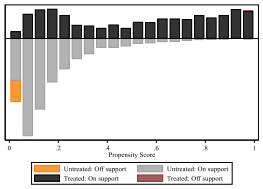

Figure 5. Distribution of samples satisfying the common support hypothesis

After cross-sectional PSM processing, the multi-period Difference-in-Difference method is used to re-estimate the impact of the NICPP on GTI. The regression results are shown in **Table 3**. Column (1) is the regression result of the fixed effect model, Column (2) is the regression result of the samples whose weight is not missing value, Column (3) is the regression result of the sample satisfying the common support hypothesis, and Column (4) is the regression result of the frequency weighting as the weight. From the regression results of column (3), it can be seen that the baseline regression results are still robust even if the sample selection bias is considered.

Table 3. Baseline regression and cross-sectional PSM-DID results

Variable	(1)	(2)	(3)	(4)
	fe	weight!=.	on_support	weight_reg
Policy	0.9826***	0.5206***	0.9744***	0.2665
	(8.2676)	(4.4409)	(8.1955)	(1.3481)
Industry	-0.0083**	-0.0068	-0.0086**	0.0059
	(-2.3476)	(-1.1915)	(-2.2085)	(0.5651)
Finance	0.0239	0.0052	0.0248	0.0629
	(0.3387)	(0.0551)	(0.3351)	(0.2994)
Open	-4.9348***	-5.8898***	-4.9912***	-4.2898
	(-2.8585)	(-2.9327)	(-2.8384)	(-1.4855)
Inform	0.3304	3.7833	0.2420	23.1359**
	(0.3113)	(1.6124)	(0.1999)	(2.1257)
Internet	1.7074***	1.7604***	1.7264***	3.2266**
	(4.0716)	(3.4666)	(4.0341)	(2.3661)
Constant	0.4179**	0.3464	0.4478*	-1.6029
	(2.0073)	(0.9809)	(1.8964)	(-1.3417)
Fixed effect	Yes	Yes	Yes	Yes
N	4283	1679	4111	4283
Group R^2	0.4791	0.4329	0.4805	0.5982

Period-by-period PSM: This method matches the city sample year by year, and then combines the data obtained from matching each year into panel data before regression. The period-by-period PSM equilibrium test is performed by Logit regression to obtain the changes in the coefficients of the variables before and after matching. If the regression coefficients of the matched variables decrease, insignificant and pseudo R^2 significantly decrease after matching, it indicates that there is no systematic bias. The results of the year-by-year PSM balance test are given in **Table 4** and **Table 5**. Comparing the regression results before and after matching, we can see that the regression coefficients of most of the matched variables become smaller and insignificant after matching, and the pseudo R^2 is also significantly reduced, indicating that there is no systematic bias and the balance test is satisfied.

Table 4. Year-by-year balance test before matching

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	2003b	2005b	2007b	2009b	2011b	2013b	2015b	2018b
Industry	0.0637***	0.0620***	0.0347**	0.0293	0.0071	-0.0088	0.0492*	0.0555**
	(3.4409)	(3.7231)	(1.9604)	(1.6078)	(0.3054)	(-0.3910)	(1.9576)	(2.4115)
Finance	2.9550***	3.9176***	3.8514***	3.2215***	2.2920***	3.1327***	2.6429***	1.9916***
	(4.6919)	(5.7121)	(6.6365)	(6.7158)	(3.0945)	(6.6416)	(5.9216)	(4.4871)

Open	22.2352***	30.9481***	35.5194***	27.3399***	22.6724**	23.5279***	29.6321***	17.0812*
	(3.8039)	(4.8929)	(4.4446)	(2.6299)	(2.2437)	(2.5850)	(3.0796)	(1.6912)
Inform	-25.4916**	-26.3686**	-38.333***	-27.3950**	-41.5168	-1.1e+02**	-26.2005	-27.7109
	(-2.1157)	(-2.1628)	(-3.1301)	(-2.2767)	(-1.1183)	(-3.3039)	(-0.6128)	(-1.4375)
Internet	6.4442	3.5263	4.9925	3.4431	5.9302**	3.8139***	3.1460**	4.4685***
	(0.9992)	(0.8791)	(1.6320)	(1.3823)	(2.5313)	(3.2286)	(2.0411)	(3.9083)
R_p^2	0.3402	0.3946	0.4197	0.3828	0.3464	0.3657	0.3139	0.2974

Table 5. Year-by-year balance test after matching

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	2003a	2005a	2007a	2009a	2011a	2013a	2015a	2018a
Industry	0.0148	0.0206	-0.0052	0.0099	-0.0149	-0.0039	0.0505	0.0197
	(0.5973)	(0.9257)	(-0.2336)	(0.4005)	(-0.5670)	(-0.1607)	(1.4886)	(0.6865)
Finance	0.5083	1.0322	0.4537	0.5537	0.5647	0.8917	0.8115	1.0284*
	(0.5998)	(1.0374)	(0.4284)	(0.8041)	(1.0135)	(1.3646)	(0.9775)	(1.7798)
Open	2.9437	7.5199	2.7638	11.4187	3.4470	20.5412	2.1153	-4.8667
	(0.3799)	(0.8541)	(0.2601)	(0.8225)	(0.3253)	(1.5740)	(0.1468)	(-0.4914)
Inform	-3.5718	-11.8496	7.1185	-4.9216	-9.0100	10.8811	-19.0187	-33.5934
	(-0.1939)	(-0.6160)	(0.3558)	(-0.3030)	(-0.2610)	(0.2718)	(-0.4739)	(-1.4488)
Internet	4.5144	0.2420	2.4392	1.4393	0.7554	-0.5634	0.1801	0.7679
	(0.6824)	(0.0679)	(0.4919)	(0.5179)	(0.3121)	(-0.3405)	(0.1065)	(0.6241)
R_p^2	0.0200	0.0200	0.0152	0.0302	0.0212	0.0508	0.0434	0.0476

After the year-by-year PSM treatment, the multi-period Difference-in-Difference method was applied to re-regress to estimate the impact effect of NICPP on GTI, and the regression results are shown in **Table 6**. Column (1) shows the regression results for samples whose weights are not missing values, column (2) shows the regression results for samples that satisfy the common support assumption, and column (3) shows the regression results for frequency weighting as weights. From the regression results in column (2), it is clear that the baseline regression results hold significantly.

Table 6. Baseline regression and year-by-year PSM-DID results

Variable	(1)	(2)	(3)
	weight!=.	on_support	weight_reg
Policy	0.3113***	0.6600***	0.2040
	(3.0162)	(5.9580)	(1.4566)
Industry	-0.0075*	-0.0010	-0.0085
	(-1.6565)	(-0.4057)	(-1.4368)

Finance	0.1128	0.1142*	0.0791
	(1.1847)	(1.7711)	(0.4493)
Open	-3.8494**	-2.5043*	-4.5834**
	(-2.4443)	(-1.8489)	(-2.2298)
Inform	-0.8167	0.0634	1.6080
	(-0.5416)	(0.0629)	(0.3470)
Internet	1.8971***	2.0988***	1.4321**
	(3.3200)	(4.5998)	(2.4143)
Constant	0.3734	-0.0204	0.3616
	(1.3126)	(-0.1319)	(0.6780)
Fixed effects	Yes	Yes	Yes
N	1441	3380	2203
Group R^2	0.4572	0.4118	0.4656

4.3.2 Placebo test

In order to exclude bias in the policy evaluation of NICPP due to omitted variables, this paper uses a placebo test to conduct robustness tests to ensure the true validity of the policy effect estimates. The Stata was used to conduct 500 randomized experiments on 75 pilot cities in 289 municipal level cities, and a dummy treatment group with randomized pilot cities and randomized pilot times was constructed to obtain 500 groups of $Fake\_Policy$ (i.e., $Fake\_treat \times Fake\_Time$); finally, the regression coefficients of these 500 $Fake\_Policy$ variables were analyzed to obtain their kernel density and p-value distribution. The results are shown in **Figure 6**. The regression coefficients gained from the randomized treatment are mainly concentrated around 0, which is significantly different from the estimated coefficients of the baseline regression, so the problem of bias of omitted variables on the results of the baseline regression in this paper can be excluded, and the conclusions of this paper are still robustly established.

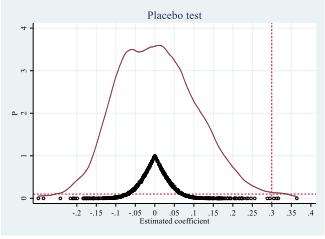

Figure 6. Distribution of coefficient estimates for the placebo test

4.3.3 Remove the interference of municipalities and special economic zones

China's municipalities directly under the central government have great advantages over general municipal level cities in terms of economic resource agglomeration and central policy tilt. As an experimental field of Reform and Opening-up, special economic zones have certain particularities in terms of the independence of policy formulation and the attractiveness of investment invitation. Therefore, the implementation effect of the NICPP in municipalities and special economic zones and the GTI may also differ from those of general municipal level cities in terms of resource endowment. In this regard, this paper removes the samples of municipalities and special economic zones to re-regression, and the regression results are reported in column (1) of **Table 7**. The results show that the research conclusions have not changed significantly.

4.3.4 Excluding other policy effects

As the process of China's Reform and Opening-up continues to accelerate, economic reform has become a huge and complex systematic project. The central government's reform measures at the provincial, municipal, and enterprise levels may be implemented simultaneously or cross-implemented. Therefore, policies closely related to GTI may have an impact on the regression results. In order to eliminate the influence of other policies on the conclusion of this paper, according to the focus of policy implementation, the year of implementation and the relevant literature, this paper selects three pilots of National New Districts, National Smart Cities and National Intellectual Property Demonstration Cities as control variables to join the baseline regression model to examine the impact of NICPP on GTI after controlling the interference of other relevant policies. The above three policy pilots were selected because: (1) As a major national regional economic policy, the implementation of the National New Districts in 1992 has had a greater impact on economic growth and innovation incentives, and there is an impact on the effect on NICPP; (2) The implementation of the National Smart Cities from 2012 has placed a strong emphasis on information digital technology and the knowledge society, and society has begun to implement the Innovation 2.0 concept, which will interfere with the core conclusions of this paper; (3) The National Intellectual Property Demonstration Cities pilot policy, which has been in place since 2012, is likely to stimulate GTI through a better IP protection system, interfering with the assessment of policy effects on NICPP. The above three policies overlap somewhat in time with the NICPP in this study, and may also contribute to GTI in cities in terms of policy efficacy, so we hope to assess again the influence of the NICPP on GTI in cities, after controlling for the interference of related policies. The regression results are shown in Column (2) of Table 7. From the estimation results, it can be seen that after controlling the above three policies, the estimation coefficient of the NICPP is reduced, but the results are still significantly positive, indicating that the impact of other policies will weaken the policy effect of the NICPP to a certain extent, but it will not significantly affect the causal

relationship between the NICPP and the GTI, which proves the reliability of the conclusion of this paper.

Table 7. Robustness test: excluding other policy effects

variable	(1)	(2)
	Excluding municipalities and special economic zones	Eliminate other policy interference
Policy	0.8811***	0.4942***
	(8.0576)	(5.3568)
Industry	-0.0029	-0.0064*
	(-1.1416)	(-1.9602)
Finance	0.0645	-0.0298
	(0.9644)	(-0.4878)
Open	-4.0350**	-4.7829***
	(-2.4327)	(-3.0402)
Inform	1.0128	-0.0288
	(1.0318)	(-0.0313)
Internet	2.2056***	1.3181***
	(5.3985)	(3.8076)
Constant	0.0758	0.4079**
	(0.5059)	(2.1460)
Fixed effect	Yes	Yes
N	4204	4283
Group R^2	0.4809	0.5860

4.3.5 Change the estimation method

The number of green invention patent applications per 10,000 people is used as the core dependent variable in the model of this paper. Considering that the patent data has the characteristics of a count variable and shows a normal distribution in general, the Poisson model is further considered in this paper for robustness testing. Meanwhile, since the number of urban green invention patent applications has a large number of zero values and there is the problem of left-hand side truncation, this paper also replaces the regression model with Tobit model for the robustness test. The regression results are shown in **Table 8**. After the above two model tests, the estimated coefficients of the NICPP are still not significantly different from the baseline regression results in terms of coefficient size and significance, which verifies the robustness of the research findings in this paper.

Table 8. Robustness test: replacement regression model

Variable	(1)	(2)
	Poisson model	Tobit model
Policy	1.0451***	0.9542***
	(16.7486)	(27.8468)
Industry	0.0074*	-0.0014
	(1.9198)	(-1.3744)
Finance	0.2751***	0.0160
	(6.3646)	(0.6479)
Open	14.6785***	1.9365***
	(11.3264)	(4.1076)
Inform	-2.4258	-0.3919
	(-1.3637)	(-0.6517)
Internet	3.1188***	3.2741***
	(20.7141)	(36.9706)
Constant	-4.9883***	-0.2415***
	(-19.6688)	(-3.3689)
Fixed effects	Yes	Yes
N	4878	4878
R_p^2	0.3444	0.1838

4.4 Heterogeneity analysis

Due to the different characteristics of each city, such as administrative level and geographical location, there are also great differences in the GTI. Therefore, the degree of influence of the NICPP on it will also be affected. The research on the heterogeneity caused by the differences in the characteristics of these cities will help us to understand the applicability and effect of policy implementation for different cities more deeply, and provide some research reference for decision makers to implement policies and classify guidance.

4.4.1 Differences in urban geographical location

The Hu Huanyong Line is delineated according to the influence range of the southeast monsoon. The ecological environment on the northwest side of the Hu Huanyong Line is relatively worse, and thus it is relatively weak in economic construction and population growth. The southeast side of the Hu Huanyong Line has a suitable climate and has gradually become the focus of population agglomeration, economic development and cultural construction. Therefore, this paper constructs a virtual variable (hu) of urban geographical location, and sets the city on the southeast side of Hu Huanyong Line to 1, and the city on the northwest side to 0. Based on the baseline regression model,

the interaction term (*Policy*×*hu*) of the virtual variable of the NICPP ($Policy$) and the virtual variable of the urban geographical location ($Policy$) is introduced to verify the impact of the geographical location difference of the city on the effect of the NICPP. The results are shown in the column (1) of **Table 9**. The regression results of heterogeneity analysis show that the coefficient of interaction item (*Policy*×*hu*) is 0.7505 and passes the statistical significance test of 1 %, indicating that the NICPP has a stronger incentive effect on the GTI on the southeast side of the Line. The level of GTI on the southeast side of the Line is 0.7505 units higher than that of the cities on the northwest side, which verifies the research Hypothesis 2. The possible reason is that the cities on the southeast side of Hu Huanyong Line are more suitable for people's life in terms of geographical location and climate environment, and have more advantages in resource and population agglomeration than the cities on the northwest side of Hu Huanyong Line. Therefore, based on more suitable climate environment, richer innovation resources and more population market environment, the cities on the southeast side of Hu Huanyong Line can play a more powerful incentive effect of green innovation policy. Although the NICPP can increase the city's attractiveness to green innovation resources, the cities on the northwest side of the Line are caught in the embarrassing situation of "Even a clever housewife cannot cook a meal without rice" due to the problems of urban endowments such as resources and population, thus affecting the full play of the pilot policy effect to some extent.

4.4.2 Differences in administrative levels of cities

The administrative levels of Chinese cities are divided into several levels, with higher levels having greater administrative freedom and governing space. Therefore, in this paper, the dummy variable of administrative ($rank$) is assigned to 1 for cities belonging to provincial capitals, municipalities directly under the central government and special economic zones, and 0 for other general municipal level cities. The results are shown in column (2) of Table 9. Based on the baseline regression model, the interaction term (*Policy*×*rank*) of the dummy variable of the NICPP ($Policy$) and the dummy variable of the city administrative level ($rank$) is introduced to verify the influence of the difference of the city administrative level on the effect of the NICPP. The results are shown in column (2) of Table 9. The regression results of heterogeneity analysis show that the coefficient of interaction term (*Policy*×*rank*) is 0.2788 and passes the 1% statistical significance test, indicating that the NICPP has stronger incentive effect on GTI with higher administrative level. The level of GTI with higher administrative level is 0.2788 units higher than that of general municipal level cities on average, which verifies the research Hypothesis 2. The possible reason is that compared with general municipal level cities, provincial capitals, municipalities directly under the central government and special economic zone cities, as provincial centers, national economic development centers, and national reform demonstration centers, have a more complete administrative system reform, a more solid economic construction foundation, a larger scale of infrastructure investment

and other economic and social foundations, so they can have a greater talent attraction, financial agglomeration, knowledge flow. And therefore, they can play a greater role in the implementation of NICPP, and further promote the level of GTI. General municipal level cities are weaker than cities with higher administrative levels in terms of their ability to attract investment, administrative reform dynamics, and the gathering of innovation resources, which to a certain extent restricts the NICPP's role in promoting GTI.

Table 9. Heterogeneity analysis

Variable	(1)	(2)
	Hu Huanyong Line	Provincial capitals and municipalities
Policy	0.3442*	0.8511***
	(1.8058)	(18.6218)
Policy×hu	0.7505***	
	(3.2274)	
Policy×rank		0.2788***
		(4.5369)
Industry	-0.0076**	-0.0081***
	(-2.2739)	(-4.6092)
Finance	0.0585	0.0089
	(0.9365)	(0.2250)
Open	-4.4986***	-5.1412***
	(-2.6352)	(-8.5419)
Inform	-0.0076	0.5005
	(-0.0072)	(0.8489)
Internet	1.7100***	1.6770***
	(4.1412)	(14.9723)
Constant	0.3620*	0.4273***
	(1.8374)	(4.1867)
Fixed effects	Yes	Yes
N	4283	4283
Group R^2	0.4887	0.4815

4.5 Mechanism test

From multiple perspectives, the above empirically tests that the NICPP has a significant effect on the level of GTI. The theoretical hypothesis part of this paper shows that the implementation of the NICPP can improve the local government's emphasis on GTI, increase the R&D investment in GTI from the financial subsidy level, and enhance the GTI ability. Second, NICPP improves the attractiveness of the city's talent to form talent agglomeration effect, and then further improves the

level of GTI; thirdly, the NICPP will reduce the entry threshold of enterprises, increase the level of innovation and entrepreneurship in the city, and then enhance the level of GTI. This paper will test the mechanism of the above three aspects, and the mediating effect model is constructed as follows:

$$Medium_{i,t} = \alpha + \alpha_1 Policy_{i,t} + \sum \varphi Control + \mu_i + \theta_{t,d} + \varepsilon_{i,t} \quad (3)$$

$$Gpatent_{i,t} = \rho + \rho_2 Medium_{i,t} + \rho_1 Policy_{i,t} + \sum \varphi Control + \mu_i + \theta_{t,d} + \varepsilon_{i,t} \quad (4)$$

Where $Medium_{i,t}$ is the mediating variable, which represents the three variables of innovation input agglomeration (Rdr), scientific research talent agglomeration ($Tecpeo$) and entrepreneurial vitality empowerment ($Company$). Other variables are consistent with the baseline regression model settings above.

4.5.1 Mechanism test of innovation input agglomeration

The governments of municipal level cities that have been qualified as national innovative cities will pay more attention to the R&D investment in the field of GTI: on the one hand, they will directly subsidize the relevant science and technology enterprises to stimulate innovation through greater R&D subsidies, so as to reduce the cost of GTI of enterprises and benefit the level of innovation of enterprises, and thus increase the level of GTI; on the other hand, a larger special R&D budget will be allocated to support local universities, research institutes, as well as science and technology enterprises in order to stimulate the green innovation vitality of them, and to generate more GTI outputs and improve the level of GTI. In order to test the mechanism of fiscal subsidy effect, this paper uses the proportion of government science expenditure in local budget as the proxy variable to measure innovation input agglomeration (Rdr). **Table 10** reports the regression results. The estimated coefficient in column (1) is significantly positive at the 1% level, which proves that the NICPP will significantly increase the proportion of local government's scientific research investment. $Policy$ and Rdr in column (2) are significantly positive at the 1% level to verify research Hypothesis 3. It shows that the NICPP on the one hand strengthens the government's emphasis on GTI activities, and on the other hand encourages local governments to increase the expenditure on scientific and technological research and development to implement the NICPP and support the GTI of universities, research institutions, and scientific and technological enterprises. It shows that the NICPP is to promote the level of GTI through the mechanism of innovation input agglomeration.

Table 10. Mechanism test: innovation input clustering

Variable	(1)	(2)
	Rdr	*Gpatent*

Policy	0.0070***	0.7780***
	(5.8647)	(7.7208)
Rdr		29.1313***
		(8.3623)
Industry	-0.0001	-0.0060**
	(-1.5707)	(-2.1998)
Finance	-0.0008	0.0466
	(-0.7780)	(0.8214)
Open	-0.0546**	-3.3439**
	(-2.5050)	(-2.4522)
Inform	-0.0079	0.5616
	(-0.8210)	(0.5658)
Internet	0.0161***	1.2391***
	(4.4013)	(3.6115)
Constant	0.0083***	0.1751
	(3.0990)	(1.0534)
Fixed effects	Yes	Yes
N	4283	4283
Group R^2	0.4767	0.5637

4.5.2 Mechanism test of scientific and technological talent agglomeration

The GTI is inseparable from the contribution of high-quality scientific and technological personnel, while the NICPP can create a policy highland for the pilot cities to attract innovative elements, especially scientific and technological talents to form agglomeration effect, and ultimately promote GTI. The existing literature on the measurement of human capital generally adopts the years of education or educational level of employees (Cao et al., 2022). However, in view of the availability of human capital data at the urban level, this paper draws on the construction ideas of Bai et al. (2022), which uses the proportion of the total number of employees in scientific research, technical services and geological exploration and the number of employees in information transmission, computer services and software to the total population at the end of the year to measure the scientific research talent agglomeration in municipal level cities. The employees in these two industries have higher knowledge and technical level, as well as professional ability than other industries, thus they are representative of urban talent agglomeration. The testing result is shown in **Table 11**.

Table 11. Mechanism test: scientific research talent agglomeration

Variable	(1)	(2)

	Tecpeo	*Gpatent*
Policy	0.0026***	0.5722***
	(5.6729)	(5.3732)
Tecpeo		111.3279***
		(8.1863)
Industry	-0.0000*	-0.0074**
	(-1.8338)	(-2.4885)
Finance	0.0004	-0.0414
	(1.5647)	(-0.7558)
Open	-0.0068	-3.9342***
	(-1.4370)	(-2.7433)
Inform	0.0036	-0.1261
	(0.9922)	(-0.1817)
Internet	0.0043***	1.0184***
	(2.7603)	(3.2486)
Constant	0.0031***	0.1881
	(4.0750)	(1.0446)
Fixed effects	Yes	Yes
N	4008	4008
Group R^2	0.5821	0.5821

4.5.3 Mechanism test of entrepreneurial energy empowerment

GTI, as a new innovation mode for environmental sustainability, is different from the traditional innovation mode, which also puts forward higher requirements for innovation subjects. The NICPP can provide a better top-level design for local governments to introduce more GTI and entrepreneurship policies, set off the entrepreneurial boom in green innovation-related industries, and thus stimulate the green innovation vitality of cities. The existing literature is divided into various measures of entrepreneurial vitality, the more representative one is the data of private enterprises in *China Statistical Yearbook*. The second is to obtain enterprise micro data through data collection and management platforms authorized by the State Administration for Market Regulation, such as “QiChacha” and “TianYanCha” (Bai et al., 2022). The third is to refer to *China City and Industry Innovation Power Report 2017* published by the Center for Industrial Development of Fudan University, taking the number of newly established enterprises in cities and the registered capital of established enterprises into consideration to construct comprehensive indicators. Limited by the difference in data caliber of statistical yearbooks and data availability, we use the ratio of the sum of newly registered enterprises in the three industries of water resources, environment and public facilities management, and scientific research and technology services and information

transmission, software and information technology services to the regional population at the end of the year as a proxy variable for innovation vitality empowerment ($Company$), and the data of newly established enterprises are obtained from the TianYanCha for the years 2003-2019 are matched by region, year, and industry to the corresponding cities to form panel data. The regression results are reported in **Table 12**. The estimated coefficients in column (1) are significantly positive at the 1% level, indicating that the NICPP can provide a better environment for innovation and entrepreneurship in cities, increase the investment confidence of investors and entrepreneurs, promote the agglomeration of multiple innovation elements in the pilot cities, and enhance the innovation vitality of cities. The coefficient of both $Policy$ and $Company$ in column (2) is significantly positive at the 1% level, which verifies the research Hypothesis 5 and indicates that the NICPP provides an excellent institutional environment for innovation and entrepreneurship, attracts a large amount of capital, talents and policy resources, promotes the entrepreneurship of relevant industries, so that the relevant industries can carry out GTI and R&D activities more efficiently under the incentive of this good institutional and market environment. Furthermore, the level of GTI is improved, which verifies that the NICPP affects the level of GTI through the path of entrepreneurial energy empowerment.

Table 12. Mechanism test: innovation and vitality empowerment

Variable	(1)	(2)
	Company	*Gpatent*
Policy	3.5755***	0.7524***
	(5.1261)	(5.6287)
Company		0.0638***
		(3.1420)
Industry	0.0042	-0.0086***
	(0.1865)	(-2.8843)
Finance	1.2553***	-0.0589
	(2.9255)	(-1.0429)
Open	-22.8452**	-3.4934**
	(-2.4728)	(-2.3712)
Inform	-1.0385	0.4105
	(-0.1088)	(0.4935)
Internet	5.3256	1.3773***
	(1.6340)	(4.1567)
Constant	-0.1303	0.4324**
	(-0.1045)	(2.4916)
Fixed effects	Yes	Yes
N	4268	4268

Group R^2	0.3045	0.5968

5 Conclusions and policy implications

Under the background of the increasing contradiction between social and economic development and environmental protection, superimposed on the pressure of economic transformation and upgrading and the external international environment and other domestic and foreign uncertainties, GTI has become an important driving force to enhance the competitiveness of cities and even countries, and is the key to realize the transformation of cities to modernization and green development. In this context, promoting the construction of innovative cities is of great significance to stimulate the GTI enthusiasm of various innovation subjects, enhance the GTI, and facilitate the high-quality development of China's economy. It is an important measure to implement China's innovation-driven development and green transformation of development mode. Based on the quasi-natural experiment of NICPP, this paper takes 289 municipal level cities from 2003 to 2019 as research samples, and systematically evaluates the impact of NICPP on GTI and its mechanism by using multi-period Difference-in-Difference model. The study found that the NICPP has significantly improved the level of GTI, and this promotion has a certain lag and continuity. After a series of robustness tests, the conclusion of this paper is still robust. Heterogeneity analysis shows that the promotion effect of NICPP on GTI is affected by urban administrative level and geographical location difference, that is, in cities with higher administrative level and greater geographical advantages, the promotion effect of NICPP on GTI is more obvious. Through the test of the mechanism, it is found that the NICPP mainly improves the level of GTI through three influence paths: innovation input agglomeration, scientific and technological talent agglomeration, as well as empowerment of entrepreneurship activity. The research in this paper is of great practical significance for improving the NICPP, promoting the construction of the "Innovative Countries" and promoting GTI. Based on the above research conclusions, the policy implications of this paper are as follows:

First, emphasis on policy subsidies for the NICPP to fully release the GTI policy effects of the pilot policy. On the one hand, from the point of view of the financial subsidy allocation system, the government should pay attention to the incentive effect of the financial subsidy policy on GTI, allocate the financial subsidies reasonably and formulate a more complete GTI assistance plan; provide differentiated financial subsidy policies for different innovation subjects in different industries and stages to form an external financing environment with government capital leading private capital. On the other hand, from the evaluation of financial subsidies, the government should establish a perfect post-evaluation mechanism for financial subsidies, and conduct long-term sustainable tracking and supervision as well as performance evaluation of the green innovation incentive results of financial subsidies, so as to optimize the GTI effectiveness of policies.

Second, we should attach importance to the two major mechanisms of talent agglomeration

and entrepreneurial empowerment of NICPP, and focus on the construction of innovative cities to enhance the level of GTI. To further play the role of the NICPP and enhance the level of GTI, the construction process should focus on three aspects: First, complete the talent attraction system to play talent agglomeration effect. On the one hand, it is necessary to improve the talent introduction system from the aspects of job promotion, employment assistance and housing subsidies. On the other hand, we should strengthen personnel cultivation and skills training to build a comprehensive, multi-level, multi-channel training and introduction of parallel talent attraction system; second, create a green environment for innovation and entrepreneurship, improve urban entrepreneurial activity. On the one hand, governments should optimize the city's business environment by further improving business-related laws and regulations to create an excellent market competition environment. On the other hand, it is necessary to optimize the urban business environment, reduce market access thresholds and transaction costs, deepen the reform of decentralization, management and service of administrative departments, create a fair market competition environment and administrative environment, and increase the willingness of relevant industries to innovate and start businesses, thus boosting the level of GTI.

Third, create a complete innovation intermediary agent service system around GTI. Actively improve the intellectual property protection system, encourage various high-tech intermediary agents to integrate into the GTI system to play a greater role, promote the exchange and interaction of different GTI subjects and knowledge transfer by improving the quality and efficiency of services, provide professional science and technology intermediary agent services for GTI, and further promote the market-oriented transfer of green innovation results.

Acknowledgment

We acknowledge the financial support from The Project of Philosophy and Social Science Research in Colleges and Universities of Jiangsu Province (2022SJYB0102); The Talent Introduction Research Start-up Fund Project of Nanjing University of Posts and Telecommunications (NYY222010).

Authors' contributions

B.L. and Z.L. conceived and designed the experiments. X.Y. and J.W. performed the experiments. Z.L. and Z.Q. analyzed the data and wrote the manuscript. All authors read and approved the final manuscript.

Funding

The Project of Philosophy and Social Science Research in Colleges and Universities of Jiangsu Province (2022SJYB0102); The Talent Introduction Research Start-up Fund Project of Nanjing University of Posts and Telecommunications (NYY222010)

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare that they have no competing interests.

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