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Original Research

Can the Energy-Consuming Right Trading Policy Improve Urban Green Technology Innovation Capacity? Evidence from China

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Abstract

Green technology innovation plays an important role in achieving high-quality economic development in China. It is of great theoretical value and practical significance to study the effect of the Energy-consuming Right Trading Policy (ERTP) on green technology innovation. Based on the panel data of 279 cities in China from 2006 to 2020, this paper analyzes the effect of the ERTR on urban green technology innovation capacity (GTIC) by using the difference-in-differences (DID) model. The study shows that the ERTR can significantly improve urban GTIC and validates the "Weak Porter Hypothesis". After a series of robustness tests, this conclusion still holds. Furthermore, the mechanism analysis shows that the ERTP can promote urban GTIC through industrial structure upgrading. In addition, the heterogeneity analysis indicates that the ERTR can significantly improve the GTIC of eastern cities and non-resource cities. This paper fills the gap of related studies and provides an important reference for improving the ERTP.

Keywords: energy-consuming right trading policy, green technology innovation capacity, difference-in-differences model, industrial structure upgrading

Introduction

Since the reform and opening up, China's economy has been growing at a high rate. At the same time, it also has faced problems such as environmental pollution and excessive consumption of resources. At present, China's economy has entered the stage of high-quality development. Innovation is gradually replacing traditional factors as the core engine of development [1]. The 20th Party Congress noted the need to implement the new development concept of innovation, coordination, green, development, and sharing. As the combination of green development and innovation drive, green technology innovation can bring the dual benefits of environmental protection and economic development. It is an effective way for China to accelerate its high-quality development to improve green technology innovation capability (GTIC). The "14th Five-Year Plan"

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calls for building a market-oriented green technology innovation system and taking action to tackle critical issues in green technology innovation. But green technology innovation has dual externalities: On the one hand, green technology innovation can lead to positive externalities due to knowledge spillover effects. On the other hand, green technology innovation can also lead to positive environmental externalities by promoting energy conservation and emission reduction [2]. In this case, the benefit that the enterprises get from green technology innovation is less than the social benefit. Enterprises lack the motivation for green technology innovation. As a result, the GTIC can hardly meet the demand for high-quality development. Therefore, effective policy interventions are indispensable for improving GTIC [3]. Environmental policy and science and technology policy are the main instruments for the government to stimulate enterprises to engage in green technology innovation [4, 5]. As an important environmental regulation policy, the ERTP is a major institutional innovation in energy conservation. And cities play a significant role in China's economic development. Therefore, it is of great practical significance to analyze the impact of the ERTP on the urban GTIC.

The National Development and Reform Commission officially proposed the pilot of ERTP in 2016 to promote sustainable economic development and green development. As a major initiative to promote the reform of ecological civilization system, the ERTP can solve the increasingly serious energy and environmental problems and accelerate the green transformation of the economic development mode [6]. Green technology innovation is the key to the green transformation of the development mode, which helps to break the energy and environmental constraints in China's high-quality economic development [7]. The "Weak Porter Hypothesis" argues that appropriate environmental regulation policies can induce firms to innovate and thus promote urban innovation [8–10]. However, the applicability of the "Weak Porter Hypothesis" is still controversial. Therefore, it is of great theoretical value and practical significance to clarify the relationship between the ERTP and urban GTIC. It can provide an important reference for the applicability of the "Weak Porter Hypothesis" in China. It can also help to improve urban GTIC and accelerate high-quality development.

The marginal contributions of this paper are as follows. First, this paper expands the research perspective on the green innovation effects of the ERTP by exploring its impact on cities, which fills a research gap. Second, this paper examines how the ERTP contributes to urban GTIC by scrutinizing its impact mechanism from the standpoint of industrial structure upgrading. It expands the investigation into the policy dividends of the ERTP and offers a fresh perspective on the mechanism of its green innovation effects. Third, considering the differences between cities, this paper further investigates the heterogeneity of policy effects of the ERTP from the perspectives of urban location and resource endowment. This paper provides an important reference for future policy optimization.

This paper is structured as follows: Section 2 is the literature review. Section 3 is the policy background and research hypotheses. Section 4 is the study design, including model setting, variable selection, and data description. Section 5 is the empirical results and analysis, including the trend analysis, DID model regression analysis, robustness test, mechanism test, and heterogeneity analysis. Section 6 is conclusions and implications.

Literature Review

Green technology innovation is an important factor in promoting the green transformation of economic development and achieving high-quality development. It plays a crucial role in promoting green and sustainable economic development [11]. There have been abundant studies on the driving factors of GTIC in academia. Regarding the internal factors, research and development investment [12], employee experience [13], ownership structure [14], and corporate debt structure are closely related to the GTIC [15]. Regarding the external factors, social expectation [16], the digital economy development [17], consumer demand [18], and infrastructure construction are also important factors in enhancing GTIC [19]. Moreover, green technology innovation exhibits dual externalities, which make it heavily reliant on external policies [2]. Therefore, external policies play a crucial role in the development of green technology innovation and are key factors influencing its progress [20].

Research on the relationship between environmental regulation policies and green technology innovation has become a focus because environmental regulation policies can mitigate the double externalities of green technology innovation [21]. Related studies mainly focus on the "Weak Porter Hypothesis", but it is not difficult to find that the existing studies have not yet formed a consistent conclusion. Some scholars have supported the "Weak Porter Hypothesis" that environmental regulation policies can promote green technology innovation [22]. Taking environmental information disclosure policies as an example, Peng and Ji found that environmental regulations can promote green innovation by increasing investment in innovation and attracting talented individuals to the field [23]. Zhong and Peng studied the impact of the new environmental protection law on heavily polluting enterprises and found that environmental regulations can effectively promote green innovation [24]. Some studies have come to the opposite conclusion [25, 26]. Jiang et al. analyzed the impact of environmental regulations on innovation from both industrial and regional perspectives, and their findings suggested that mandatory environmental regulation can hinder innovation [27]. Wang et al.

conducted a study focusing on the implementation of environmental taxes and found that environmental regulations can hinder green innovation [28]. Some scholars have argued that the relationship between environmental regulation and green technology innovation is nonlinear [29]. Li et al. conducted research on the data from Guangdong Province and identified an inverted U-shaped relationship between environmental regulations and technological innovation [30]. Zhang et al. found that there was a U-shaped relationship between environmental regulations and green innovation, where they initially have a suppressing effect and later promote it [31]. With further research, some scholars have subdivided the environmental regulatory policies. Fang and Shao divided environmental policies into command-and-control and market-incentive policies and found that only market-incentive policies significantly promote green technology innovation [32]. However, Peng et al. argued that command-and-control environmental policies are more effective than market-based incentive policies in promoting green technology innovation [5]. Shen et al. found an inverse "N" type relationship between market command-and-control environmental policies and green technology innovation and a "U" type relationship between market-incentive environmental policies and green technology innovation [21]. The variations in research subjects and the implementation environments of environmental regulation across different literature studies lead to divergent conclusions in the existing literature. Thus, the study of environmental regulations and green innovation requires an analysis that accounts for specific backgrounds and circumstances.

With the development of global industrialization, climate warming and environmental pollution are having an increasingly significant impact on all countries of the world [33]. Environmental policies have been introduced one after another in countries to solve increasingly serious environmental problems. China's current environmental policies started to take off after the United Nations Conference on Human Environment in 1972. Since then, a series of environmental policies have been introduced one after another [34]. Due to different means of restraint, China's environmental regulatory policies can be divided into two categories: command-and-control and market-incentive [35]. Laws and regulations are the main regulatory instruments of command-and-control policies. And market mechanism is the main regulatory instrument of market incentive policy. Both can solve environmental problems to some extent [34–36]. However, command-and-control environmental policies set uniform technology or pollution emission standard for firms, violating the equilibrium law. It is inefficient and cannot provide additional incentives for research and development [37, 38]. Therefore, many countries take market-incentive environmental policies as the main environmental governance instrument [6, 39, 40]. With China's market-oriented reforms, China has also started to use market mechanism to solve environmental problems. In 2002, China launched the first SO_2 emissions trading system; in 2007, China launched the pilot of emissions trading system in 11 provinces; in 2011, China launched the pilot of carbon emissions trading in 7 provinces. Studies have shown that the above policies have effectively promoted technological innovation [41, 42], energy conservation and emission reduction [43], total factor productivity of enterprises [44], and green development [36, 45]. China has achieved many beneficial results through market-based incentive environmental policies. Based on this, the ERTP was officially proposed in 2016. Unlike China's existing market-incentive environmental policies, the ERTP focuses on source control of pollution and is a significant innovation in China's environmental regulatory system [46].

As a critical market-based incentive environmental policy in China, the ERTP has been studied from both policy design and policy effects. Regarding policy design, studies have made suggestions to improve the design of ERTP from the perspectives of energy-consuming rights allocation and market regulation [47, 48]. Regarding the policy effects, studies have focused on the energy-saving effect [6, 46], environmental and economic benefits of ERTP [49-51]. In addition, Some studies analyzed the impact of ERTP on the total factor productivity [52, 53]. Research on the relationship between ERTP and GTIC is still in the exploratory stage. Shen and Chen used industrial enterprise data to explore the relationship between ERTP and GTIC [54]. The study finds that ERTP can promote the GTIC of enterprises, but there is heterogeneity among different enterprises. Zhang and Chen further clarified the transmission mechanism that ERTP influences the GTIC of enterprises [55]. The study found that the ERTP mainly promotes the GTIC of enterprises through R&D funds, R&D personnel, tax incentives, and government subsidies.

The review of existing literature has demonstrated that there have been extensive research achievements in the spheres of green innovation, environmental regulations, and ERTP, providing a robust foundation for subsequent research. Nevertheless, there is a need to deepen and expand the research on the effects of ERTP on promoting green innovation. First, although some studies have begun to discuss the relationship between ERTP and GTIC, these studies have only focused on the GTIC of enterprises. This paper extends the research perspective to the city level and analyzes the effect of ERTP on urban GTIC. Secondly, studies have explored the transmission mechanism that ERTP influences the GTIC from the perspective of enterprises and government, but no studies have included industrial structure in the analysis framework. The transmission mechanism that ERTP influences GTIC needs to be further explored. This paper analyzes and verifies the transmission mechanism that ERTP influences GTIC from the perspective of industrial structure upgrading. Thus, this paper enriches the research on the channels through which the ERTP exerts its policy effects. In addition, There is a lack of research on the heterogeneity of ERTP in different types of cities. This paper analyzes the differentiated effects of ERTP from the perspective of location and resource endowment. Thus, the research on the heterogeneous effect of ERTP in different types of cities is expanded.

Based on data from 279 cities in China from 2006 to 2020, this paper analyzes the impact of the ERTP on the urban GTIC and its transmission mechanism. Furthermore, this paper also analyzes the heterogeneity of the policy effects and makes targeted suggestions for improving ERTP.

Policy Background and Research Hypotheses

Policy Background

With global warming and severe environmental pollution, countries are facing new challenges in development. The State Council proposed implementing the ERTP in the General Plan for the Reform of the Ecological Civilization System in 2015 to achieve sustainable economic development. In the same year, China's 13th Five-Year Plan proposed establishing and improving the allocation system of energy-consuming rights, water use rights, and carbon emission rights. In 2016, the National Development and Reform Commission released the Pilot Program of the Paid Use and Trading Policy of the Energy-consuming Right. The document indicates that the ERTP policy will be piloted in 2017 in four provinces, namely Zhejiang, Fujian, Henan, and Sichuan. Specifically, the pilot areas determine the initial energy-consuming quotas, or energy-consuming rights, for each energy-consuming unit according to the local development status and the total energy consumption issued by the state. Moreover, energy-consuming units that consume more energy than their energy-consuming rights must pay additional fees to the government. In addition, the government allows energy-consuming units to trade the energy-consuming rights they hold. Henan Provincial Government indicated that only four areas in Zhengzhou City, Pingdingshan City, Hebi City, and Jiyuan Demonstration Zone would be piloted first. Except for Henan Province, the rest of the pilot provinces have piloted the policy throughout the province. The pilot of ERTP provides a good opportunity for this paper to investigate the impact of ERTP on urban GTIC.

Research Hypotheses

As a critical environmental regulation policy, the ERTP can effectively promote green technology innovation according to the "Weak Porter Hypothesis". The reasons can be analyzed from two aspects: cost optimization effect and innovation compensation effect [55]. From the viewpoint of cost optimization effect, the ERTP can force enterprises to innovate green technology by increasing the production cost of high energy-consuming enterprises. Due to the policy restrictions, enterprises that consume more energy than their quotas will have to pay extra costs to buy energy-consuming rights on the market. Enterprises can choose to downsize, relocate or innovate green technology to reduce the cost of excess energy consumption [56]. If an enterprise chooses to downsize or relocate, on the one hand, the enterprise will lose plant construction costs and fixed equipment maintenance costs [54]. On the other hand, these enterprises' market share and competitiveness will decrease. Therefore, enterprises will reduce energy consumption through green technology innovation to pursue cost optimization. From the innovation compensation effect, the ERTP can increase the profits of low energy-consuming enterprises, thus stimulating enterprises to innovate green technology. Low energy-consuming enterprises can earn extra profit by selling their excess energy-consuming rights, which can motivate enterprises to reduce energy consumption through green technology innovation. In addition, the results of green technology innovation can help enterprises improve production methods and increase production efficiency and market competitiveness [57]. With the dual incentives of cost and profit, companies will be more rewarded for green technology innovation. Therefore, enterprises will pay more attention to green technology innovation and eventually improve urban GTIC. Based on the above analysis, this paper proposes the Hypothesis 1.

Hypothesis 1: The ERTP can improve urban GTIC.

The essence of industrial structure upgrading is the transfer of production factors from inefficient to high-efficiency production sectors. And it is also the process of rationalization of internal resource allocation and improvement of production efficiency [58]. Due to the ERTP, companies with more efficient energy utilization can sell their excess energy-consuming rights to gain additional revenue. Production elements such as capital and talent will flow from industries with low energy utilization to industries with high energy utilization because of the market mechanism, which will promote the industrial structure upgrading [46]. In this case, enterprises with low energy utilization will innovate or introduce energy-saving technologies and equipment to reduce energy consumption, which will promote the industrial structure upgrading. Industrial structure upgrading cannot be separated from the industrial transfer [59]. From the perspective of factor flow, industrial upgrading makes talents and technical resources flow to high-efficiency and high-tech industries, which improves the efficiency of innovation resources utilization. At the same time, the mobility of R&D personnel also leads to knowledge spillover effects, which eventually improves the efficiency of green technology innovation [60, 61]. From the perspective of industrial cooperation, industrial structure upgrading will deepen the industrial division and enhance innovation cooperation within and between industries [61]. With the deepening of enterprise cooperation, enterprises can improve the efficiency of green technology innovation by imitating and learning from cooperative enterprise, which intensifies the spillover effect of green technology innovation. Eventually, the urban GTIC will be improved. Based on the above analysis, this paper proposes the Hypothesis 2.

Hypothesis 2: The ERTP can improve the urban GTIC by promoting industrial structure upgrading.

Study Design

Model Setting

DID Model

In this paper, the pilot of ERTP is regarded as a quasi-natural experiment. The first pilot cities of the ERTP are regarded as the treatment group and the remaining cities as the control group. The difference-in-differences (DID) model is built as follows.

$$lngti_{it} = \beta_0 + \beta_1 treat_i \times post_t + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

i and t represent city and year, respectively. $lngti_{it}$ represents the GTIC of city i in year t. $treat_t$ is the policy dummy variable, and the value is 1 for the pilot cities of ERTP; otherwise, it is 0. $post_t$ is the time dummy variable. It is assigned to 1 in the year after the implementation of the ERTP; otherwise, it is assigned to 0. $treat_i \times post_t$ is the interaction item of $treat_i$ and $post_t$. X_{it} is the control variable. μ_t represents the city fixed effect. δ_t represents the year fixed effects. ε_{it} is the random error term.

Parallel Trend Test Model

An essential prerequisite for using the DID model is that the parallel trend assumption is satisfied. The following model is built to test whether the sample selected in this paper satisfies this assumption.

$$lngti_{it} = \theta_0 + \theta_j \sum_{j=-5, j\neq -1}^{3} treat_i \times year_j + \alpha X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

θ_j represents the estimated coefficient of ERTP before and after the policy implementation. If the difference between the sample year and the policy occurrence year is j, $year_j$ takes the value of 1; otherwise, it takes 0. In addition, this paper takes the year before the policy implementation as the base year to avoid the effect of cointegration. The remaining variables are the same as described in the DID model.

Mechanism Test Model

The following model is built to investigate the transmission mechanism of policy effects [62].

$$M_{it} = \varphi_0 + \varphi_1 treat_{it} \times post_{it} + \tau X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

$$lngti_{it} = \vartheta_0 + \vartheta_1 treat_i \times post_t + \beta_3 M_{it} + \omega X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

Where M_{it} is the intermediary variable. The rest of the variables are defined as in the DID model.

Variable Selection

Explained Variable

Urban GTIC (*lngti*) is the explanatory variable. The number of green patents can directly reflect the results of green technology innovation and is often used to measure GTIC. The number of green patents includes the number of patent applications and the number of patents granted. The number of patents granted is generally the result of 1~3 years after the application, and there is hysteresis [63]. It does not reflect the technological innovation capability well. Therefore, the urban GTIC is measured by the number of green patent applications plus one and taking the natural logarithm [55].

Core Explanatory Variable

The core explanatory variable is the ERTP ($treat_i \times post_t$). The value of $treat_i \times post_t$ is 1 for the pilot cities of ERTP. Otherwise, it is 0.

Mediating Variables

Industrial structure upgrading is the mediating variable. Industrial structure upgrading is a dynamic evolutionary process, including two dimensions of industrial structure optimization and industrial structure rationalization [61, 64]. Therefore, this paper intends to measure industrial structure upgrading in two dimensions: industrial structure optimization and industrial structure rationalization. The industrial structure rationalization (*rs*) indicates the quality of aggregation between industries and it is calculated as follows [65].

$$rs_{i,t} = \frac{1}{\sum_{j=1}^{3}(\frac{Y_{i,j,t}}{Y_{i,t}}) \ln(\frac{Y_{i,j,t}}{L_{i,j,t}}/\frac{Y_{i,t}}{L_{i,t}})} \quad (5)$$

where $rs_{i,t}$ is industrial structure rationalization for city i in year t. $Y_{i,j,t}$ indicates the industrial value added of industry j in city i in year t. $Y_{i,t}$ is the GDP for city i in year t. $L_{i,j,t}$ denotes the number of practitioners of industry j in city i in year t. $L_{i,t}$ denotes the total practitioners for city i at year t. Therefore, the bigger the value of *rs*, the more reasonable the industrial structure.

Industrial structure optimization (*ts*) indicates the process of industrial structural improvement and it is calculated as follows [66].

$$ts_{i,t} = \sum_{j=1}^{3} \frac{Y_{i,j,t}}{Y_{i,t}} \times lp_{i,j,t} \tag{6}$$

$$lp_{i,j,t} = \frac{Y_{i,j,t}}{L_{i,j,t}} \tag{7}$$

where $ts_{i,t}$ is industrial structure optimization for city i in year t. $lp_{i,j,t}$ denotes the labor productivity of industry j in city i in year t. The other indicators are defined as in Equation (5). The bigger the value of *rs*, the more reasonable the industrial structure. In Equation (7), the labor productivity (*lp*) has a dimension, so this paper adopts the normalization method to eliminate the dimension.

Control Variables

The following control variables were selected to control the effect of other factors on urban GTIC by referring to the existing literature. (i) Economic development level (*gdp*) is measured by the GDP of cities. Economic development level can impact innovation investments and consequently affect green innovation. (ii) Education expenditure (*edu*) is measured by the share of education expenditure in fiscal expenditure. Increased education expenditure can accelerate the accumulation of talent, thereby impacting green innovation. (iii) Population density (*dpop*) is the ratio of the total population of a city to the land area of the city's administrative district at the end of the year. Population density can influence green innovation through the quantity of talent and labor force. (iv) The level of urbanization (*urban*) is measured by the proportion of the urban population to the total population of the city. Cities with higher levels of urbanization tend to have more developed infrastructure, which is conducive to promoting green innovation. (v) The level of financial development (*fin*) is measured by the ratio of the balance of loans from financial institutions to the city's GDP at the end of the year. Financial development can lower financing constraints and funding costs, thus impacting research and development investment. (vi) Human capital (*hc*) is measured by the ratio of the general population with a bachelor's degree or higher to the city's resident population. Human capital affects green innovation by influencing the input of innovative talent. The measurement methods and data sources of the variables are provided in Table 1.

Data Description

Considering the issue of data availability, balanced panel data of 279 Chinese cities from 2006 to 2020 are selected in this paper. The data are mainly from China City Statistical Yearbook, China Statistical Yearbook, EPS database, CSMAR database, and some cities' annual statistical reports. The green patent data are mainly from the National Intellectual Property Database. A small number of missing values were complemented by the interpolation method. The descriptive statistics of the main variables in this paper are shown in Table 2.

This paper utilized the Pearson correlation coefficient to conduct correlation analysis. The correlation analysis between variables is presented in Table 3. The correlation analysis on the main variables indicates a significant correlation coefficient of approximately 0.1715 between ERTP and urban GTIC at the 1% level, thereby providing initial evidence of their relationship. The mediating variables are positively correlated with urban GTIC. Among the control variables, education expenditure (*edu*) is significantly negatively correlated with urban GTIC. Economic development level (*gdp*), population density (*dpop*), the level of urbanization (*urban*), the level of financial development (*fin*), and human capital (*hc*) are all significantly positively correlated with urban GTIC.

Empirical Results and Analysis

Trend Analysis

Fig. 1 depicts the trend of GTIC of the experimental and control groups. As shown in Fig. 1, the gap between the experimental and control groups' GTIC has widened since 2017. Accordingly, this paper tentatively argues that the widening gap in GTIC between pilot cities and non-pilot cities after 2017 is caused by the ERTP. However, other factors besides ERTP will influence the trend of the mean value. Whether the ERTP can improve the urban GTIC needs to be further tested. Therefore, this paper will next use the DID model to test the relationship between ERTP and GTIC.

DID Model Regression Aanalysis

This paper uses the DID model to test the impact of the ERTP on urban GTIC. The regression results are shown in Table 4. Column (1) shows the regression results without the control variables, and column (2) shows the regression results with the control variables added. According to Table 4, the regression coefficient of the ERTP is significantly positive with or without the control variables. The results show that the ERTP significantly improves urban GTIC. Hypothesis 1 was verified.

According to Table 4, the estimated coefficients of the level of financial development (*fin*), human capital (*hc*), and population density (*dpop*) are not significant. They have no significant effect on urban GTIC. The estimated coefficients of economic development level (*gdp*), urbanization level (*urban*), and education expenditure (*edu*) are significantly positive, which indicates that the above variables have a significant positive relationship

Table 1. The measurement methods and data sources of variables.

Variables	Name	Symbol	Measurement method	Data sources
Explained variable	Urban green technology innovation capacity	*lngti*	The number of green patent applications plus one and taking the natural logarithm [55].	The National Intellectual Property Database.
Core explanatory variable	Energy-consuming right trading policy	*treat × post*	The value of $treat_i \times post_t$ is 1 for the pilot cities of ERTP. Otherwise, it is 0.	The Pilot Program of the Paid Use and Trading Policy of the Energy-consuming Right.
Control variables	Economic development level	*gdp*	The GDP of cities.	EPS database;
	Education expenditure	*edu*	The share of education expenditure in fiscal expenditure.	EPS database;
	Population density	*dpop*	The ratio of the total population of a city to the land area of the city's administrative district at the end of the year.	EPS database;
	The level of urbanization	*urban*	The proportion of the urban population to the total population of the city.	EPS database;
	The level of financial development	*fin*	The ratio of the balance of loans from financial institutions to the city's GDP at the end of the year.	EPS database; CSMAR database;
	Human capital	*hc*	The ratio of the general population with a bachelor's degree or higher to the city's resident population.	EPS database; Cities' annual statistical reports
Mediating variables	Industrial structure rationalization	*rs*	$\frac{1}{\sum_{j=1}^{3}(\frac{Y_{i,j,t}}{Y_{i,t}})\ln(\frac{Y_{i,j,t}}{L_{i,j,t}}/\frac{Y_{i,t}}{L_{i,t}})}$; $Y_{i,j,t}$ indicates the industrial value added of industry *j* in city *i* in year *t*. $L_{i,j,t}$ denotes the number of practitioners of industry *j* in city *i* in year *t* [65].	China Statistical Yearbook; EPS database
	Industrial structure optimization	*ts*	$ts_{i,t} = \sum_{j=1}^{3}\frac{Y_{i,j,t}}{Y_{i,t}} \times lp_{i,j,t}$ $lp_{i,j,t} = \frac{Y_{i,j,t}}{L_{i,j,t}}$; ; $lp_{i,j,t}$ denotes the labor productivity of industry *j* in city *i* in year *t* [66].	China Statistical Yearbook; EPS database

Table 2. Descriptive statistics of variables.

Variables	Obs	Mean	Std.Dev.	Min	Max
lngti	4185	3.7643	1.8821	0.0000	10.0879
treat × post	4185	0.0392	0.1941	0.0000	1.0000
gdp	4185	0.2161	0.3239	0.0052	3.8701
cdu	4185	0.1808	0.0427	0.0177	0.3774
dpop	4185	0.4380	0.3395	0.0047	2.9273
urban	4185	52.4341	16.0642	16.6900	100.0000
fin	4185	0.9148	0.5795	0.0753	9.6221
hc	4185	1.6484	1.9516	0.0039	12.7643
ts	4185	2.0519	0.0853	1.5805	2.2870
rs	4185	9.8486	7.2118	0.0474	64.3868

Table 3. Correlation analysis.

Var	*lngti*	*treat × post*	*gdp*	*cdu*	*dpop*	*urban*	*fin*	*hc*	*ts*	*rs*
lngti	1.0000									
treat × post	0.1715***	1.0000								
gdp	0.7110***	0.0978***	1.0000							
cdu	-0.1538***	-0.0212	-0.1147***	1.0000						
dpop	0.4673***	0.0576***	0.4991***	0.1463***	1.0000					
urban	0.5700***	0.0875***	0.4842***	-0.3060***	0.2978***	1.0000				
fin	0.4767***	0.0972***	0.3558***	-0.2481***	0.0992***	0.4444***	1.0000			
hc	0.5306***	0.0142	0.3643***	-0.2714***	0.2139***	0.4824***	0.5632***	1.0000		
ts	0.2442***	-0.0609***	0.2690***	-0.2732***	0.0243	0.5407***	0.2364***	0.3389***	1.0000	
rs	0.6580***	0.2074***	0.5304***	-0.1732***	0.2601***	0.5191***	0.2946***	0.2673***	0.2079***	1.0000

***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.

with urban GTIC. Economic development, population increase, urban expansion, and education development can provide more financial, talent, and resource support for green technology innovation, which is conducive to improving urban GTIC.

Robustness Test

Parallel Trend Test

This paper takes the year before the policy implementation as the base year. Four years before and four years after the base year are selected for regression to test whether the sample meets the parallel trend assumption. The regression results are shown in Fig. 2. As can be seen from Fig. 2, the coefficient of the ERTP is not significant before the policy is implemented. The result shows that there is no significant difference between the GTIC of the pilot and non-pilot cities before the implementation of the policy. The parallel trend assumption is satisfied. After the policy is implemented, the coefficient of the ERTP is significantly positive, which indicates that the ERTP significantly improves urban GTIC.

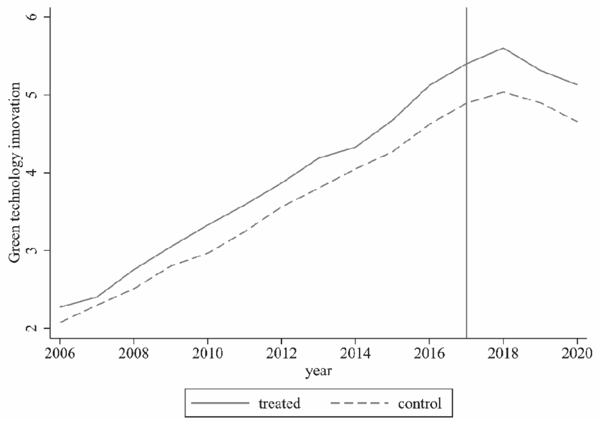

Fig. 1. The trend of GTIC.

Table 4. The effect of ERTP on urban GTIC.

Variables	*lngti*	
	(1)	(2)
treat × post	0.1839*** (0.0675)	0.1538** (0.0687)
gdp		0.2266* (0.1219)
cdu		1.4038*** (0.6566)
dpop		-0.0451 (0.2768)
urban		-0.0199 (0.0372)
fin		0.0175*** (0.0043)
hc		-0.0141 (0.0248)
Constant	2.1041*** (0.0398)	1.1122*** (0.2649)
year	yes	yes
city	yes	yes
Observations	4185	4185
R^2	0.8068	0.8112

Note: (1) Values in parentheses are robust standard errors for clustering to the city level; (2) ***,**, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.

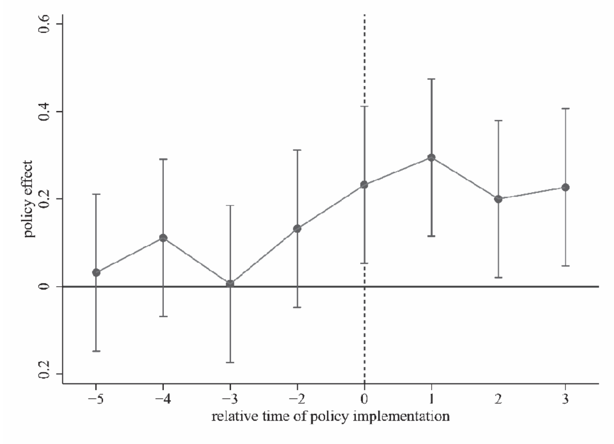

Fig. 2. Parallel trend test.

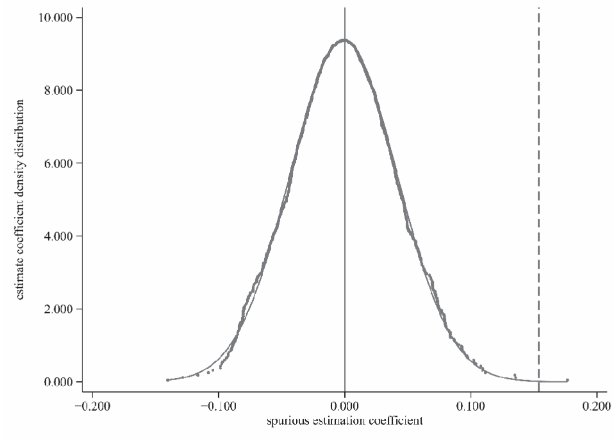

Fig. 3. Placebo test.

Placebo Test

This paper constructs a spurious treated group by randomly selecting pilot cities of the ERTP and randomly generating the pilot time to exclude the influence of other factors [67, 68]. The remaining cities are the spurious control group. Then, this paper uses the DID model to regress the spurious treatment group and control group. After repeating the above process 1000 times, the reliability of the conclusion is judged based on the density distribution of the regression coefficients. Suppose the estimated coefficients are distributed around 0 under the randomization treatment. In that case, it indicates that the conclusions are reliable and that there are no significant omitted variables causing bias in the regression results. Otherwise, it indicates that other omitted variables heavily confound the regression results. The distribution of the spurious regression coefficients is shown in Fig. 3. The results show that the estimated coefficients of the ERTP in the spurious regressions are concentrated around 0, and the difference between the estimated coefficient values and the true regressions is significant. The results show that the estimated coefficients of the ERTP in the spurious regressions are concentrated around 0 and differ significantly from the truly estimated coefficients. The above results indicate that the conclusion of this paper passed the placebo test and that the conclusion is robust.

PSM-DID

The DID method can identify the net effect of the policy by comparing the control group with the treated group. However, due to selection bias, the DID method cannot ensure that pilot and non-pilot areas have the same characteristics before the policy is implemented. This paper uses the propensity score matching method (PSM) to match cities in the control and treated groups to overcome the selection bias between pilot and non-pilot cities. Specifically, this paper builds the logit model with urban GTIC as the outcome variable and the control variables in the DID model as covariates. Then, this paper uses the one-to-one nearest neighbor matching method with put-back for matching. Finally, the matched samples are regressed again according to the DID model. The propensity score density function is plotted in this paper to show the matching effect clearly (Fig. 4). Fig. 4 shows that the propensity score probability densities of the control and treated groups are closer after matching. Therefore, the matching result is favorable. The regression results after PSM are shown in column (1) of Table 5. As shown in column (1) of Table 5, the estimated coefficient of the ERTP is still significantly positive, which is consistent with the regression results of the DID model. It again indicates that the ERTP significantly improves urban GTIC, and the conclusion is robust.

Eliminate Competitive Policies

China introduced low-carbon city pilot and carbon emission trading policies in 2010 and 2011, respectively. Research has found that low-carbon city pilots and carbon trading policies can significantly improve GTIC [69, 70]. Therefore, this paper excludes the cities that implemented low-carbon city pilot policy and carbon trading policy from the regressions to avoid the interference of the above policies. The regression result is shown in column (2) of Table 5 after excluding city samples of low-carbon city pilots and carbon emission trading pilots. The estimated coefficient of the ERTP is still significantly positive according to column (2) in Table 5. The results show that the ERTP significantly improved urban GTIC. It indicates that the conclusion is robust.

Exclusion of Administrative Grade Differences

Significant differences between municipalities directly under the central government, provincial capitals and sub-provincial cities and ordinary prefecture-level cities can lead to biased regression

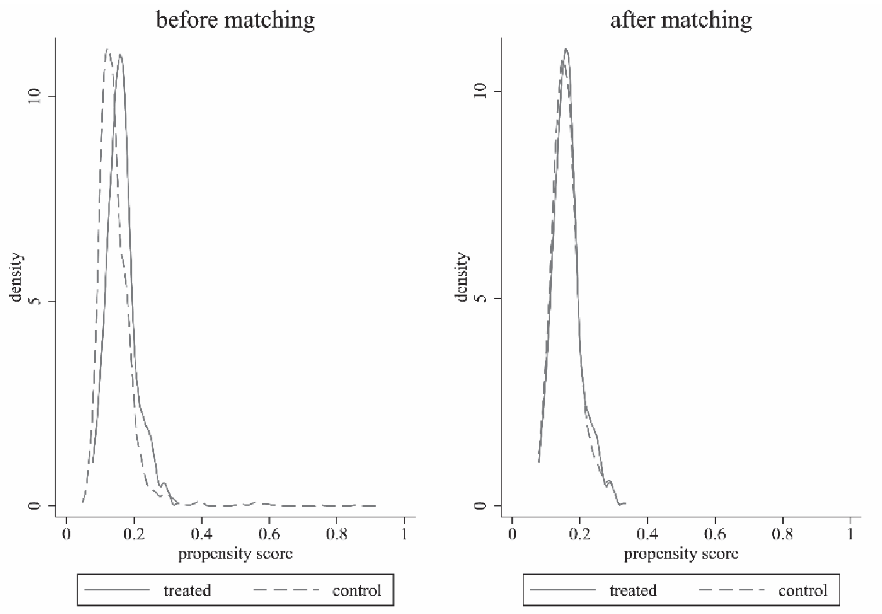

Fig. 4. Propensity score matching.

results. Therefore, this paper regresses again after excluding the samples of municipalities directly under the central government, provincial capitals, and sub-provincial cities to test the reliability of the conclusion [71]. The regression results are shown in column (3) of Table 5. It can be found that the estimated coefficient of the ERTP is significantly positive. Again, the results show that the ERTP significantly improved urban GTIC, and the conclusion is robust.

Elimination of Uutlier Interference

Extreme outliers in the sample data can seriously affect the regression results [72]. Therefore, this paper shrank the continuous variables at the upper and lower 1% to eliminate the effect of outliers. Then, the processed samples were regressed again according to the DID model. The regression results are shown in column (4) of Table 5. As shown in Table 5, the estimated coefficient of the ERTP is still significantly positive after excluding the outliers. It shows that the ERTP significantly improved urban GTIC, and the conclusion is robust.

Mechanism Test

The previous analysis and robustness tests have shown that the ERTP can significantly improve urban GTIC. This paper will further investigate the transmission mechanism of the effect of ERTP. This paper will take industrial structure rationalization (*rs*) and industrial structure optimization (*ts*) as mediating variables and regress them according to the mechanism test model. The regression results are shown in Table 6. Columns (1) and (3) report the estimation results of Equation (3), and columns (2) and (4) report the estimation results of Equation (4). The estimated coefficient of the ERTP (*treat* × *post*) in column (1) is significantly positive. It indicates that the ERTP significantly promotes industrial structure rationalization. Column (2) shows that the estimated coefficient of the ERTP is still significantly positive after including industrial structure rationalization, but the coefficient value of the ERTP is smaller than the coefficient value in the original model. It shows that the ERTP can improve the urban GTIC through industrial structure rationalization. Similarly, The estimated coefficient of the ERTP in column (3) is significantly positive. It indicates that the ERTP significantly promotes industrial structure optimization. Column (4) shows that the estimated coefficient of the ERTP is still significantly positive after including industrial structure optimization, but the coefficient value of the ERTP is smaller than the coefficient value in the original model. It shows that the ERTP can improve the urban GTIC through industrial structure optimization. In summary, the ERTP improves urban GTIC by promoting industrial structure upgrading. Hypothesis 2 of this paper has been verified.

Heterogeneity Analysis

Location Heterogeneity

Chinese territory is vast. The geographical environment, resource endowment, and economic base vary significantly among regions, so the effect of the policy cannot be generalized [73]. This paper divides the samples into the group of central and western cities and eastern cities to further investigate the differences in policy effects among regions. Then the grouped samples were regressed according to the DID model

Table 5. Robustness test.

Variables	*lngti*			
	(1)	(2)	(3)	(4)
treat × post	0.1322* (0.0689)	0.1699** (0.0855)	0.1291* (0.0740)	0.1468** (0.0701)
Constant	1.2127*** (0.3205)	1.1824** (0.4576)	0.8163* (0.4193)	1.0176*** (0.3487)
Control	yes	yes	yes	yes
year	yes	yes	yes	yes
city	yes	yes	yes	yes
Observations	4051	2380	3660	4185
R^2	0.8136	0.8015	0.7985	0.8086

Note: (1) Values in parentheses are robust standard errors for clustering to the city level; (2) ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.

[74]. The regression results are shown in Table 7. Columns (1) and (2) indicate the regression results of cities in the eastern region, and columns (3) and (4) indicate the regression results of cities in the central and western regions. According to columns (1) and (2), the estimated coefficient of ERTP is significantly positive with or without control variables. However, according to columns (3) and (4), the estimated coefficient of ERTP is not statistically significant with or without control variables. The results show that the ERTP significantly improved the urban GTIC in the eastern region. On the contrary, the ERTP has no significant effect on the urban GTIC in the central and western regions. The possible reason is that cities in the eastern region pay more attention to technological innovation and have a better economic base. As a result, eastern cities have a richer talent pool and more financial support for innovation [75].

Resource Heterogeneity

Resources significantly impact the industry structure of cities, and urban innovation capacity may also vary due to different industries [76]. Therefore, this paper divides the sample into resource-based cities and non-resource-based cities to investigate the differences in policy effects according to the National Sustainable Development Plan for Resource-based Cities [77]. Then the grouped samples were regressed according to the DID model. The regression results are shown in Table 8. Columns (1) and (2) denote the regression results for resource-based cities, and columns (3)

Table 6. Mechanism test.

Variables	*rs*	*lngti*	*ts*	*lngti*
	(1)	(2)	(3)	(4)
treat × post	0.0114** (0.0051)	0.1462** (0.0688)	1.0916* (0.6485)	0.1450** (0.0664)
rs		0.6606** (0.3253)		
ts				0.0081** (0.0039)
Constant	2.0311*** (0.0190)	-0.2295 (0.7175)	3.8549 (2.3363)	1.0812*** (0.2647)
Control	yes	yes	yes	yes
city	yes	yes	yes	yes
year	yes	yes	yes	yes
Observations	4185	4185	4185	4185
R^2	0.075	0.8116	0.7186	0.8106

Note: (1) Values in parentheses are robust standard errors for clustering to the city level; (2) ***, **, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.

Table 7. Location heterogeneity.

Variables	Eastern cities		Central and western cities	
	(1)	(2)	(3)	(4)
treat × post	0.4175*** (0.0906)	0.3481*** (0.0881)	-0.0290 (0.0774)	-0.0989 (0.0711)
Constant	2.8737*** (0.0659)	1.6676*** (0.3382)	1.6741*** (0.0498)	0.9441** (0.3775)
Control	no	yes	no	yes
year	yes	yes	yes	yes
city	yes	yes	yes	yes
Observations	1500	1500	2685	2685
R^2	0.8621	0.8683	0.7821	0.7884

Note: (1) Values in parentheses are robust standard errors for clustering to the city level; (2) ***,**, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.

Table 8. Resource heterogeneity.

Variables	Resource-based cities		Non-resource-based cities	
	(1)	(2)	(3)	(4)
treat × post	0.0302 (0.1022)	-0.0008 (0.0976)	2.8737*** (0.0659)	0.2035** (0.0785)
Constant	1.6571*** (0.0637)	0.9629* (0.5752)	2.3994*** (0.0502)	1.6316*** (0.3400)
Control	no	yes	no	yes
year	yes	yes	yes	yes
city	yes	yes	yes	yes
Observations	1665	1665	2520	2520
R^2	0.7496	0.7575	0.8453	0.8479

Note: (1) Values in parentheses are robust standard errors for clustering to the city level; (2) ***,**, and * represent statistical significance at the 1%, 5%, and 10% level, respectively.

and (4) denote the regression results for non-resource-based cities. According to Table 8, the ERTP can significantly improve the GTIC of non-resource-based, but the effect is not significant for resource-based cities. The possible reason is that the development of resource-based cities relies heavily on natural resources, which results in a lagging industrial level and a low reserve of innovative talents [56]. Therefore, the ERTP has no significant effect on the GTIC of resource-based cities.

Conclusions and Implications

Based on the data from 279 cities in China from 2006 to 2020, this paper used the DID model to study the impact of the ERTP on urban GTIC. The findings of the study are as follows. (i) The DID model regression revealed that the coefficient for the ERTP is 0.1538, which is significant at the 5% level. This suggests that the implementation of the ERTP resulted in an average increase of 0.1538% in GTIC. Moreover, the results confirm the applicability of the "Weak Porter hypothesis" in China. To validate the research findings, robustness tests such as parallel trends analysis, placebo test, propensity score matching, and eliminating competitive policies were conducted, and the above conclusion still holds. (ii) Through the mediation test model regression, it was found that the regression coefficient of the ERTP is significantly positive, and the regression coefficient decreases. The results indicate the presence of partial mediation effects. The ERTP can improve urban GTIC through industrial structure upgrading. (iii) The impact of ERTP on GTIC shows heterogeneity across different cities. This paper conducted group regression analysis from the perspective of resource endowment and urban scale. The results revealed that the regression coefficient of the ERTP was significantly positive in the samples of eastern cities and non-resource-based cities, but was not significant in the samples of central and western cities and resource-based cities. These findings suggest that the ERTP has a significant promoting effect on GTIC in eastern cities and non-resource-based cities, while it is not significant in central and western regions and resource-based cities.

Based on the above conclusions, this paper makes the following recommendations. (i) The government should summarize the experience of the pilot areas and continuously promote the pilot of ERTP. This paper found that the ERTP can significantly improve urban GTIC. Therefore, the government should further improve supporting policies, improve the trading system, and strengthen supervision and management to optimize the effect of the policy. (ii) The government should actively promote industrial structure upgrading. This paper found that the ERTP can improve urban GTIC through industrial upgrading. On the one hand, the government should use the market mechanism to optimize the allocation of resources. Eventually, the industrial structure upgrading and the ERTP will jointly improve urban GTIC. (iii) The government should reasonably allocate energy-consuming rights according to the conditions of the city. This paper found that the ERTP has no significant effect on GTIC in central and western cities and non-resource-based cities. Therefore, the government should appropriately adjust the allocation method and amount of energy-consuming rights and make targeted supporting policies to maximize the effect of the ERTP.

This paper fills some research gaps, there is still room for further research. First, there is usually a spillover effect of technological innovation. However, this paper does not analyze the spillover effect of urban GTIC. Moreover, enterprises, research institutions, and universities are the main innovators of green technologies. The contribution of different innovators to the urban GTIC also needs further study. We hope that future work will improve related research.

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Conflict of Interest

The authors declare no conflict of interest

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