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Can Pollution Regulations Enable Key Industries to Reduce CO_2 Emissions?—Empirical Evidence from China, Based on Green Innovative Technology Patents and Energy Efficiency Perspectives

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Abstract: Under the influence of the dual policies of sustainable economic development and the national dual-carbon target, the establishment of an environmental protection department for the treatment of heavily polluting industries is imminent, and the country has launched pollution control policies and regulations to restrict the emission rights of heavily polluting industries. Therefore, this paper focuses on whether the restriction of emission rights in key industries has reduced carbon emissions. To achieve this, this paper uses panel data of prefecture-level cities in China from 2006 to 2019 and adopts a two-way fixed-effects DID model to systematically analyze the impact of the key pollution industry governance policies launched by the Ministry of Environmental Protection on CO_2 emissions in 2017. And further analyze the role of variables such as green technology innovation patents and energy efficiency using this model, while parallel trend tests and placebo tests, and related policies are used to ensure the robustness of the regression results. This paper reveals that: (1) The heavy pollution industry governance policy implemented in 2017 can effectively reduce CO_2 emissions in the cities of the treated group, and the effect is more significant in the year of policy implementation; (2) Green utility patents and energy-use efficiency are the effective mediating mechanisms to reduce CO_2 emissions; (3) Over time, the effect of heavy pollution industry governance policy on CO_2 emissions gradually decreases; (4) The reliability of the baseline regression results of this paper is proved by the use of parallel trend tests, placebo tests, and tests excluding the influence factors such as relevant policies in the same period. Therefore, the key polluting industries treatment policy launched by China's Ministry of Environmental Protection in 2017 under the recent dual-carbon policy development goals formulated by China, can effectively reduce carbon emissions; however, in the future economic development process, the government should give more consideration to the continuity of the policy impact and its coherence on economic development when implementing the policy.

Keywords: environmental regulation; technological innovation; carbon trading rights; energy efficiency; carbon peaking; carbon neutrality policies

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1. Introduction

Since the Industrial Revolution, the intensive use of modern machinery has made it possible to maximize the output of natural resources such as land, water, and minerals to their maximum production potential [1]. Along with the accelerated economic development, natural resources have been exploited in large quantities, and the unreasonable use of resources and unrestricted sewage have caused huge changes in the global climate, creating a huge challenge to the sustainable development of the global economy. In recent years, global warming, droughts, melting glaciers, rising sea levels, and decreasing food production have become increasingly serious problems, mainly due to the current overexploitation of resources and increasing air pollution [2,3]. For example, air pollution in London, once known as the "fog city", and the appearance in the 21st century of haze in the cities of China, are both a consequence of neglecting environmental protection in economic development. The study of economic development and environmental pollution has long been the focus of research, and economic growth has always seemed to sacrifice the natural environment [4,5]. In the process of economic development, we should not only consider the immediate benefits of over-exploiting resources and discharging sewage, but also consider the long-term sustainability of economic development and ensure a model of green products that are inherited from generation to generation. Especially in recent years, the emission of greenhouse gases such as haze, carbon dioxide, and methane has had a more drastic impact on the environment and has a serious impact on the global human living environment.

In the process of rapid economic development, massive coal resources are required in various production processes. The burning of coal resources increases the emission of greenhouse gases such as carbon dioxide and methane in the air, which has a serious impact on the natural environment and human health and is not consistent with the goal of sustainable development [6]. This aggressive approach to traditional economic development is not in conformity with the modern view of ecological economics. As research on environmental pollution deepened, people gradually realized the importance of changing the economic development model, and organizations such as the United Nations began to rule on the right to discharge in economic development. In December 1997, the United Nations Framework Convention on Climate Change established the Kyoto Protocol, with the participation of more than 100 countries worldwide, to develop carbon reduction plans. This convention stipulates that the Kyoto Protocol would come into force in 2005, and, thus, the governance of carbon emission trading rights officially began. Currently, the United Nations regulates the carbon emission authority of each country in general through policies such as the Kyoto Protocol and the United Nations Framework Convention on Climate Change [7,8], to promote energy conservation and emission reduction in countries around the world, rather than in any one country, as a country's contribution to energy saving and emission reduction is limited, and we need to rely on the strength of all countries to build a better living environment for human production and life.

Since China's reform and opening, the country's economy has grown tremendously and people's living conditions have improved remarkably, with per capita disposable income rising from 0.09 thousand yuan in 1990 to 35,100 yuan in 2021, an increase of 38 times year-on-year. Today, with the rapid development of the economy, people's growing material and spiritual–cultural needs conflict with the increasingly prominent environmental pollution problems. The traditional crude economic development model that relies on natural energy sources such as coal and oil is increasingly being criticized [9]. Especially since 2010, China's air quality and water pollution problems have affected people's health. For example, haze increases respiratory and other diseases, water pollution seriously affects people's daily lives, and carbon emissions from coal energy aggravate the emissions of SO_2, $PM_{2.5}$, and CO_2 in the air, which further affects the life of people [10]. As shown in Figure 1, China's CO_2 emissions were still at a high level compared to other countries from 1990 to 2019, and further strengthening of environmental management efforts is necessary. It is also clear from Figure 2 that China's CO_2 emissions are at a high level, both in terms of CO_2 per capita and CO_2 per GDP. Therefore, in 1995, China responded positively to the global demand for carbon emission reduction and promoted green and sustainable economic development based on the "Outline of New and Renewable Energy Development 1996–2010". In particular, in September 2020, the Chinese government put forward the dual goals of carbon peaking and carbon neutrality, with an aim to achieve carbon peaking in 2030 and carbon neutrality in 2060 [11].

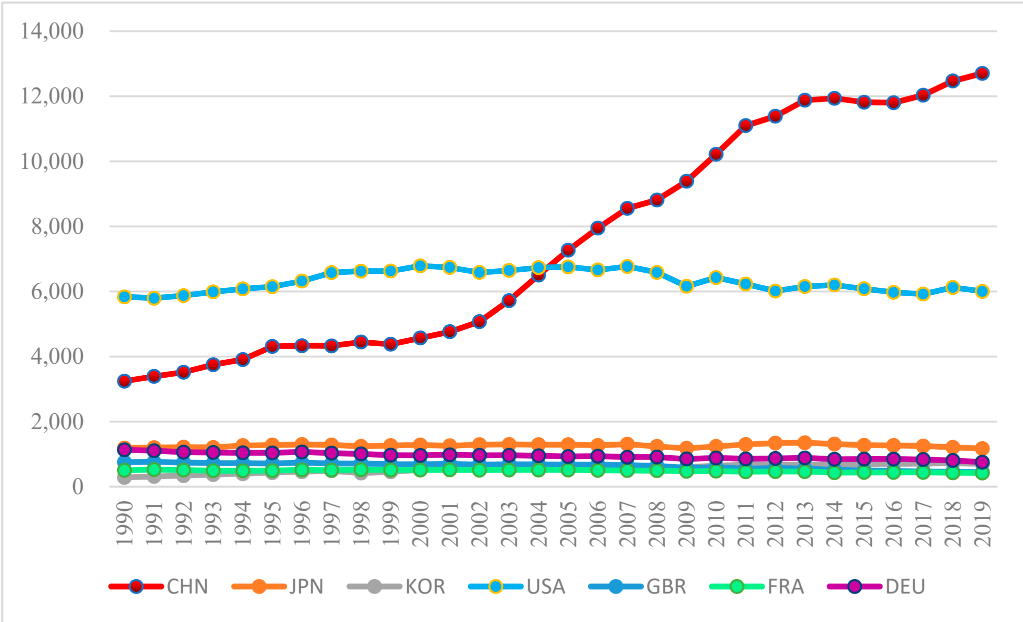

Figure 1. 1990–2019 CO_2 emissions of representative countries in the world (MT of CO_2 equivalent). Data source: World Bank/ourworldindata.org.

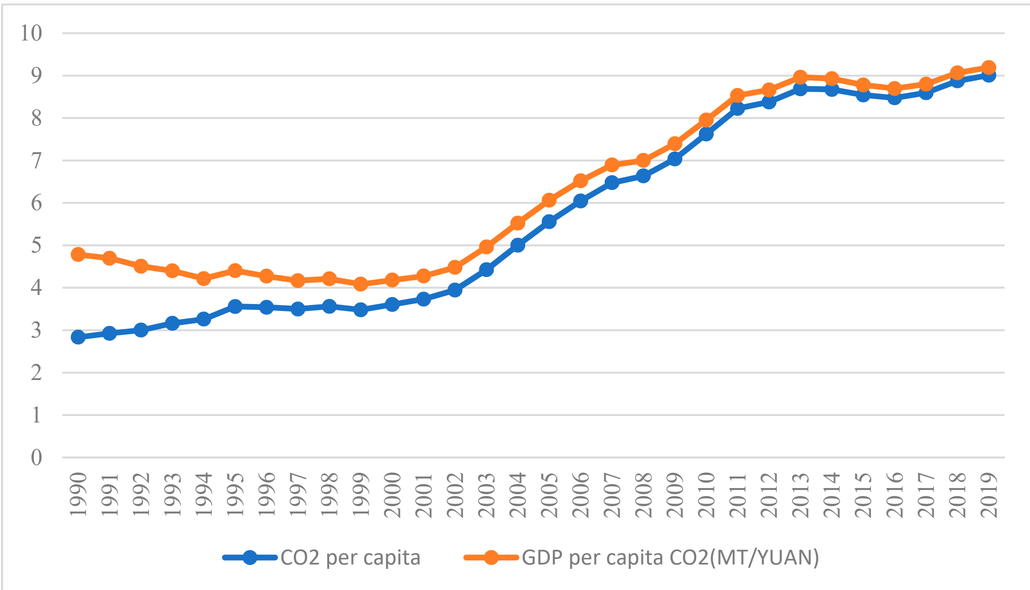

Figure 2. 1990–2019 CO_2 per capita and CO_2 per GDP in China. Data source: World Bank/ ourworldindata.org.

Economic development and energy consumption are inseparable, and finding a way to reduce the harm caused by environmental pollution in the process of economic development is the current imperative for China's economy to take the path of green and sustainable development. At the same time, governments at all levels have also promulgated relevant policies, such as Shandong Province, which, during the Eleventh Five-Year Plan, promulgated the "2010 Annual Energy Conservation Target Responsibility Book" to assess the performance of each city in the province during this period of energy conservation and emission reduction, and Handan City in Hebei Province in 2014, which issued "Fifteen Measures on Supporting the Accelerated Development of Energy Conservation and Environmental Protection Industry" to complete the requirements of the performance indicators. The promulgations of these policies have put forward relevant policy objectives and implemented strict environmental regulations, which provide a guarantee for promoting the green and sustainable development of the economy. In order to execute the Implementation Plan of the Pollutant Discharge Permit System (No. 81, 2016), the General Office of the Ministry of Environmental Protection issued the Pilot Work Plan for Pollutant Discharge Permit Management for Key Industries in May 2017. In this plan, it is explicitly stipulated that 11 provincial environmental protection departments and 6 prefecture-level municipal environmental protection departments take the lead or participate in a pilot project of the application and issuance of emission permits for the corresponding key industries. How this pilot performed will affect current emissions regulation, especially the impact on regional carbon emissions achieved, and is the focus of this study.

2. Literature Review and Theoretical Mechanisms

2.1. Literature Review

Rapid economic development is often at the expense of the local natural environment. In the process of urban industrialization, enterprise production can take up a large amount of land, and consume a large number of natural resources such as water and coal, and problems such as river sewage, land desertification, and air pollution are becoming increasingly prominent. The contradiction between economic development and environmental protection is becoming more and more prominent, and almost every developed country has gone through the process of pollution before treatment [12].

In the face of increasingly prominent global environmental problems, international environmental public interest organizations and various countries around the world have successively introduced various policies to manage the environmental hazards arising from the production process. The most typical approach is to determine emissions trading rights, i.e., enterprises and individuals purchase emissions trading rights for production, and this practice has to a certain extent alleviated the environmental pollution in the regions employing this approach. Industrial emissions and industrial discharges have a huge impact on the living environment and sustainable development of human beings, so various countries have introduced various rules to regulate environmental pollution [13,14]. Especially in recent years, greenhouse gas emissions have changed the trajectory of the global ecosystem and forced countries to introduce relevant policy measures. Liu. et al. & Padhy et al. [15,16] studied carbon emissions and greenhouse gases. Similarly, Wanyi Chen [17] studied carbon trading rights and environmental regulation and showed that carbon emissions trading restrains over-investment and promotes the investment efficiency of enterprises.

The Porter hypothesis supports the idea that stricter environmental regulation may even encourage innovation. According to Porter, strict environmental regulations have prompted companies to invest more in R&D and find greener ways of production, which in turn has accelerated the pace of innovation [18–21]. Qi, S. et al. present evidence in support of the Porter hypothesis of emissions trading rights through Chinese data [22]; Zhang, T. Y. demonstrates that the impact of environmental regulation is conducive to innovation through literature from other countries, and Rongxin Wu & Boqiang Lin have shown which Chinese policies have a disincentive effect on environmental pollution. The study of the relationship between technological innovation and carbon emissions has been a popular topic, and technological innovation can be said to be a product of strict environmental regulation to a certain extent [23–25].

Technological innovation is mainly reflected in enterprises' increased investment in R&D, which can accelerate the birth of new technologies and the efficiency of new energy use to effectively reduce environmental pollution [26]. Ganda (2018) has studied the impact of green energy investments on carbon emissions in OECD countries for the period 2000–2014. They point out that investments in green energy, i.e., renewable energy, not only improve energy efficiency but also reduce environmental degradation by lowering carbon emissions [27,28]. Using data from OECD countries for the period 2000–2014, Ganda (2019) examines the impact of investment in innovation and technology on environmental degradation. They use a generalized method of moments approach and report that innovation and technology investments reduce carbon emissions to improve environmental quality [29–31]. Their empirical results further show that, although the impact of innovation and technology investment on carbon emissions is not unique, OECD countries can reduce carbon emissions through innovation and technology investment. Nesta et al. (2014) found that R&D expenditures have a significant and positive impact on reducing CO_2 emissions [32]. Their empirical analysis suggests that energy R&D investments must be regulated so that energy intensity, fossil fuel energy consumption, and CO_2 emissions can be minimized.

2.2. Theoretical Mechanisms

The government uses strict environmental regulations to suppress high energy consumption in the production process of enterprises, which can effectively improve the environmental quality of the region over a certain period. What are the main mechanisms for these environmental improvements? Existing studies suggest that a strict environmental regulation policy can make enterprises in the region more productive and increase their investment in human capital and technological research and development, thus reducing their emissions and improving the environmental quality of the region [33,34]. At present, increasing R&D investment in green patented technologies, improving the overall level of human capital, enhancing energy use efficiency, and accelerating the development of new energy sources are the main ways to reduce regional environmental pollution. This paper uses data at the prefectural city level as the research object, thereby studying the mechanism of energy use efficiency and green patented technology input of the region as the mediating variables affecting carbon emissions in the region.

2.2.1. Energy Use Efficiency

Energy use efficiency mainly refers to the impact of coal and other natural energy consumption on the total local GDP in the production process. The higher the energy use efficiency, the higher the GDP value generated by each unit of coal energy consumption, which indicates that enterprises can reduce CO_2 emissions from the side by making efficiency in the production process. A study by Chen and Lei (2018) examined the impact of technological innovation and renewable energy consumption on the environment-energy growth relationship in a panel of 30 countries by applying Johansen co-integration and quantile regression methods. Their empirical findings point to a significant negative impact of technological innovation on CO_2 emissions. They emphasized the need for high-producing countries with high CO_2 emissions to invest more in innovative energy technologies by reducing CO_2 emissions. A study by Lin and Wang (2015) investigated the impact of technical efficiency and technological progress on CO_2 emissions in China over the period 2000–2011. Their empirical evidence suggests that total factor CO_2 emission performance is higher in the East and Northeast and lower in the West and Central regions and that there is considerable potential for minimizing carbon emissions in the East and West [35,36]. Jin et al. (2017) studied the impact of technological advances in China's energy sector on CO_2 emissions over the period 1995–2012. Their empirical results confirm that technological advances in the energy sector have a significant and positive impact on reducing CO_2 emissions, while energy efficiency can significantly reduce CO_2 emissions. They suggest that, based on the empirical results, to achieve low carbon emissions, the government should increase its investment in energy research and improve energy efficiency. Therefore, this paper adopts energy use efficiency, which is the ratio of energy consumption to the region's GDP, as a mediating mechanism to investigate the impact of the pilot work program for key emission permit management policy on energy use efficiency and thus determine its impact on carbon emissions in the region.

2.2.2. Green Utility Patent Technology

Green utility patent technology can effectively reflect R&D into environment-related patent technology in the region. It can also indicate the importance of R&D investment and corresponding human capital investment in the region. The ratio of practical green patented technologies shows the true percentage of technology patent applications used in the region, and the level of this ratio will regulate the environmental conditions of the region. Cho and Sohn (2018) researched the impact of green R&D investments and green patent applications on CO_2 emissions in Italy, the UK, France, and Germany over the period 2004–2012 [37]. They report that CO_2 emissions and R&D investment have had little impact on changing green patent applications. Their empirical results emphasize that carbon emissions associated with fossil fuel energy can be effectively minimized only by promoting green technologies. The practical green patent technology index used in this paper mainly adopts the ratio of green patents applied for in the region to the total number of patents applied for and uses this index as a mediating mechanism to measure the impact of environmental policy on the practical green patent index and thus on carbon emissions of the region.

3. Data Sources

3.1. Structure of the Econometric Model

The relationship between environmental regulation policies and pollution has always been the focus of our research. The DID model (Details in Abbreviations Section) has been widely used in the analysis of government policies, as it can readily avoid the possible endogeneity problems of econometric models. Moreover, the intuitive and vivid analysis of policy effects can well illustrate the implementation effects of policies. The essence of the method is to analyze the responses of the treatment and control groups before and after the policy, to judge the impact of the policy on the actual treatment group and the effect of the policy. Therefore, this paper uses the DID model to construct a quasi-natural experiment to study the impact of emission limits on carbon neutrality in key industries. The policy was issued on 20 May 2017, when the General Office of the Chinese Ministry of Environmental Protection issued the Pilot Work Program for Key Emission Permit Management, which identified 11 provincial-level environmental protection departments and 6 prefecture-level municipal environmental protection departments to take the lead, or participate, in the corresponding key industry emission permit application and issuance pilot work. To standardize the pilot work, the task requirements, time points, and scheduling plans were clarified. For the assumptions of the DID model, the six prefecture-level cities in the policy of the Key Emission Permit Management Pilot Work Program in 2017 are selected as the treatment group in this paper because the province-level data are too macroscopic and the control group data are relatively small. This paper uses 2017 as the policy impact time, lead cities that were not included in the key polluting industries before 2017 but were included in the key polluting industries after 2017 as the treatment group, and cities that were not included in the key polluting industries from 2006 to 2019 as the control group. Using this approach, the impact of the key emission permit management pilot work policy on the lead cities is compared. Therefore, the econometric model of this paper is set as follows.

$$CO_2 = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 Control_i + \varepsilon_{it} \quad (1)$$

To reduce the heteroskedasticity in the econometric model setting, the explanatory variables and significant control variables of Equation (1) are logged in this paper, and the specific econometric model is shown below.

$$\ln CO_2 = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 \ln Control_i + \varepsilon_{it} \quad (2)$$

$$lnCO_2 per\ capita\ GDP = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 \ln Control_i + \varepsilon_{it} \quad (3)$$

$$lnCO_2\ per\ unit\ GDP = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 \ln Control_i + \varepsilon_{it} \quad (4)$$

$$lnCO_2 percapita = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 \ln Control_i + \varepsilon_{it} \quad (5)$$

$\ln CO_2$ is the explained variable of Equation (2), which is the total annual carbon emissions of each city. $lnCO_2 per\ capita\ GDP$ is the explained variable in equation (3), which is the carbon emissions of a city's GDP per capita. $lnCO_2$ per unit GDP is the explained variable in Equation (4), which represents the carbon emissions per unit of GDP for each city. $lnCO_2 per\ capita$ is the explained variable in equation (5), which represents the per capita carbon emissions of each city. In Equations (2)–(5), $Post_i$ is a dummy variable set to 1 after 2017 and 0 before 2017. $Treat_i$ is a dummy variable set to 1 for cities included in the lead of key polluting industries and 0 for all others. The coefficient of $Post_i \times Treat_i$ captures the level of CO_2 emissions in the pilot region relative to the non-pilot region during the policy period and is the core explanatory variable to be estimated in this paper. $\ln Control_i$ is the ensemble of control variables in this paper; and ε_{it} is the error term.

3.2. Core Variables

3.2.1. Explained Variables

The core explanatory variable in this paper is the shock effect between the pilot policy of the key emission permit management and the time of policy implementation. By the data requirements of the DID model for the control group, given that the six cities that are the lead cities of the environmental policy are the data of the treatment group, the city policy of the treatment group is 1, and that of the control group is 0, in Table 1. First, our criterion for selecting cities in both the treatment and control groups was prefecture-level cities. Secondly, we make a simple comparison between the data of treatment and control groups according to their geographical location, GDP, GDP per capita, carbon emission per GDP, the population size of the area, and carbon emission per capita. Table 1 shows the basic data display for the cities in the treatment and control groups for 2017 according to the DID data processing requirements.

Table 1. Comparison of data for cities in the treatment and control groups.

Policy	City	Province	CO_2 (Ten Thousand Tons)	GDP (Hundred Million)	Per GDP (Yuan)	CO_2 Per Unit GDP	Population (Ten Thousand)	CO_2 Per Capita
1	Shenzhen	Guangdong	5895	22438.39	183127	0.03	1252.00	4.71
0	Guangzhou	Guangdong	5559	21500.00	150678	0.04	898.0	6.19
0	Zhuhai	Guangdong	1021	2675.18	155502	0.01	119.00	8.59
0	Shanghai	Shanghai	11754	30133.86	124600	0.09	2418.33	4.86
0	Beijing	Beijing	12901	28000.40	129000	0.10	2170.70	5.94
1	Baoding	Hebei	942	3449.74	29580	0.03	1199.00	0.79
0	Zhangjiakou	Hebei	781	1427.02	32219	0.02	465.00	1.68
0	Hengshui	Hebei	557	1523.19	34177	0.02	454.00	1.23
0	Chengde	Hebei	458	1465.45	41299	0.01	380.00	1.21
1	Tangshan	Hebei	2486	6530.15	82972	0.03	755.00	3.29
0	Cangzhou	Hebei	746	3643.40	48384	0.02	778.00	0.96
0	Shijiazhuang	Hebei	2521	6460.90	59645	0.04	1087.00	2.32
0	Langfang	Hebei	501	2881.01	61586	0.01	474.00	1.06
1	Xingtai	Hebei	695	2236.36	30486	0.02	735.16	0.95
0	Handan	Hebei	1709	3379.53	35567	0.05	1051.00	1.63
0	Qinhuangdao	Hebei	1041	1500.34	48356	0.02	298.00	3.49
0	Anyang	Henan	1169	2268.00	44201	0.03	512.85	2.28
1	Zibo	Shandong	2151	4781.30	101781	0.02	470.80	4.57
0	Yantai	Shandong	1436	7343.53	103771	0.01	654.00	2.20
0	Jinan	Shandong	2497	7151.63	98275	0.03	644.00	3.88
0	Rizhao	Shandong	1132	2008.88	69062	0.02	304.00	3.73

Data source: Statistical bulletin of prefecture-level cities in China, China Environmental Statistics Yearbook.

This paper examines the impact of trading policies on carbon neutrality for the governance of key polluting industries. In this paper, we construct DID dummy variables using the pollution control policies of the lead city as the basis. A city is assigned a value of 1 (as a treatment group) if it was designated as a lead city for the pilot policy in 2017, and a value of 0 (as a control group) if it was selected as a city that was not designated for inclusion in the pilot policy in 2017. Our city selections for the control group are based on regional characteristics, mainly from the perspective of geographic location, GDP, GDP per capita, etc. Cities that are similar to the treatment group are selected following the principles assumed by the DID model for the control and treatment group data. First, according to the geographical location of the cities, cities in the same province as the treatment group are selected as the control group as much as possible, because the same provinces have a high degree of similarity in their intrinsic economic development and environmental policies (except for Anyang City, but this city can be used as a control group city because of its high degree of similarity). Second, the control group was selected according to the level of economic development, and cities similar to the treatment group were selected based on GDP and GDP per capita for comparison (Shenzhen is a mega-city in China, and its economic volume and development level are comparable to Shanghai and Beijing, so Shanghai and Beijing are selected as the cities in the control group of Shenzhen). Finally, comparisons are made based on the characteristics of regional CO_2 emissions. As shown in Table 1, there is a high similarity between the control and treatment group cities, so these cities can be used as a control group for comparison.

3.2.2. Explained Variables

The focus of this paper is carbon neutrality and carbon emission reduction based on regional carbon emissions, and the data used are mainly the total annual carbon emissions of each city. CO_2 emissions are mainly generated by direct energy, such as fossil energy combustion, and indirect energy consumption, such as urban electricity and heat consumption, and energy consumption is generally counted at the provincial and municipal levels, so this paper uses CO_2 emissions at the prefectural level. More specifically, the carbon emissions of this paper are measured by four basic indicators, including natural gas, liquefied petroleum, society-wide electricity supply, and society-wide heat supply (emission coefficient of raw coal heat generation), and then calculated by summing. Among these, direct carbon emissions, such as those from liquefied petroleum and gas energy consumption, are mainly measured using the relevant conversion factors provided by IPCC 2006. For carbon emissions generated by the regional power grid, we mainly referred to the approach of Glaeser and Kahn [38–40], i.e., there is only one emission factor for each regional power grid, and we measured the carbon emissions according to the baseline emission factors of the power grid and urban electric energy consumption in the six regions of the Chinese power grid in previous years. For the emission coefficient of raw coal heat generation for heating at a national level, the China Urban Construction Statistical Yearbook provides the statistics of centralized heating in each city in previous years. According to IPCC2006, the carbon emission factor per kg of raw coal is 2.53 kg(CO_2/kg), so the amount of raw coal consumed for thermal energy can be used to calculate the carbon emissions from central heating. The carbon emissions from the above consumption types are summed to obtain the total carbon emissions of each city.

3.2.3. Control Variables

The control variables in this paper are per capita GDP (per GDP), industrial structure (INS), industrial structure rationalization index (ISRI), the percentage of patents granted for inventions (IPG), and technology progress level (TPL). The data sources of control variables are China Environment Statistical Yearbook, China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Research Data Service Platform (CNRDS), and EPS database.

(1) Per capita GDP (per GDP), expressed in this paper as the ratio of local GDP to the total number of people, and using CPI to eliminate the effect of inflation, is calculated based on the annual statistical bulletin of each city.

(2) Industrial structure (INS), which is expressed by the ratio of the total output value of the secondary industry to the total output value of the tertiary industry in the region, can reflect whether the overall industrial layout of a region is reasonable.

(3) Industrial Structure Rationalization Index (ISRI), industrial structure rationalization is a measure of whether the setting of industry matches the economic development demand, a measure of whether the energy utilization efficiency and factor input-output structure are reasonable, and also the reflection of the level of coordination between industrial structures [41]. This paper measures the level of rationalization of the industrial structure of each city based on the Thiel index, which is an indicator of the output value and the structure of employed persons in the three major industrial structures in China. If the Thiel index is 0, the industrial structure of the city is more balanced, while, if the Thiel index is not 0, the industrial structure is not reasonable. This mainly reflects the deviation of the output value and employment structure of different industries and the merits of the different economic statuses of each industry. The specific formula is,

$$Thiel_{i,t} = \sum_{m=1}^{3} y_{i,m,t} \ln\left(\frac{y_{i,m,t}}{l_{i,m,t}}\right), m = 1,2,3 \tag{6}$$

where $y_{i,m,t}$ denotes the share of m industries in area i to the regional GDP in period t. This indicator is a reflection of the high-level industrial structure and reflects the process of the industrial structure change. $l_{i,m,t}$ denotes the share of employees in industry m to the total employment in area i in period t.

(4) Invention patent granted number ratio (IPG), using the ratio of the number of invention patent applications to the total number of patent applications, which can reflect the actual level of progress of regional scientific research.

(5) Science and technology progress level (TPL), which is expressed in this paper as the ratio of regional science and technology expenditures to general fiscal budget expenditures. Higher R&D investment could help reduce carbon emissions in key polluting industries by enabling enterprises to improve R&D innovation, raise productivity levels, and transform production patterns.

3.2.4. Mediating Variables

(1) Green Utility Patent Share (GUP), the ratio of green utility patents to the total number of utility patents obtained annually in the region, which measures the actual level of technology innovation patents used in the region. In this paper, the CNRDS database is used to express the ratio of the number of green patent applications to the sum of all patent applications, which is used to measure the impact of green utility technology innovation on carbon emissions in key polluting industries—a new idea to transform energy use.

(2) Energy Use Efficiency (EUE) is mainly the ratio of regional energy consumption to GDP (million tons of standard coal/billion yuan), thus measuring the impact of energy use efficiency in a region's production process on economic development.

3.3. Data Sources

3.3.1. Data Sources

In this paper, we use data from 25 cities from 2006 to 2019, with a total of 6 lead cities in the governance of key polluting industries (as the treatment group), 19 cities as the control group according to the principle of DID treatment, and CO_2 data at the prefecture-level from the China Environmental Statistical Yearbook. The data sources for all variables are shown in the Table 2.

Table 2. Data sources of all variables.

Variable Type	Variable Name	Indicators	Data Source
Explained variable	CO_2	Annual average emissions (ten thousand tons)	China Environmental Yearbook
Core explanatory variable	DID Policy	/	Ministry of Environmental Protection, China
Intermediate variables	GUP EUE	Green Utility Patent Share Energy Use Efficiency	CNRDS EPS
Control variables	Per GDP	Real GDP per capita	China Statistical Yearbook
	INS	Industrial structure	National Bureau of Statistics of China
	ISRI	Industrial Structure Rationalization Index	National Bureau of Statistics of China
	IPG	Invention patent granted number ratio	CNRDS
	TPL	Science and technology progress level	CNRDS

3.3.2. Descriptive Statistics of All Variables

Table 3 provides the descriptive statistics of all variables. Overall, the data are rational and do not contain any apparent outliers.

Table 3. Descriptive statistics of all variables.

Variable	Obs	Mean	Std. Dev.	Min	Max	Unit
$\ln CO_2$	350	7.1363	1.0136	5.2126	9.5329	ten thousand tons
$\ln CO_2$per capita GDP	350	0.0349	0.0301	0.0059	0.1914	%
$\ln CO_2$ per unit GDP	350	0.3796	0.1580	0.1257	0.9373	%
$\ln CO_2$percapita	350	1.1777	0.5565	0.2771	3.0010	%
lnperGDP	350	10.7358	0.6493	8.3610	12.2233	Yuan
lnISRI	350	0.2219	0.1409	0.0001	0.5734	%
lnINS	350	0.6296	0.2461	0.1693	1.2625	%
lnIPG	350	0.1163	0.0675	0.0094	0.3706	%
lnTPL	350	0.0210	0.0199	0.0011	0.1218	%
lnGUP	350	0.1140	0.0495	0	0.2726	%
LnEUE	350	0.6904	0.2247	0.1886	1.1537	%

4. Empirical Test

Panel data from prefecture-level cities in China from 2006 to 2019 are used to conduct the empirical test. A two-way fixed effects DID model is used for the econometric regressions, which ensures the robustness of the regression results. To a certain extent, this approach can reduce the statistical bias caused by heteroskedasticity. Considering the robustness of the regression results, we use the logarithms of the main variables and fix individual and time effects, because this can better reduce heteroskedasticity and intra-group autocorrelation.

4.1. Baseline Regression

In this paper, a two-way fixed effects DID model is used to test the effect of pollution control permit policies in key industries on CO_2 emissions. The specific regression results are shown in Table 4. The results show that a pollution control permit scheme policy for key industries can significantly reduce the pollutant CO_2 emissions in the region, both in terms of total CO_2 emissions and per capita CO_2 emissions. More specifically, the indicators in column 1 of Table 4 are the total CO_2 emissions in the region, and they show that the coefficient of influence of the key polluting industries treatment permit scheme policy on the total CO_2 emissions is −0.320 and is significant at the 1% level. The indicators in column 2 of Table 4 are the CO_2 emissions of GDP per capita in the region and show that the coefficient of influence of the policy of governance permits for key polluting industries on total CO_2 emissions is −0.012 and is significant at the 1% level. The fourth column of indicators in Table 4 shows the CO_2 emissions per capita in the region and shows that the coefficient of influence of the key polluting industries' governance permit scheme policy on total CO_2 emissions is −0.257 and is significant at the 1% level. The above results of the benchmark regression illustrated the impact of the key pollution industry governance permit scheme policy introduced by China's Ministry of Environmental Protection in 2017 on carbon emissions. Whether in terms of total CO_2 emissions, CO_2 emissions per capita GDP, or CO_2 emissions per capita, the impact coefficients of the regression results were significantly negative. This shows that the implementation of the policy was effective in 2017—that is, the heavy pollution industry treatment permit scheme policy has a significant curbing effect on carbon emissions in lead cities, leading to an improvement in the local pollution environment.

Table 4. Baseline regression of the impact of pollution permit management in key industries on CO_2.

	(1)	(2)	(3)	(4)
	lnCO_2	**lnCO_2 Per Capita GDP**	**lnCO_2 Per Unit GDP**	**lnCO_2 Per Capita**
DID	−0.320 ***	−0.012 ***	−0.092 ***	−0.257 ***
	(0.069)	(0.003)	(0.024)	(0.049)
lnperGDP	0.076	−0.056 ***	−0.019	0.123 **
	(0.084)	(0.004)	(0.030)	(0.060)
lnISRI	−0.137	−0.013	0.000	0.045
	(0.267)	(0.011)	(0.094)	(0.189)
lnINS	0.289	0.020 **	0.082	0.127
	(0.189)	(0.008)	(0.066)	(0.134)
lnIPG	−0.073	0.005	−0.124	0.509
	(0.462)	(0.020)	(0.162)	(0.327)
lnTPL	0.283	0.117 *	−0.531	−0.355
	(1.445)	(0.061)	(0.507)	(1.024)
_cons	5.843 ***	0.598 ***	0.666 **	−0.368
	(0.868)	(0.037)	(0.304)	(0.615)
N	350	350	350	350
R^2	0.521	0.552	0.457	0.336
time	Yes	Yes	Yes	Yes
ind	Yes	Yes	Yes	Yes

Note: (1) ***, **, * denote significance levels of 1%,5%, and 10%, respectively; values in square brackets below the coefficients are robust standard errors; FE denotes fixed-effect models. (2) "time" represents time-fixed effects. (3) "ind" represent individual fixed effects.

The results of the control variables in Table 4 show that industrial structure, industrial structure rationalization, patent application share, and technology level are not significant and have no statistically significant effect on carbon emissions. While this may be limited by the availability of data in this paper, it suggests that the current levels of science and technology and technological innovation do not have a significant impact on carbon emissions, and continuous follow-up studies on these influencing factors are needed.

4.2. Robustness Test

4.2.1. Parallel Trend Test

The parallel trend test is the basis for the use of the DID method of measurement and is used to ensure that the treatment group and control group are consistent before the policy is generated. That is, the basis to be satisfied when doing DID model estimation is to be able to perform consistent estimations, requiring that the treatment and control groups satisfy the parallel trend assumption, and, therefore, that the overall trends in the treatment and control groups need to be essentially the same in the absence of policy intervention [42,43]. Figure 3 shows the parallel trend graph for cities in the treatment and control groups under the econometric estimation, from 2006 to 2019. This paper found that none of the estimated coefficients of this econometric test were significant until the policy was implemented in 2017. This means that there is no statistically significant difference between the treatment and control groups in this paper, which satisfies the parallel trend hypothesis required for the DID econometric examination. Further study shows that the estimated coefficient for a lead city in the treatment group is most significant in the year of policy implementation, i.e., 2017, which is also in line with the basic hypothesis of this paper. The impact of the pilot was also more significant in the 2nd year after implementation (2018) but gradually less significant in the 3rd year (2019). This may be explained by the fact that in the year the policy is implemented, the Chinese government took the impact of the policy as the performance assessment of local government officials in that year, and, therefore, the policy was most impactful in that year. In the later stages of the policy's implementation, it may be that it was no longer combined with local performance appraisals of local officials, or that the local environment has been effectively improved, so the impact of the policy is less significant.

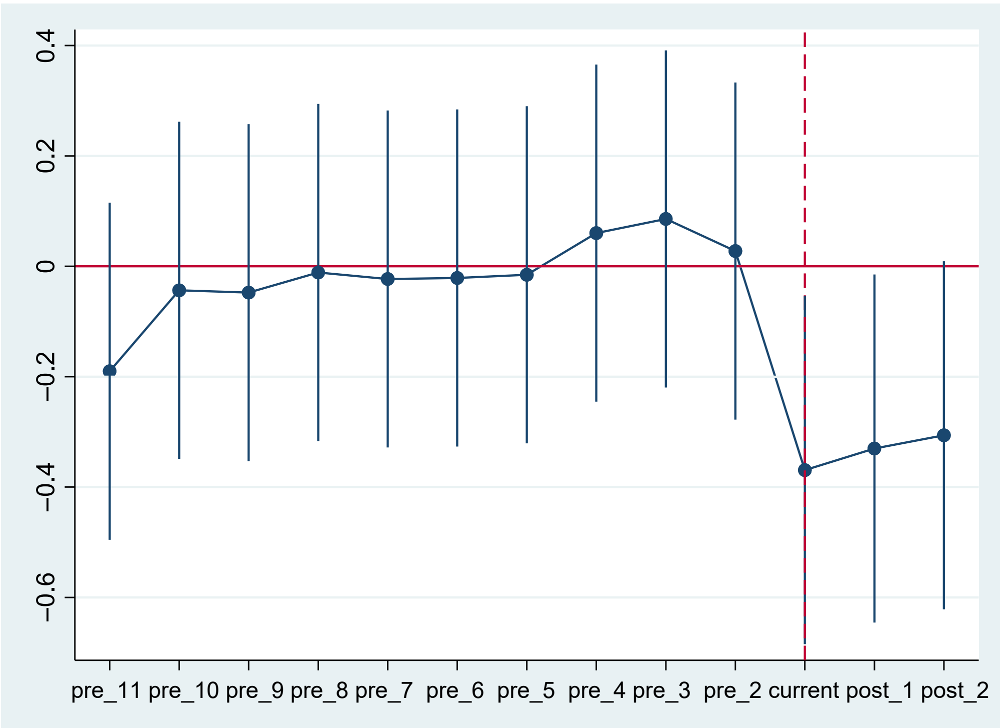

Figure 3. Parallel trend test of emission permit management policies in key polluting industries.

4.2.2. Placebo Test

To exclude some unobservable factors and ensure the robustness of the regression results in this paper, we further examined the data through a placebo test [44,45]. Specifically, in this paper, 6 cities were randomly selected from 27 cities as the treatment group, and these 6 cities were assumed to be the lead cities in implementing this pollution control permit scheme policy, while the other 21 cities were the control group. Then, 500 random samples were taken and a baseline regression was performed according to Equation (2). Figure 4 shows the estimates of the regression after 500 random assignments. The results show that the mean value of the estimated coefficient of the policy interaction is almost zero. We further plotted the distribution of the 500 estimated coefficients and their related p-values, and we can see that most of them are concentrated around the 0 points, and most of the p-values are also larger than 0.1. Moreover, the estimated coefficient of the core explanatory variables in Table 4 is −0.32, which can be seen as a significant outlier in the placebo test. All the above results show that the baseline estimation results of this paper were robust.

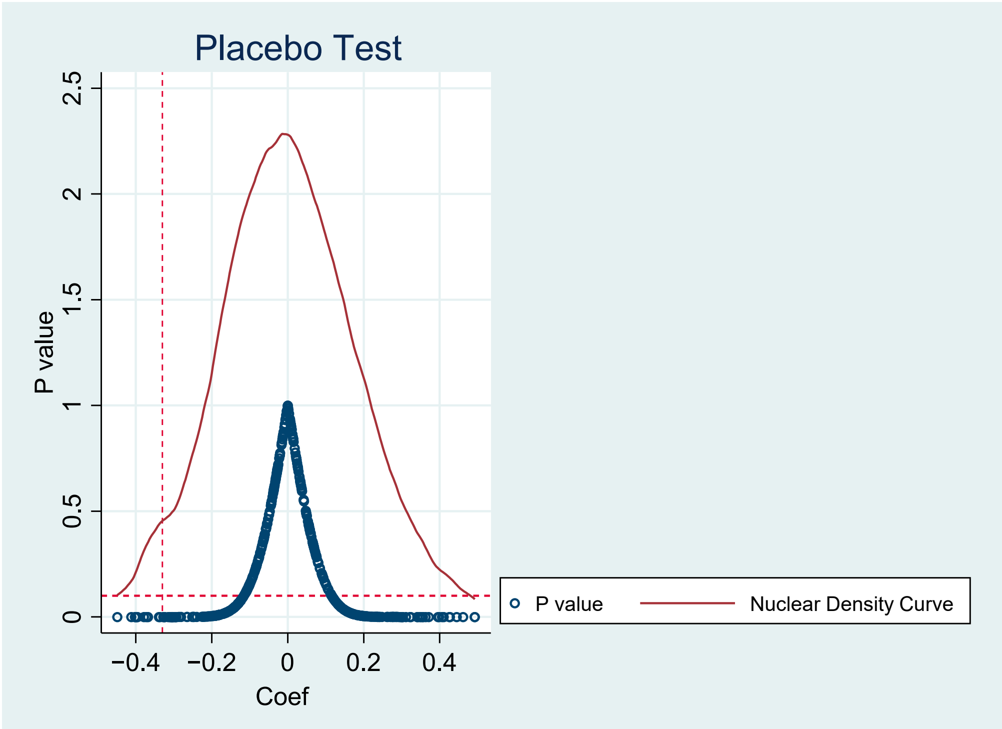

Figure 4. Placebo Test of Emission Permit Management Policies for Key Polluting Industries.

4.3. Mechanism Test

Environmental policies have a dampening effect on carbon emissions, so what are the main ways in which this mitigation or dampening effect is achieved? This paper examines the mechanisms by which environmental policies affect carbon emissions by drawing on the Turken et al. mediating effects model and found that environmental policies can effectively improve energy efficiency and the use of green and innovative technologies and, thus, reduce carbon emissions [45,46].

4.3.1. Energy Use Efficiency

Energy use, especially the consumption of coal and oil, has the most significant impact on the greenhouse gases in the air. Therefore, we measure the value of energy created in the region as the ratio of the total amount of energy consumed in the region (EUE) to the GDP of the region. We found that the percentage of energy consumption in the regional GDP is gradually decreasing, while the total regional GDP is increasing. This shows that the energy efficiency of the region is gradually increasing, which in turn can effectively reduce the carbon emissions of the region. This paper draws on the mediating effects model to identify whether the pilot work program for key emission permit management policy in the region had an impact on the efficiency of energy use in the region and, thus, on carbon emissions, as shown in the following econometric model.

$$lnEUE = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 \ln Control_i + \varepsilon_{it} \qquad (7)$$

$lnEUE$ is the explained variable of Equation (7), which is the efficiency of energy use in the region. $Post_i$, $Treat_i$, and $Post_i \times Treat_i$ have the same meaning as in Equations (2)–(5), $\ln Control_i$ is the ensemble of control variables in this paper; and ε_{it} is the error term. Table 5, shows that the coefficient of the effect of the policy on energy use efficiency is significantly positive, so the implementation of the policy can effectively improve the efficiency of regional energy use and, thus, reduce the carbon emissions of the region.

Table 5. Tests for the mediating role of energy use efficiency and the share of green patented technologies in carbon emissions.

	(1)	**(2)**
	lnEUE	**lnGUP**
DID	0.376 ***	0.011 **
	(0.110)	(0.004)
lnperGDP	−0.142	0.015 ***
	(0.089)	(0.003)
lnISRI	−0.357	−0.000
	(0.307)	(0.013)
lnINS	0.411 ***	−0.026 ***
	(0.107)	(0.007)
lnIPG	0.564	0.086 ***
	(0.469)	(0.025)
lnTPL	−0.906	−0.147 *
	(1.848)	(0.086)
_cons	2.728 ***	−0.060 **
	(0.921)	(0.028)
N	350	350
time	Yes	Yes
ind	Yes	Yes

Note: (1) ***, **, * denote significance levels of 1%,5%, and 10%, respectively; values in square brackets below the coefficients are robust standard errors; FE denotes fixed-effect models. (2) "time" represents time-fixed effects. (3) "ind" represent individual fixed effects.

4.3.2. Percentage of Practical Patents for Green Technology

Green utility patent technology has a significant effect on carbon emission reduction. This paper explores the impact of pollution control permitting policies on green utility patent technology in key industries concerning the Turken et al. intermediary effect model, and then explores the role of the intermediary mechanism of green utility patent technology, and the specific econometric model shown below.

$$\ln GUP = \beta_1 + \beta_2 Post_i + \beta_3 Treat_i + \beta_4 Post_i \times Treat_i + \beta_5 \ln Control_i + \varepsilon_{it} \quad (8)$$

$\ln GUP$ is the explained variable of Equation (8), which is the Green utility patent technology in the region. $Post_i$, $Treat_i$, and $Post_i \times Treat_i$ have the same meaning as in Equations (2)–(5), $\ln Control_i$ is the ensemble of control variables in this paper; and ε_{it} is the error term. Table 5 shows that the estimated coefficient of this policy is significantly positive, indicating that the implementation of this policy can improve the efficiency of the use of green utility patent technology and thus reduce CO_2 emissions. This is because the use of green practical patent technology can itself indicate the importance of technological innovation in the region, which can effectively improve the productivity of enterprises and reduce the carbon emissions of the region.

5. Conclusions and Suggestions

5.1. Conclusions

This paper uses a two-way fixed effect DID econometric model using panel data of prefecture-level cities in China from 2006 to 2019. This paper systematically investigates the relationship between the permit policy of emission management in key industries and carbon emissions. Robustness tests such as the parallel trend test and placebo test were carried out to ensure the reliability of the regression results. The results of the benchmark regressions in this paper show that permit scheme policies for emission management of key industries can effectively reduce carbon emissions in the area where the policies are implemented, and accelerate the rate of carbon neutrality and carbon peaking in the region. Through further study, it is found that the regression results of this paper are consistent with the results of the parallel trend test and the placebo test, and the results of this paper remain robust after excluding the effects of relevant environmental regulatory policies in the same period. Meanwhile, the study of control variables such as ISRI and IPG found that, although the direction of their regression coefficients was negative, the significance was not yet prominent, and the short-term impact on carbon emissions in the region was not yet evident. Furthermore, the parallel trend test results show that the policy has the largest impact on regional carbon emissions in the year of implementation, and its policy effect decreases in significance as time goes on. Finally, the two mediating variables—green patent technology application and energy use efficiency—have shown that the permit scheme policy for emission management of key industries can effectively reduce the carbon emissions of the region through these two mediating mechanisms. This paper is limited by the availability of data and will continue to follow up on the sustainable impacts of this policy and related variables on carbon emissions in future studies to make more practical recommendations.

5.2. Suggestions

In summary, considering China's dual-carbon target policy and the demand for sustainable development, it is necessary to further promote the power of science and technology, accelerate the production technology of green new energy, and fundamentally reverse the current high pollution and high energy consumption production mode, which requires the collaborative efforts of both the Chinese government and enterprises. On the part of the government, firstly, it needs to develop practical technologies that encourage green innovation, increase support for researchers and encourage scientific and technological innovation; and secondly, provide appropriate encouragement to scientific and technological innovation enterprises, while developing stricter environmental regulation policies. For enterprises, we should speed up the conversion rate of green and innovative patents, increase R&D investment, optimize the working environment of researchers, and make use of government policies to enhance the green production efficiency of enterprises.

Moreover, after the new policy is introduced, the government should consider the sustainability effect of the policy, which could be added to the performance appraisal of local government officials to strengthen the continuity of the policy effect. At the same time, considering the goal of the dual-carbon target policy, alternative new energy sources can be found at the national level to further reduce the consumption of energy with high pollution and energy consumption. Within the framework of sustainable development goals, we should further optimize the industrial structure and the proportion of industries among regions, accelerate the agglomeration of high and new technologies, and reduce the proportion of polluting industries, making economic development move in the direction of becoming green and sustainable.

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Abbreviations

The following abbreviations are used in this manuscript:

DID	Difference-in-Differences Model
GDP	Gross Domestic Product
R&D	Research and Development

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