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The Green Innovation Effect of Environmental Regulation: A Quasi–Natural Experiment from China

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Abstract: The "Two Control Zones" (TCZ) policy is the first air pollution regulation policy in China. We aim to examine the impact of the TCZ policy on green technological progress applying a difference–in–differences (DID) approach, using a city–level panel data set from 1990 to 2016. We show that the TCZ policy effectively increases the number of green patents of the cities in the two control zones. In particular, the TCZ policy has a significantly positive effect on the quantity and structure of human capital, including the number of inventors of patents and green patents, and the percentage of population with a higher education level. Moreover, the effects are heterogeneous, that is, the TCZ policy has a greater impact on the number of green patents in the control zones, where there are better R&D bases and more foreign investments.

Keywords: environmental regulation; green innovation; TCZ policy; human capital

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1. Introduction

In recent years, global economic development began facing severe challenges, so economies are seeking new drivers for economic growth. Innovation is considered an important means to break through the bottlenecks and shape new advantages in economic development. In the meantime, economic development resulted in serious environmental pollution problems all over the world. To balance environmental protection and sustainable economic development, the ability to innovate green technologies is seen as a potential solution. Green technology innovation refers to an economic behavior that emphasizes environmental performance improvement and can effectively balance economic development and ecological protection issues. Hence, with the increase in the challenges of resources and the environment, it is essential to promote the development of a green economy by promoting green technologies [1–3]. The sustainable development can thus be achieved through the innovation and progress of green technology [4]. Green technologies raised public attention in both academics and industry.

In the 2000s, Porter and Van Der Linde [5] proposed that environmental regulation can reduce the pollution caused by enterprises and incentivize enterprises to innovate to make up for the cost of pollution. Since then, a number of studies explored the relationship between environmental regulation and innovation from the perspectives of different industries, regions, and countries [6]. The Porter hypothesis is examined in developed economies [7,8], but it remains unclear whether it applies to emerging economies. Lanjouw and Mody [9] argued that environmental regulation in emerging economies cannot enhance domestic investment in pollution control technologies or green patents. Instead, it may increase the probability of importing green technology from advanced economies and strengthen foreign patents. It is, therefore, still worthwhile to investigate whether the environmental regulation has a significant impact on green innovation and provide a rigorous theoretical analysis and causal identification framework to test the impacts.

As an emerging economy, China's rapid economic development brought numerous forms of material national wealth. However, it brought a series of environmental problems, such as resource shortage, environmental pollution, and ecological deterioration, which became a public concern. To address these issues, the Chinese government took several environmental regulatory measures. However, we still have little knowledge about whether these regulatory measures have a positive effect on regional technological innovation, especially green innovation capacity. To fill in the gap, this study aims to examine and provide a robust estimation on the impacts of environmental regulation on green technology innovation within the Chinese context. Specifically, we focus on the "Two Control Zones" (TCZ) policy carried out in 1998, which was the first regulation policy for air pollution in China.

To control acid rain and sulfur dioxide pollution effectively, the Chinese government approved and implemented the "Two Control Zones" (TCZ) policy in 1998. The two control zones include the acid rain control zone and the sulfur dioxide control zone. In particular, the acid rain control zone is the region where the average pH value of rainfall is less than or equal to 4.5; the sulfur dioxide control zone is the area where the average sulfur dioxide concentration exceeds the national secondary standard of the past three years. The total area of the two control zones accounts for 11.4% of the total area of the national territory, the total population of the two control zones accounts for about 39% of the country's population and the GDP accounts for 67%, indicating a wide coverage of the impacts of the "two control zones" policy. The cities on the list of the two control zones are subject to strict environmental regulation, including restrictions on high–energy consumption, use of heavy–polluting energy sources, and sulfur dioxide emissions.

In our study, we are interested in whether and how the TCZ policy affects green technology innovation. To provide a robust estimation, we apply our analysis to a city–level panel data set from 1997 to 2016 in China, and examine the effects of environmental regulation policies on green innovation, considering the implementation of TCZ policy as a quasi–natural experiment. We apply a DID model, which is considered as the most effective model for policy evaluation. We find that the TCZ policy effectively increases the number of green patents of cities in the two control zones. In particular, the TCZ policy has a significantly positive effect on the quantity and structure of human capital, including the number of inventors of patents and green patents, the ratio of incumbents and newcomers, and the percentage of population with higher education levels. The effects are heterogeneous, that is, the TCZ policy has a greater impact on the number of green patents of cities in the two control zones where there are more R&D bases and more foreign investment.

To our knowledge, our study makes three main contributions to the literature: (1) This study is among the first to investigate the effects of TCZ policy on green technological progress from the perspective of environmental regulation–influenced regions; (2) we apply a DID technique to address the potential endogenous issue arising from omitted variables. It provides reliable and robust empirical evidence for analyzing the impacts of the environmental policy of TCZ on green technological progress; (3) we examine the mechanism of environmental regulation policy impacting the green technology innovation from different perspectives of human capital. It provides a new perspective to explain how environmental regulation policy affects green technology innovation. In addition, the heterogeneous effects of environmental regulation on green technological innovation are examined in terms of R&D base and foreign investment, thus revealing the comprehensive impacts of environmental regulation on green technological innovation.

The remainder of the paper is organized as follows: Section 2 presents a literature review and theoretical analysis, Section 3 presents the data and empirical design, Section 4 reports the empirical results, followed by the discussion in Section 5, and Section 6 concludes.

2. Literature Review and Theoretical Hypothesis

2.1. Literature Review

Many studies focused on the impact of environmental regulation on environmental quality and economic output. For example, studies argue that environmental regulation can effectively constrain pollutant emissions from firms [10–12] and greenhouse gas emissions [13–15], such as environmental protection taxes and emissions trading systems [12,16,17]. The existing studies also tested the pollution haven hypothesis (pollution haven hypothesis) [18–20], which argues that FDI will increase pollutant emissions [21], in which case areas with lax environmental regulation will be more attractive to FDI than strict areas, becoming pollution havens [22].

Then, a part of the study focuses on the microeconomic behavior of firms. It argues that environmental regulation may have some negative effects, such as reducing firm productivity [23], increasing unemployment [24,25], and reducing firms exports [26], among others. However, others also found positive effects, such as favoring industrial structure upgrading [27–29], boosting total factor productivity [30,31], and improving the capacity utilization of firms [12].

In addition, other studies focused on the influence of environmental regulation on corporate innovation, but they remain inconclusive. Based on the Porter hypothesis, reasonable environmental regulation can promote firm innovation [8]. According to the innovation compensation theory, environmental regulation is a triggering factor for technological change, inducing technological innovation that can compensate for environmental regulation payments [32–34]. Environmental regulation can incentivize companies to green upgrade through advanced technologies, such as cleaner production and green manufacturing [35,36]. Zhao and Sun [37] and You et al. [38] confirmed the validity of Porter's hypothesis.

In contrast, some scholars hold a different opinion that environmental regulation hinders corporate innovation, as strict environmental regulation adds unnecessary costs to firms [39–41]. Influenced by environmental governance costs [42], resources for technological innovation will be squeezed [40,43], which leads to a reduction in innovation activities [44]. Overall, there are many heterogeneities in regions and firms hardly following consistent rules of behavior, and different individuals exhibit differentiated technological innovation behavior under environmental regulatory policy constraints [45,46]. Bitat [47] used a panel of German firms to show that traditional regulatory measures cannot trigger innovative behaviors efficiently on a firm level. Moreover, some studies argued that the impact of environmental regulation on technological innovation is indeterminate and shows a non–linear relationship [48,49].

Given the uncertainty of the above findings, this paper suggests that different environmental regulatory measures and regional characteristics may be responsible for such contrasting results [37], and that the implications of the Porter hypothesis require further research. Moreover, although studies concentrated on the effect of environmental policy implementation on technological innovation, only a few studies examined the effect on green technological innovation [48,50–52]. Related studies show that environmental innovation has a positive impact on firms' competitive capability but may have a negative impact on the ecological footprints [53,54]. There is a positive correlation between green entrepreneurship and green innovation [55]. However, the influence of government behavior on enterprise environmental innovation and upgrade remains uncertain [56,57]. At the same time, the specific impact path of environmental policy on green technology innovation is no further distinction. There are potential endogeneity problems in the existing methods of assessing the effectiveness of environmental regulation.

Based on this, this paper explores how to achieve a win–win outcome for both environmental protection and economic development by studying the impact of environmental regulation on green innovation. The study focused on identifying the direct impact of China's TCZ policy on regional green innovation and the specific effect paths. We seek to expand the theoretical framework between environmental regulation and green innovation.

2.2. Theoretical Hypothesis

Due to the market scale effect and production endowment advantage, enterprises are reluctant to conduct green technology innovation activities. Faced with a market failure dilemma, designing and implementing scientifically sound environmental regulation increasingly became an effective means of addressing energy and environmental issues.

Environmental regulation releases a signal that the pollution will be controlled and regulated by the government effectively, indicating that the environmental quality will be improved. According to existing studies, air pollution is harmful to human health and leads to an increasing probability of cardiovascular and respiratory diseases [58,59]. Thus, air pollution leads to population outflow by significantly increasing residents' willingness to migrate internationally [60]. In contrast, there is a positive relationship between environmental quality and residents' health, implying that the environmental quality is better, and the city has a higher level of residential health [61,62]. The more educated or labor–productive groups are, the more sensitive they are to air pollution [63]. Because the population with high education and labor productivity has more knowledge and skills, they have more choices for work. Therefore, they will choose the cities with better urban environmental quality as the place of working and living. Environmental regulation becomes one of the guarantees of city quality, contributing to the inflow of labor and accumulation of human capital for the target cities.

According to the generalized Hicks theory, the incentive of environmental regulation towards the performance of green technology innovation stems from the implicit compliance costs of firms [50]. Under environmental regulation, companies have to improve their production processes, procedures, or equipment to meet the goal of maintaining legal emission standards over time at a lower cost. In such a case, pollution raises the cost of employing a highly qualified workforce, as they will demand higher salaries to participate in a heavily polluted city. Environmental regulation decreases that cost to a degree. Environmental regulatory policy promotes the internalization of environmental management costs and provides incentives for firms to make green innovation decisions. Thus, environmental regulatory policy, as an exterior compulsory driving force, creates a stimulating effect for green innovation and encourages firms to engage in green technological innovation [64].

At the same time, with the inflow of the workforce, especially high–quality human capital, the accumulation of knowledge and absorptive capacity related to environmental innovation can be increased, leading to improved innovation efficiency [65]. Especially in developing countries, access to external technology spillovers is an important channel for firms to acquire technological innovation capabilities. Under environmental regulations, firms will also have to import more high–quality intermediate goods and capital equipment from outside in the short run to meet higher environmental requirements. The technology spillover effects of trade provide firms with more learning opportunities, thus increasing their level of innovation [66].

Therefore, Hypothesis 1 is proposed according to the mentioned analysis: environmental regulation has a positive effect on green innovation performance.

Hypothesis 2 is proposed according to the mentioned analysis: environmental regulation has a positive impact on green technology innovations by attracting human capital inflow.

3. Data and Empirical Design

3.1. Data

To evaluate the impact of TCZ policy on green innovation performance, the number of green patents of the city is used to measure the development of green technology innovation. Green patent data are from the Chinese invention patent database, and the identification of green patents is based on the International Patent Classification (IPC) system code of the "IPC Green Inventory" published by the World Intellectual Property Organization (WIPO) on 16 September 2010. We can merge the Chinese invention patent database with IPC code to identify whether the patent is green or not. Green inventory patents are those related to non–fossil fuel–based methods of propulsion, such as electric or hydrogen cars and related technologies (e.g., batteries). After classifying whether each patent is a green patent, we build a year–city level green patent database based on the city and year information of the patent.

The cities in two control zones are identified by the state document named "The Official Reply of the State Council Concerning Acid Rain Control Areas and Sulfur Dioxide Pollution Control Areas". The document specifies 175 cities and regions in the two control zones, including 158 prefecture–level cities, 13 regions, and 4 municipalities directly under the central government.

The city–level data comes from China City Statistic Yearbook (CCSY) from 1990 to 2016. The control variables include total population, annual gross regional product, investment in fixed assets, foreign investment utilized, number of students in higher education institutions, number of teachers in higher education institutions, the proportion of employment in the secondary industry, employment at the end of the year, and number of new contracts signed in the current year.

Table 1 summarizes the statistic (observations, mean value, and stand deviation) of the main characteristics we used in this paper. The logarithm of the number of green patents each city applies for is 1.109 on average per year. The average annual total population is 5.652 ten thousand persons. The average annual gross regional output value is CNY 14.895 ten thousand. On average, the investment in fixed assets and foreign investment utilized in each city is CNY 13.809 ten thousand and USD 8.225 ten thousand per year, respectively. The logarithm of the number of students and teachers in higher education institutions is 8.87 and 6.537 per year on average, respectively. Approximately, the logarithm of employment and proportion of employment in the secondary industry is 3.746 and 3.503 on average in each city. The log number of new contracts each city signs is 3.746 on average per year.

Table 1. Summary statistic.

Variables	Obs	Mean	Std. Dev
Number of green patent applications (unit)	9234	1.109	1.409
Tcz × Post dummy (unit)	9234	0.342	0.474
Total population (ten thousand persons)	7857	5.652	0.832
Annual gross reginal product (CNY ten thousand)	7830	14.895	1.561
Investment in fixed assets (CNY ten thousand)	7830	13.809	2.084
Number of students in higher education institutions (persons)	7776	8.870	2.752
Number of teachers in higher education institutions (persons)	7776	6.537	2.059
Foreign investment utilized (USD ten thousand)	7750	8.225	2.898
Proportion of employment in the secondary industry (%)	9000	3.503	0.488
Employment (ten thousand persons)	8947	3.746	1.036
Number of new contracts signed (unit)	7578	3.221	1.589

Notes: Number of green patent applications, number of students in higher education institutions, number of teachers in higher education institutions, the proportion of employment in the secondary industry, and employment number of new contracts signed are measured in logs.

3.2. Empirical Design

To estimate the efficacy of TCZ policy for green technological innovations, a difference–in–differences (DID) model is used. Compared to changes in cities that were never under environmental regulation, we focus on how the number of green patents of cities in two control zones changed when the TCZ policy was enacted.

The DID method is adept at catching pre–existing differences between treated cities and untreated cities, thus eliminating selection bias while controlling for confounding variables that are likely to impact both sets of cities. The estimated equation is as follows:

$$G_{i,t} = \beta Tcz_i \times Post_t + \eta X_{i,t} + \gamma_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

where i represents cities, t represents year; $G_{i,t}$ represents green technological innovations, which are measured as the log of the number of green patents applied by city i at year t; Tcz_i is 1 if city i is in two control zones and equals 0 if city i is not; $Post_t$ equals 1 for all years after 1998 (TCZ policy period) and otherwise equals 0. $Tcz_i \times Post_t$ is the interaction between the Tcz_i and $Post_t$, which captures the average difference change in the number of green patents of treated cities compared to untreated cities. Therefore, we focus on the coefficient measuring the DID effect and we posit β is positive, which means the TCZ policy will increase the number of green patents effectively. X_{it} represents city–level control variables, including total population (Pop), annual gross regional product (GDP), investment in fixed assets (Fixedinvest), foreign investment utilized (FDI), the logarithm of number of students in higher education institutions (Students), the logarithm of number of teachers in higher education institutions (Teachers), the logarithm of the proportion of employment in the secondary industry (Second), the logarithm of employment at the end of the year (Employment) and the logarithm of the number of new contracts signed in the current year (Contracts). The control variables represent the number of labors, development of economy and education, as well as degree of investment and openness. γ_i is a vector of city dummies and δ_t is a vector of year dummies to control city–fixed effects and year–fixed effects, respectively.

4. Empirical Results

4.1. The Impact of TCZ Policy on the Green Innovation Performance

Table 2 shows the DID results on the green innovation performance for TCZ policy corresponding to Equation (1). In column (1), we include no additional control variables, city–fixed effects, or year–fixed effects. The coefficient of the interaction term (Tcz × Post) in column (1) is significantly positive. In column (2) we include control variables, suggesting that TCZ policy increases the number of green patent applications by 71.8% on average and the p–value is less than 0.01. In column (3) we include control variables and control for city–fixed effects, while in column (4) we control for city–fixed effects, and year–fixed effects. Both of the results of column (3) and (4) remain highly significant (at the 1 percent level), and column (4) indicates there is a 53.4% increase in green patent applications of the cities in two control zones compared to the other cities. The finding is consistent with the hypothesis that more green patents were applied by target cities after the TCZ policy was enacted.

Table 2. Baseline Estimate.

	Green Patent Applications			
	(1)	**(2)**	**(3)**	**(4)**
Tcz × Post	0.760 ***	0.718 ***	0.596 ***	0.534 ***
	(0.079)	(0.098)	(0.089)	(0.084)
Pop		−0.451 ***	−0.745 ***	−0.316 ***
		(0.052)	(0.068)	(0.078)
GDP		0.559 ***	0.597 ***	0.219 **
		(0.070)	(0.084)	(0.094)
Fixedinvest		0.183 ***	0.228 ***	−0.069
		(0.040)	(0.047)	(0.048)
Students		−0.013	−0.007	−0.044 *
		(0.027)	(0.032)	(0.023)
Teachers		0.135 ***	0.005	−0.037
		(0.039)	(0.050)	(0.035)
FDI		−0.016	−0.019	−0.018
		(0.018)	(0.021)	(0.018)
Second		−0.053	0.065	0.098
		(0.071)	(0.086)	(0.080)

Table 2. *Cont.*

	Green Patent Applications			
	(1)	**(2)**	**(3)**	**(4)**
Employment		0.254 ***	0.188 ***	0.217 ***
		(0.051)	(0.058)	(0.051)
Contracts		0.063 ***	−0.039	0.078 ***
		(0.021)	(0.027)	(0.029)
Constant	0.153 ***	−8.399 ***	−7.178 ***	−0.054
	(0.018)	(0.420)	(0.598)	(0.930)
City FE	No	No	Yes	Yes
Year FE	No	No	No	Yes
Observations	9234	7464	7463	7463
R^2	0.245	0.699	0.775	0.814

Note: For each regression, the log volume of green patent applications is used as an outcome variable. Controls include total population at the end of the year (Pop), annual gross regional product (GDP), investment in fixed assets (Fixedinvest), foreign investment utilized (FDI), the logarithm of number of students in higher education institutions (Students), the logarithm of number of teachers in higher education institutions (Teachers), the logarithm of proportion of employment in the secondary industry (Second), the logarithm of employment at the end of the year (Employment), and the logarithm of number of new contracts signed in the current year (Contracts). Standard errors in parentheses are clustered at the city–year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

4.2. Parallel Trend Analysis

Parallel growth in treated and control groups is the key identifying assumption of using the DID method. Thereby, we assume that there is the same rate of change in the amounts of green patents applied by cities out of the two control zones as cities in the two control zones, except for the implementation of the TCZ policy. Figure 1 plots the difference in the volume of green patent applications of cities that entered two control zones relative to those cities that did not, using an 8–year window before and after TCZ policy. Figure 1 displays no significant differences in pre–trend, implying that the difference in green patent applications the years before TCZ policy is normalized to 0, and the parallel trends assumption holds. After the year of TCZ policy, the estimated coefficients of TCZ–year interaction terms are significantly positive, suggesting an increase in green patent applications in the treated cities relative to the control group.

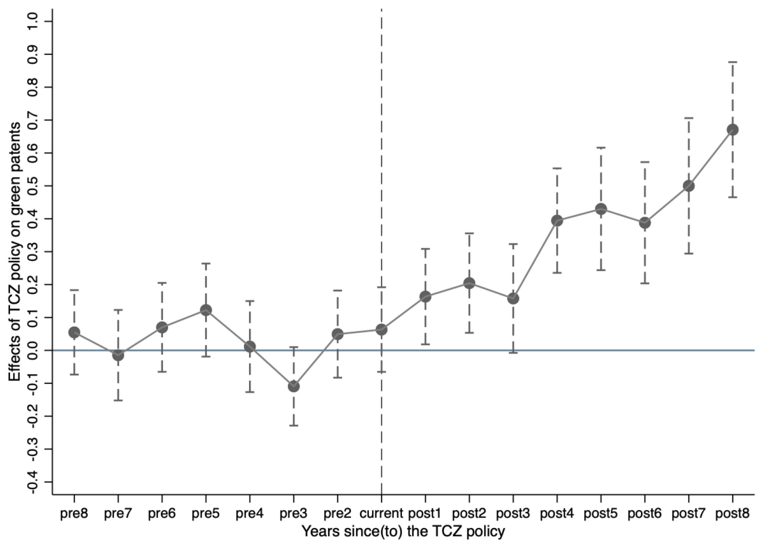

Figure 1. Treatment–year interaction coefficient for city–level green patent applications. Notes: Figure presents coefficient and 95% confidence intervals on Tcz × year interactions from the regression of *Tcz* × year interaction terms, including city–fixed effects and year–fixed effects. TCZ policy was implemented in 1998 (current), the year before TCZ policy was excluded (pre1). Standard errors in parentheses are clustered at the city–year level.

4.3. Validity Checks

4.3.1. Propensity Score Matching DID (PSM–DID)

DID estimation is most appropriate when the experiment is random. Considering that the assignment of the treated group by TCZ policy in our study may be not random, we should first use the Propensity Score Matching (PSM) approach to find and construct some comparable cities as the untreated group, and then evaluate the average impact of the TCZ policy on green patent applications using the DID model to examine whether our basic empirical results remain robust. PSM uses a logistic regression of the outcome variable that equals 1 if the city is in two control zones and equals 0 if it is not, and the independent variables include characteristics before treatment that would influence the "propensity" of cities in TCZ. Cities are matched to kernel values based on their propensity scores.

Firstly, we examine the results of treated and untreated cities before and after matching using the PSM approach. Figure 2 shows city characteristic bias between treatment and control groups before and after matching, implying that the deviation of all characteristics in both groups dropped to zero significantly after matching. From the perspective of kernel density, Figures 3 and 4 display the kernel density of treatment and control groups before and after matching, respectively. We find that the kernel density of the two groups is much closer. The above results indicate the validity of grouping using the PSM approach.

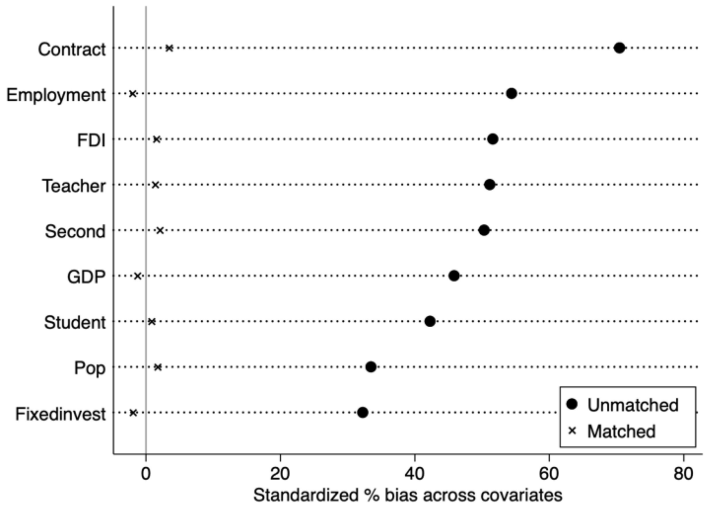

Figure 2. City characteristic bias before and after matching.

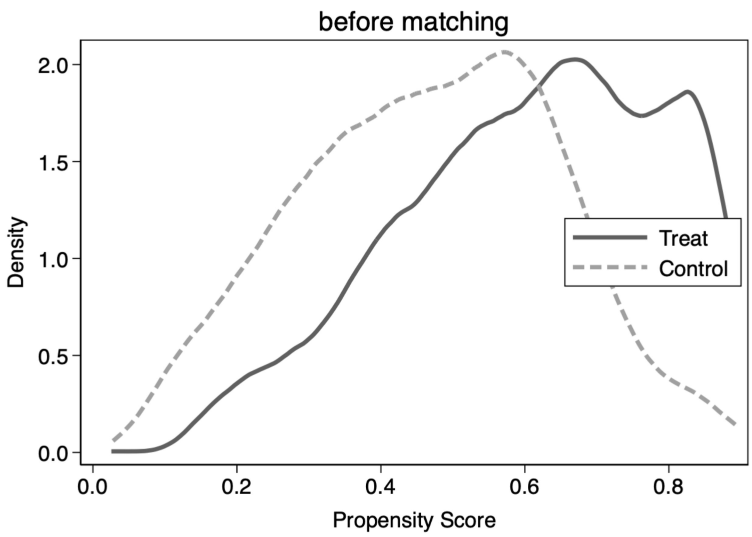

Figure 3. Kernel density of treated and control groups before matching.

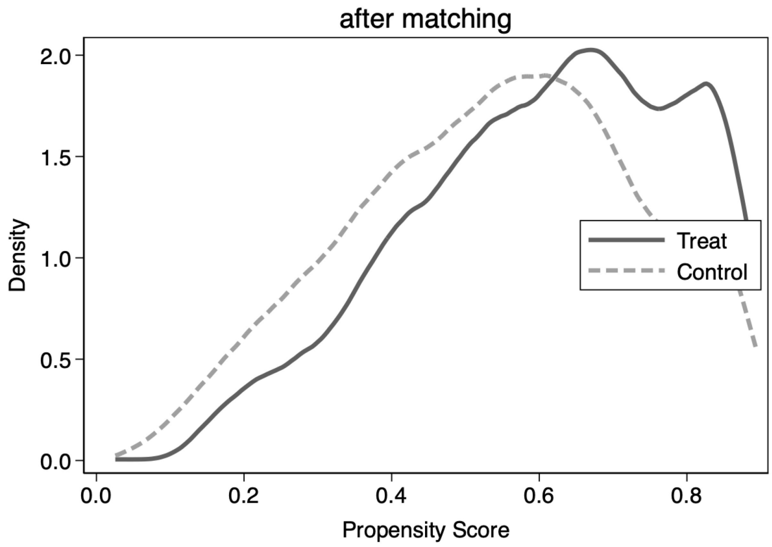

Figure 4. Kernel density of treated and control groups after matching.

Secondly, the PSM–DID results are shown in Table 3. In column (1) the regression includes no fixed effects, while column (2) only includes control city–fixed effects. Both coefficients in column (1) and (2) are significantly positive. The estimated result is controlled for city–fixed effects and year–fixed effects in column (3). The estimate for TCZ policy is significantly positive (at the 1 percent level), implying that targeted cities have 37% more green patent applications when the TCZ policy is enacted. Thus, the interference of unobservable factors in the selection of the treated and untreated groups on the conclusions of this study can be excluded.

Table 3. PSM–DID results.

	Green Patent Applications		
	(1)	**(2)**	**(3)**
Tcz × Post	0.564 ***	0.405 ***	0.370 ***
	(0.090)	(0.080)	(0.077)
Control variables	Yes	Yes	Yes
City FE	No	Yes	Yes
Year FE	No	No	Yes
Observations	7052	7051	7051
R^2	0.644	0.736	0.777

Note: For each regression, the log volume of green patent applications is used as outcome variable. Controls include total population at the end of the year (Pop), annual gross regional product (GDP), investment in fixed assets (Fixedinvest), foreign investment utilized (FDI), the logarithm of number of students in higher education institutions (Students), the logarithm of number of teachers in higher education institutions (Teachers), the logarithm of proportion of employment in the secondary industry (Second), the logarithm of employment at the end of the year (Employment), and the logarithm of the number of new contracts signed in the current year (Contracts). Standard errors in parentheses are clustered at the city–year level. *** $p < 0.01$.

4.3.2. Test on the Number of Granted Green Patents

Apart from examining the efficacy of the TCZ policy for the number of green patent applications, the further test is analyzing the policy's effect on the number of green patents granted. We put the log of the number of green patents granted into Equation (1) as the outcome variable instead of the number of green patent applications. The results in Table 4 show that all of the coefficients are statistically significant at the 1 percent level. In column (4), we include control variables, city–fixed effects, and year–fixed effects. The key interaction term's coefficient is 0.565 and statistically significant at the 1% level, indicating that the number of green patents granted increases by 56.5% in two control zones, which examines the robustness of the conclusions of this study.

Table 4. The effect of TCZ policy on green patents granted.

	Green Patent Granted			
	(1)	(2)	(3)	(4)
Tcz × Post	0.675 ***	0.675 ***	0.592 ***	0.565 ***
	(0.069)	(0.069)	(0.073)	(0.073)
Control variables	No	No	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes
Observations	9234	9234	7463	7463
R^2	0.555	0.703	0.616	0.735

Note: The dependent variable in each regression is the log of the number of green patents granted. Controls include total population at the end of the year (Pop), annual gross regional product (GDP), investment in fixed assets (Fixedinvest), foreign investment utilized (FDI), the logarithm of number of students in higher education institutions (Students), the logarithm of number of teachers in higher education institutions (Teachers), the logarithm of the proportion of employment in the secondary industry (Second), the logarithm of employment at the end of the year (Employment), and the logarithm of the number of new contracts signed in the current year (Contracts). Standard errors in parentheses are clustered at the city–year level. *** $p < 0.01$.

5. Further Discussion

5.1. Heterogenous Effect of TCZ Policy

There is large heterogeneity contained by the average TCZ policy effect on green technological innovations. We further conduct our analysis to examine how environmental regulation impact differs for the R&D base and foreign investment utilized. R&D base is measured by cumulative amounts of total patents granted over the past five years, and foreign investment utilized is measured by FDI of the city in that year. We put the two new interaction terms (TCZ × post × R&D and TCZ × post × FDI) into Equation (1), respectively. Table 5 column (1) reports the result of the heterogeneous effect on the R&D base. The coefficient of TCZ × post × R&D is significantly positive, implying that the better the R&D base cities have, the larger the number of green patents they can apply for. Compared to the city with a relatively weaker R&D base, the city with a strong R&D base usually puts more emphasis on innovation activities and accumulates more experience in developing green technology innovation, indicating that it has more ability and recourses to conduct the development of green patents when the environmental regulation regime is enacted. As the results show in column (2), the coefficient of TCZ × post × FDI is positive and statistically significant at 1% level with the value of 0.167. The cities in two control zones with more FDI have better green innovation performance. Foreign firms usually have to face more strict environmental regulations in their home country, resulting in larger amounts of green technologies in the firms. Those target cities are likely to get more technology spillover from multinationals by FDI after the TCZ policy.

Table 5. Heterogenous effect of TCZ policy.

	Green Patent Applications	
	(1)	(2)
TCZ × post × R&D	0.061 **	
	(0.031)	
TCZ × post × FDI		0.167 ***
		(0.032)
Control variables	Yes	Yes
City FE	Yes	Yes
Year FE	Yes	Yes
Observations	7463	7463
R^2	0.871	0.828

Note: For each regression, the log volume of green patent applications is used as an outcome variable. Controls include total population at the end of the year (Pop), annual gross regional product (GDP), investment in fixed assets (Fixedinvest), foreign investment utilized (FDI), the logarithm of number of students in higher education institutions (Students), the logarithm of number of teachers in higher education institutions (Teachers), the logarithm of the proportion of employment in the secondary industry (Second), the logarithm of employment at the end of the year (Employment), and the logarithm of the number of new contracts signed in the current year (Contracts). Standard errors in parentheses are clustered at the city–year level. ** $p < 0.05$, *** $p < 0.01$.

Therefore, the effect of environmental regulation on green innovation is significantly affected by the city's R&D base and FDI. For example, Beijing and Shanghai, as the pilot cities of TCZ policy, both have a high number of accumulated patents and a high level of FDI, and they are also the two cities with the largest number of green innovation patents in China.

5.2. Mechanism

We further examine the channels for cities in two control zones to increase green patents for environmental regulations. Theoretically, human capital is a crucial factor for technology innovation, indicating that the higher quality workforce a city has, the larger the number of green patents the city has. Environmental regulation has a positive impact on pollution reduction and urban quality, which attracts more talents to come to target cities. Thus, human capital is a significant mechanism in TCZ effect.

Table 6 reports the estimated results of the city and year–fixed effects models using the log number of patent inventors (Inventors), the log number of green patent inventors (Ginventors), and the percentage of population with college and higher education (Unipop) as the dependent variables according to Equation (1). We include control variables and control city–fixed effects and year–fixed effects. The coefficients are found to be positive and statistically significant at the 1% level. Column (1) and (2) lists the results of environmental regulation policy impact on patent inventors and green patent inventors. The estimates show that the number of patent inventors increases by 52.3% and the number of green patent inventors increases by 78.4% in treated cities compared to untreated cities by TCZ policy. As the result is shown in column 4, the TCZ policy increases the percentage of the population with high education by 0.9%.

Table 6. Mechanism of human capital.

	Inventors	**Ginventors**	**Unipop**
	(1)	**(2)**	**(3)**
TCZ × Post	0.523 ***	0.784 ***	0.009 ***
	(0.094)	(0.114)	(0.002)
Control variables	Yes	Yes	Yes
City FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Observations	7463	7463	747
R^2	0.911	0.782	0.906

Note: The dependent variable in each regression is the log number of patent inventors (Inventors), the log number of green patent inventors (Ginventors), and the percentage of the population with college and higher education (Unipop). Controls include total population at the end of the year (Pop), annual gross regional product (GDP), investment in fixed assets (Fixedinvest), foreign investment utilized (FDI), the logarithm of number of students in higher education institutions (Students), the logarithm of number of teachers in higher education institutions (Teachers), the logarithm of the proportion of employment in the secondary industry (Second), the logarithm of employment at the end of the year (Employment), and the logarithm of the number of new contracts signed in the current year (Contracts). Standard errors in parentheses are clustered at the city–year level. *** $p < 0.01$.

6. Conclusions

To cope with air pollution, the "Two Control Zones (TCZ)" policy was issued and enacted by China's government in 1998. As the first air pollution regulation in China, the impact of the TCZ policy influences the development of following environmental regulations.

The results in our study use a difference in difference model that explores the effect of environmental regulation on green technology innovations and the role of human capital in it. We find evidence consistent with the hypothesis that the TCZ policy significantly increases the number of green patents of cities in two control zones. The result is also robust through the method of PSM–DID and changing the dependent variable. Most importantly, our study also points out the crucial role human capital plays in the mechanism. TCZ policy, as the signal of regulating air pollution and improving urban quality, has a positive effect on the quantity and structure of human capital, leading to providing a talent pool for green technology innovation to reduce pollution.

To exploit the heterogeneity covered under the average treatment effect, the finding shows that TCZ policy is different in the R&D basis and foreign investment utilized. TCZ policy tends to improve more amounts of green patents in the cities with a stronger R&D base or with more FDI. The R&D base provides innovative talents for green technology innovation and FDI provides technology spillover and R&D funding for green technology innovation. The cities with those two characteristics have more ability to undertake the development and application for green patents to cope with TCZ policy.

The findings of this paper provide new insight into the Porter hypothesis, offering some valuable policy recommendations for developing economies. In the context of globalization, developing countries, as a link in the downstream production chain, are highly susceptible to becoming pollution havens. Policymakers of emerging economies draw environmental regulations to control pollution, while promoting the development of green technology innovation by attracting more high–quality human capital. In addition, based on our study, the government should pay more attention to strengthening its R&D base and attracting more FDI, as both of these conditions will enhance the positive impact of environmental regulation on green innovation performance.

There are also some limitations. First, the research sample of this paper is the city–level data in China. We can only control for regional and year effects. In the future, when the green patent data at the corporate level becomes available, we can study it from the perspective of micro firms. Second, green technological innovation can also be subdivided in terms of production processes, such as green process innovation and green product innovation. However, the data refinement is limited, and this paper only uses the number of green patent applications granted to measure the overall green technology innovation of cities. With the increasing availability of data, a comparative analysis of the variability in the impact of environmental regulations on the green production processes of cities will also be worthy of further research.

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