

Original Research

Can Informal Environmental Regulation Promote Green Innovation? – A Quasi-Natural Experiment Based on Environmental Information Disclosure Policy

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Abstract

As the constraints of the ecological environment become increasingly strict, how to balance between environmental protection and economic development has emerged as a crucial issue. Based on the panel data of 281 prefecture-level cities in China from 2003 to 2017, this paper considers the information disclosure policy (EIDP) as a quasi-natural experiment and evaluates the impact of EIDP on green innovation with the gradual difference-in-difference (DID) model. Furthermore, the influence mechanism and heterogeneity characteristics are analyzed. The result shows that: 1) The EIDP implemented in 2008 significantly improves the level of green innovation among Chinese cities; 2) The mechanism of the EIDP include optimizing the innovation environment, increasing innovation input and gathering innovative talents. 3) Heterogeneity analysis shows that, the impacts of EIDP on green innovation in low- and medium-level industrialized cities are greater than high-level industrialized cities, while effects on cities with low- and medium-level of economic development are much lower than those with high-level of economic development. This paper provides new evidence to the green innovation effect of informal environmental regulation and reexamines Porter Hypothesis in order to offer new references to optimize future environmental regulation policy.

Keywords: informal environmental regulation, green innovation, EIDP, difference-in-difference model

Introduction

The Chinese economy has achieved forty years of continued rapid growth, but it also comes with

an increasingly prominent environmental pollution problem [1-2]. According to the 2019 China Ecological and Environmental Bulletin, among 337 cities at the prefecture-level or above across the country, only 157 of them have reached air quality standards. The report also pointed out that 85% of groundwater and 21.7% of surface water in China are classified as Class IV and Class V, which is inferior to the water quality

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standards for human consumption [3]. Obviously, the “environmental pollution-economic development” vicious circle is caused by the extensive industrial development model in China. Therefore, to break this “strange circle”, green technology deserves to be taken into account [4].

Green innovation is the key to developing the economy and protecting the environment synchronously [5]. However, characterized by high investment, high risk and dual externalities [6], the well-designed environmental regulations are of great help in promoting green innovation, which are deemed as the initial impetus of green innovation [7].

The relationship between environmental regulation and green innovation has always been a hot topic in academe. The most famous Porter Hypothesis put forward by Porter [8] believed that appropriate environmental regulation can stimulate technological innovation and reduce innovation costs, creating success in protecting environment and developing economy. After that, many scholars conducted research on the applicability and rationality of the “Porter Hypothesis” from different perspectives and came to different conclusions. To sum up, these conclusions can be divided into several different standpoints as follows. The first viewpoint supported the “Porter Hypothesis” and believed that green innovation can be promoted by environmental regulations. Porter et al. [9] deeply demonstrated the authenticity of the hypothesis according to the “Porter Hypothesis”. Roud and Thurner [10] explored the Russian manufacturing industry and found that environmental supervision can stimulate green innovation and ameliorate the enterprise performance, moreover, state-owned enterprises are more willing to invest in ecological innovation. Zeng et al. [11] further indicated that the coordination of environmental and socio-economic regulations can further stimulate green innovation among enterprises. Asano and Matsushima [12] pointed out that, by imposing environmental taxes, the government can encourage enterprises with advanced emission reduction technologies to authorize the use right to others so as to increase the enthusiasm of other enterprises to participate in technological innovation activities. Using green innovation patents data of Chinese listed enterprises during 1990-2010, Qi et al. [13] demonstrated that environmental regulation induces green innovation activities of enterprises. However, the second viewpoint opposed the Porter Hypothesis and believes that environmental regulations, to some degree, inhibit green innovation. In light of the research on China's local manufacturing industry, Yuan and Xiang [14] concluded that environmental statutes have an extrusion effect on enterprise R&D investment which impedes green innovation activities and limits corporate's development in the long run. Data from China's 30 provinces, spanning the period 1997 to 2014, were selected as the sample, Shen et al. [15] found pollution charges played a negative role

in green product innovation. The third viewpoint took a skeptical attitude towards the Porter Hypothesis and believed that the impact of environmental regulations on green innovation is uncertain. Zhang et al. [16] found that the environmental regulations' impact on technological innovation varies at different regional development levels. From the perspective of non-linear relationship, Song et al. [17] believed that the environmental regulation impacts green innovation with an inflexion, that is, as the strength of environmental regulation increases, the impact gradually changes from negative to positive. Based upon the panel data of 30 Chinese provinces during 2000-2013, Ren et al. [18] indicated that the impact of environmental regulation on green innovation efficiency significantly varies in different regions.

Generally speaking, environmental regulations can be classified into two forms. The formal one refers to government-oriented environmental regulation, and the informal one relies on the social engagement including the public and related organizations. Formal environmental regulations involve the legislation, policies and relevant countermeasures adopted by the government to control and interpose the economic behavior of market subjects [19]. Informal environmental regulations usually mean the supervision, protest, complaint, compensation or negotiation from social groups or individuals with the interests of pursuing a higher quality environment [20].

By affecting the enterprises' production costs, formal environmental regulations can force them to develop environmentally friendly technologies and production management mode so as to solve the environmental protection market failure caused by public products and externalities. Furthermore, it can improve ecological environment and develop economy simultaneously. Therefore, the formal environmental regulation is a vital approach to realize high-quality economic growth and sustainable green development. Undeniably, traditional formal environmental regulation effectively gives the impetus to green innovation, energy saving and emission reductions, but there are some certain limitations, for example, regulations may fail due to government-enterprise collusion or rent-seeking in practice. Considering these limitations, the informal environmental regulation emerges accordingly, and it is deemed as a remedy for formal environmental regulations failure [21]. Meanwhile, with the economic development and the enhancement of citizens' environmental awareness, non-government entities play an increasingly prominent role in environmental governance [22]. The informal environmental regulation becomes a major force in environmental protection and is regarded as the third tide of regulation after government dominated command-and-control and market-oriented regulation [23].

In the sight of worldwide countries' experiences, as an important component for informal environmental regulation, EIDP is treated as the essential approach

for environmental governance. For example, as early as 1986, the United States established Pollutant Release and Transfer Register and Toxic Release Inventory. Indonesia also implemented a system of pollution control, evaluation and classification in 1995. These are all successful cases of other countries implementing EIDP. Under the background that low-carbon development is highly valued by Chinese government, it is worthwhile to think about following questions: What role does the informal environmental regulation represented by non-governmental organizations (NGOs) play in green innovation? Can EIDP promote green innovation? What's the mechanisms of the green innovation effect of EIDP? Clarifying these puzzles is helpful in deeply understanding the relationship and impact mechanisms between informal environmental regulation and green innovation, which is of great significance to promote economic transition. Therefore, this paper applies a quasi-natural experiment based on EIDP, and verifies the causality between EIDP and green innovation under DID framework using panel data of 281 Chinese cities at prefecture-level during 2003-2018. To avoid the endogeneity and estimation bias in sample selection, this study makes the cities with EIDP and the cities without EIDP to match with each other by using propensity score matching (PSM) method. The result demonstrates that EIDP has a promotion effect on green innovation and keeps tenable even after various robustness tests. The promotion effect is realized by three mediation including optimizing the innovation environment, increasing innovation investment and gathering innovation talents. In addition, heterogeneity analysis shows that the impacts of EIDP on green innovation in the low- and medium-level industrialized cities are greater than high-level industrialized cities, while effects on cities with low- and medium-level of economic development are much lower than those with high-level of economic development.

This study explains its main contributions in the following directions: first, this research has expanded the existing research field. Although there are abundant studies on the economic impact of environmental regulation in current literature, those mainly analyze the influences of command-and-control and market-incentive environmental regulatory policies. The studies on informal environmental regulation's impact on green innovation are relatively few. Therefore, this paper used EIDP, a quasi-natural experimental event, which provided a valuable supplement to the existing studies. Second, this article has enriched the existing research theory. This paper verified the causality between EIDP and green innovation via PSM and DID model. It also proved the robustness of results by parallel trend test, placebo test etc., which effectively solved the endogeneity problem of the traditional measurement model, and provided a reexamination of Porter Hypothesis. Third, this paper has provided ideas and realistic paths. This paper further explored the internal influence mechanisms of EIDP on green

innovation and the heterogeneities were fully tested. This study found the promotion effect is realized by three mediation including optimizing the innovation environment, increasing innovation investment and gathering innovation talents, which offered empirical reference to future policy optimization.

The rest of this study is structured as follows. The policy background and research hypotheses are established in section 2. The data source, methodology and indicators selection are introduced in section 3. The empirical results and robustness tests are analyzed in section 4. The influence mechanisms are further explored in section 5. The heterogeneities are discussed in section 6. Relevant policy suggestions are concluded and proposed in section 7.

Material and Methods

Policy Background and Research Hypotheses

Policy Background

Compared with developed countries, it is relatively late for China to incorporate EIDP into environmental protection laws and regulations. In 1989, China's first Environmental Protection Law stipulated that local governments of all levels should regularly publish the environmental status bulletin of their regions. Although the regulation provides a legal basis for EIDP, it only includes general provisions without illustration on liability subject, public contents etc. In order to clarify the content and specific form of EIDP, relevant environmental information disclosure policies in China have begun to be put in place since 2020, which truly achieved the systematic establishment of institution [24-25]. The Announcement on Enterprise Environmental Information Disclosure which was promulgated in 2003 stipulates the specific content and form of environmental information disclosure from relevant companies, and companies begin to be included as the main body of information disclosure. The Environmental Impact Assessment Law promulgated in 2003 and the Interim Measures for Public Participation in Environmental Impact Assessment promulgated in 2006 stipulate that the public can participate in environmental impact assessment on the basis of obtaining relevant environmental information. The Open Approach to Environment Information (for Trial Implementation) implemented in 2008 requires that government environmental protection administration and companies should disclose environmental information, which provides a legal basis for the public's participation in environmental protection.

With the development of legislation and policy formulation, some NGOs gradually appear. The most representative one is the Institute of Public and Environmental Affairs (IPE) established in 2006 [26].

Coordinating with the Natural Resources Conservation Association, IPE has become the first-mover to evaluate the environmental information of Chinese cities and issued related reports since 2008. [27]. In the report, EIDP is widely applied in the eastern and western cities, and the number of cities is continuously growing. To be more specific, the total number of cities implementing EIDP was 113 during 2008-2012, which increased to 120 in 2013. In these cities, there are 53 cities located in the eastern area, 32 cities as part of the central area and 35 cities belonging to the western area, reflecting the obvious imbalance between the East and the West of China. At the same time, EIDP becomes more systematic and complete, covering eight aspects of information including daily supervision of pollution source, centralized renovation, clean production audit, environmental behaviors evaluation on enterprises, complaints cases, the inspection and acceptance of environmental impact assessment documents, pollution charges and published applications. Moreover, EIDP is committed to expanding the evaluation scope to more provinces and cities in a more digital way so that environmental supervision and emission information can better promote the green development of China and the world.

Research Hypotheses

The “Porter Hypothesis” demonstrates that strict but flexible environmental regulation is the key to achieve the win-win goal of protecting the environment and developing the economy [28]. Regarding formal environmental regulations, both command-and-control and market-oriented policies are lack of flexibility, which may cause higher compliance costs for enterprises in the short term and ultimately reduce their innovation incentives. Compared with formal environmental regulations, the informal one supervises the emission of polluting enterprises via social participation involving the public and organizations, so it does not act on enterprises directly, nor will it cause a direct increase in the cost of energy conservation and emission reduction. Moreover, it is suggested for enterprises to cope with the pressure, which given by the local government or the public, in a more flexible way, so that technical innovation can be actively applied in saving energy and reducing emissions [29]. Therefore, as an essential form of informal environmental regulation, EIDP is mainly to alleviate information asymmetry, reduce regulation implementation costs and improve the efficiency of regulation. As explained previously, all environmental protection laws and regulations are emphasizing that the public and organizations play an important role in environmental protection. Thus, EIDP has the potential to promote green innovation, and the specific results need to be further tested.

The impact mechanism of EIDP on green innovation is shown in Fig. 1. At the local government level, EIDP helps local government officials better understand

the pollution situation. Firstly, the continuous improvement of urban infrastructure such as transportation and communication facilities improvement can break through the time and space constraints in technological innovation activities, reduce the information asymmetry of the scientific market, and further improve the efficiency and output of urban innovation [30]. Secondly, the increasing investment in innovation can stimulate innovation activity and have a positive impact on innovation output [31-32]. Thirdly, people are the most core and active element in scientific and technological innovation activities. At present, the economic and innovation competitions among countries and regions are ultimately a contest for talents. The regions with more scientific and technological talents have higher innovation output [33]. Therefore, the government might promote green innovation from supply side via three approaches including optimizing the innovation environment, increasing innovation investment and gathering innovation talents. On the social public side, EIDP is conducive to safeguarding the public’s right to know and greatly alleviating the information asymmetry of pollution [34]. On the one hand, the public can exercise the right of environmental supervision over local governments and polluting enterprises more effectively [35]. On the other hand, with the change of residents’ consumption concepts, the green innovation can be promoted from the demand side by increasing the green consumption [36].

In addition, China has a vast territory and the levels of industrialization and economic development are various from place to place. Therefore, EIDP’s impact on green innovation may also vary in different regions. Generally speaking, compared with cities with low and medium level of economic development, cities with high level of economic development are characterized by lower environmental pollution, stronger agglomeration of innovative elements such as talents or capital and higher degree of green innovation. Moreover, the positive interaction between environmental protection and innovation development has been achieved basically in these cities, hence, EIDP may have a slightly marginal effect on promoting technological innovation. Conversely, the marginal effects might be more significant in cities with low and medium level of economic development. However, compared with cities with low and medium industrialization level, cities with high industrialization level rely more on resources and pollution-intensive industries in economic development, so compulsory EIDP is conducive to adjusting and optimizing these cities’ industry structures, improving technological innovation, thus EIDP may have a more significant marginal effect.

Following hypotheses are put forward in this study based on the above analysis:

- Hypothesis 1a: the EIDP can affect green innovation positively. Hypothesis 1b: the EIDP can affect green innovation negatively.

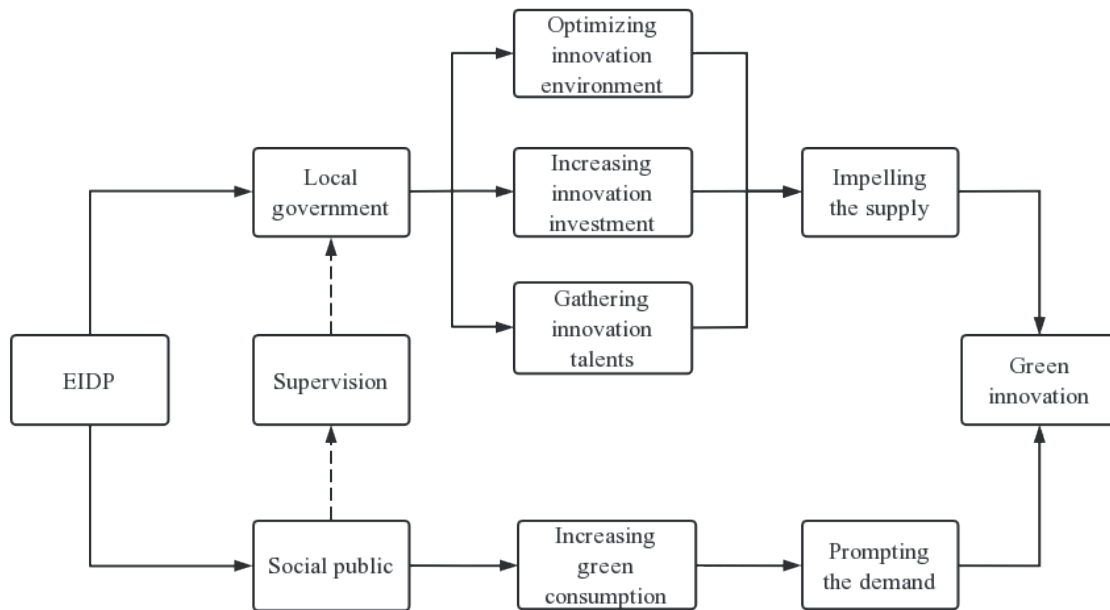


Fig. 1. The impact mechanism of EIDP on green innovation.

- Hypothesis 2: EIDP promotes the cities' green innovation level possibly from four approaches: optimizing innovation environment, increasing innovation investment, gathering innovation talents and increasing green consumption.
- Hypothesis 3: The impact of EIDP varies in cities with different industrialization level and economic development level.

- Dynamic regression model

The basic premise of an effective DID model is that the treatment group and the control group have a common trend before the policy [39]. For the purpose of clarifying common trend hypothesis, this study conducts following econometric model referring to Resul et al. [37], and Li et al. [38]:

$$Y_{it} = \sigma_0 + \sum_{k \geq -10}^9 \beta_k D_{it}^k + X_{it}\gamma + \alpha_i + \lambda_t + \varepsilon_{it} \quad (2)$$

In this model, D_{it}^k represents the event, and its value is defined as: S_i represents the specific year when city i implements EIDP, if $t - S_i = k$, then $D_{it}^k = 1$, otherwise, $D_{it}^k = 0$. Owing to the earliest and latest year of EIDP are 2008 and 2013, thus the maximum and minimum value of k are 9 and -10 in the sample scope of this paper. Meanwhile, this paper deems the tenth year before EIDP as the benchmark year, which means the dummy variable ($k \neq -10$) is eliminated. All of the other variables are the same as in model 1. This paper mainly focuses on the parameter β_k , if the null hypothesis of parameter β_k ($k \in [-9, -1]$) is zero before EIDP, then DID model in this paper can satisfy the requirements of common trend hypothesis. Meanwhile, model (2) can examine the dynamic changes of EIDP's impact on green innovation.

Methodology and Data

Model Construction

- Basic regression model

There are differences in the processing time of EIDP, for example, 113 cities began to disclose pollution source supervision information in 2008, and the number of cities increased to 120 until 2013, thus the gradual DID model is applied. Referring to Resul et al. [37], and Li et al. [38], the following model is set up:

$$Y_{it} = \sigma_0 + \sigma_1 PITI_{it} + X_{it}\gamma + \alpha_i + \lambda_t + \varepsilon_{it} \quad (1)$$

In this model, Y_{it} served as the green innovation level of i city in year t ; the core explanatory variable is $PITI_{it}$ which defined as the EIDP in a certain city, and the value is 1 for the subsequent years, otherwise the value is 0. A series of control variables is represented by X_{it} ; the city fixed effect and the year fixed effect are represented by α_i and λ_t respectively; the random error term is represented by ε_{it} . The core estimated factor is σ_1 . If σ_1 is significantly higher than 0, EIDP positively promotes green innovation. If σ_1 is obviously less than 0, EIDP inhibits green innovation significantly and insignificantly otherwise.

Variable Definition and Description

- Dependent variable

The green innovation, in this paper, is selected as the explained variable. In order to reasonably measure green innovation, this paper carries out the following treatments: (1) Learning from Qi et al. [13], the green patent data in 281 prefecture-level cities were retrieved by using the classification number in International

Patents Classification (IPC) Green Inventory; (2) Due to the low technical content of green appearance patents, green invention patents and green utility model patents are selected as green patent data. (3) Considering that it usually takes 1 to 3 years from patent application to authorization, the number of green patent applications is selected to timely and accurately reflect the city's green innovation activities in the year. Finally, the green innovation index can be concluded after summing the application quantity of green invention patent and green utility model patent in the city in that year.

– Independent variable

Whether cities are listed as the object of EIDP beyond 2008 and 2013 is served as the core explanatory variables. This paper considers EIDP from 113 cities in 2008 and 7 newly added cities in 2013 as a quasi-natural experiment, meanwhile, if the city implements EIDP, then the value is 1, otherwise is 0.

– Control variables

This paper sets the following control variables which can reflect city characteristics and affect green innovation: (1) Financial development level (FDL). The financial system is the main capital resource for enterprises to make innovations in technology, and the development degree of the financial market is directly related to the enterprises' technological innovation level. The natural logarithm of year-end loan balance from financial institutions (10,000 yuan) is employed to measure the FDL in our study. (2) City size (CS). During the progress of city development, various elements are highly concentrated, providing an ideal place for green innovation. This paper uses the natural logarithm of the city's year-end population (10,000 people) to represent CS. (3) Industrialization level (IL). Industry occupies a major position in the national economy, while it is not only the main body of wealth income but also the object of pollution. The level of urban industrialization is indicated by the ratio of gross industrial production to GDP in this paper. (4) Economic development level (EDL). Generally speaking, the consolidation of the economic foundation is an important guarantee for technological innovation in the region. Therefore, the larger the per capita GDP value is, the stronger the economic foundation

for technological innovation becomes in the region, and vice versa. The ratio of regional GDP to local population is applied to measure per capita GDP in this paper. (5) Consumption level (CL). Consumption is the initial impetus of innovation, and the direction of consumption upgrading is an important guide for industrial upgrading, which promotes related industries development and technological innovation. This paper measures the CL with the ratio of total retail sales of social consumer goods to GDP.

– Mediator variables

The following content explains how we select mediating variables and measure specific data: (1) Innovation environment (IE). It is measured by the logarithm of internet users. (2) Innovation investment (II). It is assessed by technology's expenses' proportion in government fiscal expenditures. (3) Innovative talents (IT). It is valued by the ratio of talents who engaged in scientific research in the general population. (4) Green consumption (GC). The transformation of residents' green consumption concept is indicated by the data of the actual number of publicly operated cars and trams by year end which consists of the actual number of publicly operated cars and trams plus actual taxis at the end of the year.

Data Sources and Processing

The original data of the above variables comes from China City Yearbook, China City Construction Statistical Yearbook and China Statistical Yearbook, etc. At the same time, the nominal variable is adjusted to the constant price whose base period is the year 2000. In Table 1, the descriptive statistical results of the main variables, such as green innovation, EIDP, etc. are listed.

Results and Discussion

Estimation Results and Robustness Test

The effect of EIDP on green innovation is evaluated in this study. In this section, PSM method is used

Table 1. Descriptive statistics of prefecture-level cities panel data from 2003-2017.

Variable	Definition	Obs.	Mean	S. D.	Min	Max
Green innovation	The number of green innovation applications	4215	259.993	968.082	0	21179
EIDP	Difference-in-difference item	4215	0.276	0.447	0	1
FDL	The natural logarithm of year-end loan balance from financial institution (10,000 yuan)	4215	15.938	1.373	12.548	21.045
CS	The natural logarithm of population (10,000 people)	4215	5.855	0.694	2.773	8.129
IL	Gross industrial production /GDP (%)	4215	48.397	10.955	14.950	90.970
EDL	GDP/ population quantity (10,000 yuan/person)	4215	3.420	2.858	0.189	25.688
CL	Total retail sales of consumer goods /GDP (%)	4215	35.005	9.823	2.640	76.633

for selecting sample cities of the control group, and EIDP's impact on green innovation is explored with gradual DID model. Also, the reliability of the result is guaranteed by a series of robustness tests.

Baseline Estimation Results

To avoid possible errors, PSM is used for examining sample selection [40-41]. The covariate variables include FDL, CS, IL, EDL and CL. The EIDP in cities is deemed as the explaining variable for logit regression, thus the propensity scores are concluded. Searching by neighborhood matching method, cities with closest scores are deemed as the experimental group for EIDP. Referring to Table 2, the balance test result shows that a significant systematic difference in the covariates, which comes from the matching experimental group and the control group, has not yet been found. Therefore, the basic assumption of DID model is satisfied, that is, if cities in treatment group do not implement EIDP, the trend of its green innovation output is similar to the control group. Table 3 reports the basic regression results of EIDP's impact on green innovation. Column (1) indicates the results of controlling city and year fixed effects only. The EIDP's coefficient is 59.7724, and the coefficient is significant at the level of 1%, illustrating that EIDP positively promotes green innovation. After adding control variables on by one from column (2) to (7), the EIDP's coefficient is 49.6612 which is still conspicuous at 1% level. Therefore, it comes to the conclusion that EIDP is helpful to promote green innovation, thus the hypothesis 1a is verified. Control variables illustrate that the green innovation can be positively promoted by improving CS and EDL. The cities with a larger scale and higher EDL usually possess better technologies and stronger public demands

on environmental protection, which is more conducive to promoting green innovation. However, FDL fails to promote green innovation effectively. The possible reason is that, under the current financial system, the ownership and scale discrimination in the bank system splits the financial market integrity, resulting in financial market distortion and financial mismatch. In addition, the coefficient of consumption level is not significant in the model, explaining that the promotion of CL on green innovation is insignificant. Consumers lack green products consumption consciousness at this stage, and the recognition and acceptance of green products is low in the market, leading to difficulties in impelling enterprises' green production and innovation.

Robustness Test

To further confirm the validity of the aforementioned empirical results, in our study, five methods are used for conducting robustness tests, including parallel trend hypothesis test, replacement of matching method, replacement of dependent variables, exclusion of extreme value effects, and placebo test.

– Time trend test

Fig. 2 plots the estimated value and its 95% confidence interval, which provides a visual observation on the dynamic trend of EIDP's impact on green innovation. The horizontal axis, in this figure, stands for the number of years before or after EIDP. Fig. 2 indicates there is no difference in green innovation among cities before EIDP, proving that the DID model satisfies the common trend presumption in this paper. At the same time, the estimated coefficient was not significant in the first six years after EIDP. However, as time goes by, the effects of EIDP on green innovation begin to appear and increase continuously, which indicates that the effect of EIDP lags for six-year.

Table 2. The result of balance test.

Variable	Unmatched	Mean		% reduct		t-test		V(T)/ V(C)
	Matched	Treated	Control	% bias	Bias	t	p>t	
FDL	U	17.738	16.595	130.2		11.24	0.000	3.21*
	M	17.362	17.359	0.4	99.7	0.03	0.975	1.26
CS	U	6.0764	5.7539	46.8		3.89	0.000	1.11
	M	5.9753	5.8399	19.6	58.0	1.36	0.176	1.09
IL	U	45.222	42.976	24.6		2.03	0.044	0.82
	M	46.216	44.008	24.2	1.7	1.47	0.144	0.51*
EDL	U	7.6868	4.3564	112.9		9.71	0.000	2.82*
	M	6.5854	6.5133	2.4	97.8	0.16	0.875	0.68
CL	U	43.427	42.003	12.9		1.07	0.286	0.95
	M	43.299	42.613	6.2	51.9	0.41	0.684	0.85

Notes: the result of balance test in 2017 is randomly chosen and displayed here due to space limitation

Table 3. Basic regression results of EDIP on green innovation.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Green innovation	Green innovation	Green innovation	Green innovation	Green innovation	Green innovation
Did	59.7724*** (3.8925)	59.5580*** (3.8764)	60.1078*** (4.0094)	60.1535*** (4.0080)	49.8232*** (3.3878)	49.6612*** (3.3723)
FDL		12.5720 (0.5179)	-15.5726 (-0.6529)	-15.8643 (-0.6560)	-23.2332 (-0.9825)	-23.1304 (-0.9778)
CS			814.8069*** (10.0484)	815.0186*** (10.0422)	796.0016*** (10.0323)	796.8464*** (10.0304)
IL				0.0663 (0.0738)	0.0186 (0.0212)	0.1251 (0.1268)
EDL					39.0312*** (9.7009)	39.4577*** (8.9442)
CL						0.2398 (0.2360)
_cons	0.8790 (0.0588)	-182.4162 (-0.5150)	-4,497.480*** (-8.1588)	-4,497.644*** (-8.1569)	-4,311.912*** (-7.9964)	-4,331.636*** (-7.9364)
City fixed effects	Control	Control	Control	Control	Control	Control
Year fixed effects	Control	Control	Control	Control	Control	Control
Observations	2,264	2,264	2,264	2,264	2,264	2,264
R-squared	0.316	0.316	0.349	0.349	0.379	0.379

Notes: P value in parentheses, ***, ** and * indicate significant effects at 1%, 5% and 10% levels respectively, the same in below.

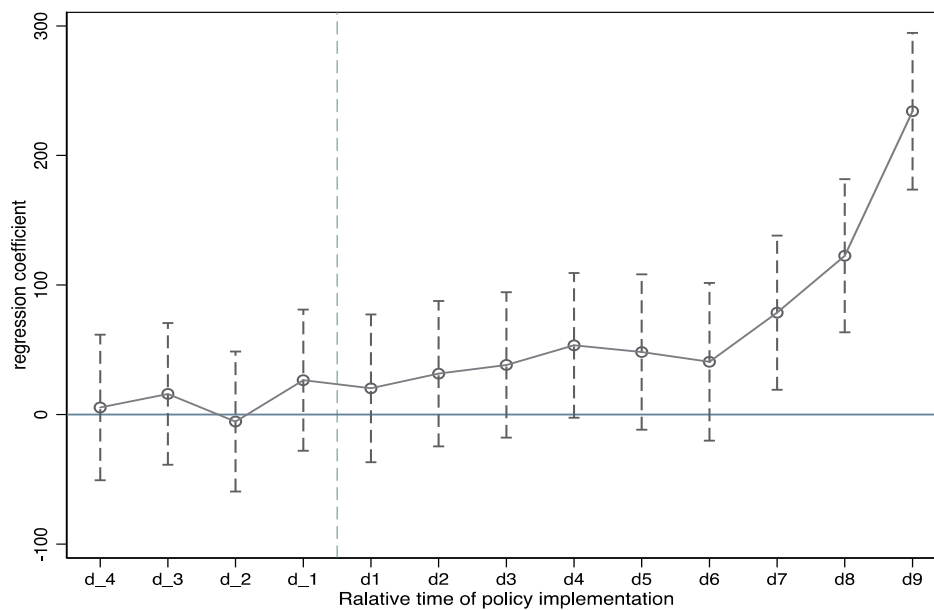


Fig. 2. The differences of green innovation level before and after EIDP.

Table 4. The regression result of robustness test.

Variables	(1)	(2)	(3)
	Replacing matching method	Replacing dependent variable	Eliminating the influence of extreme value
	Green innovation	GGIP	Green innovation
EIDP	121.7157*** (9.8108)	28.0732*** (3.8848)	45.6334*** (3.1743)
_cons	-2,581.2845*** (-6.2369)	-1,848.4747*** (-6.9016)	-3,370.7616*** (-6.2958)
Control variables	control	control	control
City fixed effects	control	control	control
Year fixed effects	control	control	control
Observations	3,701	2,264	2,264
R-squared	0.398	0.436	0.407

– Change matching method

For the sake of avoiding the bias caused by sample selection, the validity of the benchmark regression result can be further verified by changing the matching method. Cities with closest scores are deemed as the experimental group for EIDP cities using kernel matching method. The balance test result shows that, after matching, systematic difference in the covariates between the experimental group and control group does not exist. According to column (1) in Table 4, the regression result indicates a positive coefficient of EIDP, and it is obvious at the 1% level after changing the matching method, which is in line with the result of benchmark regression. The EIDP still can significantly improve cities' green innovation when taking sample selection into consideration. Therefore, the conclusion of this paper is robust.

– Replace dependent variable

In this paper, the explained variable is changed from green innovation to the quantity of granted green innovation patents (GGIP), and the regression is based on DID model. As shown in column (2) of table 4, at the 1% level, the EIDP's coefficient is significantly positive, proving a robust regression result.

– Excluding extreme value effects

For the purpose of eliminating influence caused by extreme value in the regression result, this paper carries out a tailing treatment of $\pm 1\%$ to all control variables. In accordance with column (3) of table 4, the consistency between the processed regression result and benchmark regression result is demonstrated, indicating a robust basic conclusion.

– Placebo test

To further verify whether the result of this paper is driven by unobservable factors, referring to Cai et al. [42], this paper randomly chooses the sample period as the starting year of EIDP for each sample and conducts the placebo test. Specifically, samples are grouped by cities in this paper, then we randomly choose a year from

year variables of every city group, and deem it as the implementation year of EIDP, meanwhile, the random selection can ensure that the independent variable did has no effect on green innovation. In other words, any significant finding will indicate biases in the regression result of this paper. Analyzing the regression result in figure 3, it is found that T values of EIDP's influence coefficients on green innovation appear to be normally distributed. And most of T values are concentrated around 0 and very few are distributed around ± 3 and ± 4 . The result demonstrates that the significantly positive or negative regression coefficients of constructed virtual policy $PITI_{it}^{false}$ to green innovation belong to rare events among 1000 times random tests, so the dummy treatment effect of policies' implementation does not exist. Therefore, the conclusion is robust.

Mechanism Analysis

The previous analysis shows that EIDP significantly improves the green innovation level. Thus, how does EIDP improve green innovation becomes a key issue. The EIDP's impact mechanism on green innovation is further analyzed in this section.

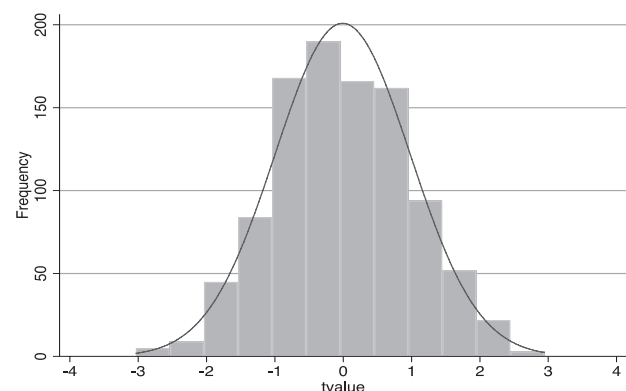


Fig. 3. 1000 times simulation of placebo test result.

In the cause of examining the EIDP’s impact mechanism on green innovation, this paper refers to Wen and Ye et al. [43-45] and uses the mediating effect model to construct following measurement model:

$$Y_{it} = \varphi_1 + \beta PITI_{it} + X_{it}\xi_1 + \alpha_i + \lambda_t + \varepsilon_{it} \quad (3)$$

$$M_{it} = \varphi_2 + \theta PITI_{it} + X_{it}\xi_2 + \alpha_i + \lambda_t + \varepsilon_{it} \quad (4)$$

$$Y_{it} = \varphi_3 + \omega PITI_{it} + \gamma M_{it} + X_{it}\xi_3 + \alpha_i + \lambda_t + \varepsilon_{it} \quad (5)$$

M_{it} represents mediator variables. Refers to the definition of mediating effect model, β is the gross effect of EIDP, ω is the direct effect of EIDP, and θ_γ is the indirect effect (mediating effect) of mediator variable M_{it} . If β , ω and γ are significant at the same time and the absolute value of ω smaller than β , M_{it} is concluded as the partial mediating variable; If β and γ are significant but ω not significant at the same time, M_{it} is concluded as the complete mediating variable. All of the other variables can be explained with same meanings in model 1.

Table 5 and Table 6 report the regression results. Column (1) and (3) in Table 5 and column (1) in

Table 5. The test result of effect mechanism.

Variables	(1)	(2)	(3)	(2)
	Model 4	Model 5	Model 4	Model 5
	IE	Green innovation	II	Green innovation
Mediator variable		2.4148*** (19.4902)		9.4160*** (3.6238)
Did	5.4993** (2.2481)	36.3814*** (2.6929)	0.3769*** (3.1563)	41.8512*** (3.0245)
_cons	-399.175*** (-4.4029)	-3,367.7033*** (-6.7016)	-5.0811 (-1.1497)	-4,405.2*** (-8.6207)
Control variables	control	control	control	control
City fixed effects	control	control	control	control
Year fixed effects	control	control	control	control
Observations	2,264	2,264	2,260	2,260
R-squared	0.538	0.479	0.923	0.398

Table 6. The test result of effect mechanism.

Variables	(3)	(3)	(4)	(4)
	Model 4	Model 5	Model 4	Model 5
	IT	Green innovation	GS	Green innovation
Mediator variable		186.6108*** (2.7837)		0.0023 (0.0611)
Did	0.0095* (1.9384)	47.8794*** (3.2538)	-8.9548 (-1.0296)	48.8186*** (3.3053)
_cons	1.0800*** (5.9157)	-4,533.1775*** (-8.2473)	-209.4587 (-0.6501)	-4,337.8854*** (-7.9290)
Control variables	control	control	control	control
City fixed effects	control	control	control	control
Year fixed effects	control	control	control	control
Observations	2,264	2,264	2,249	2,249
R-squared	0.271	0.381	0.017	0.380

Table 6 report a significantly positive coefficient of EIDP, indicating EIDP’s contributions to the optimization of IE, the increase of II and the gathering of IT. But EIDP’s coefficient is not significant in column (3) of Table 6, indicating that EIDP fails to significantly increase the public GS. Column (2) and (4) in Table 5 and column (2) in Table 6 show that the coefficients of EIDP and mediating variables are significantly positive when putting in the mediating variables including IE, II and IT. However, the column (4) in Table 6 clarifies that EIDP’s coefficient, as well as the coefficient of mediating variables, keeps insignificant when putting in the mediating variable of green consumption. Therefore, Hypothesis 2 is partially verified. The result introduces that EIDP has a significant mediating effect by optimizing the innovation environment, increasing innovation investment and gathering innovation talents, which proves that green innovation can be promoted from the supply side. And the possible reasons why the mediating effect of green consumption is not significant are shown below: with the implementation of EIDP, although the public begins to strengthen their attention and supervision on pollution, many problems such as a big gap between the current consumption mode and GS, huge waste caused by excessive or inappropriate consumption,

environment pollution and resources waste caused by lagging consumption concept or non-green products, will result in a failure when promoting green innovation from the demand side.

Heterogeneity Analysis

Heterogeneity Analysis Based on IL

According to the output proportion of the secondary industry, in this paper, sample cities are divided into three groups with high, medium and low IL and conducts regressions respectively. Table 7 demonstrates the estimation results.

From the regression results, the promotion effects of EIDP on green innovation in cities with low and medium IL are significantly positive, and effects on green innovation in cities with medium IL are significantly lower than in cities with low IL. Moreover, the promotion effects of EIDP on green innovation in cities with high IL are not significant. Cities with higher IL normally have a higher proportion of secondary industry and greater output proportion out of the total output in that region. Therefore, it is difficult to achieve industrial structure adjustment and green innovation in a short term by only putting pressure

Table 7. Regression results of cities with different IL.

Variables	(1)	(2)	(3)
	High IL	Medium IL	Low IL
	Green innovation	Green innovation	Green innovation
EIDP	43.5089 (1.5008)	37.4233* (1.7038)	63.3890*** (3.2921)
CS	2.4636 (0.0564)	-10.3020 (-0.2543)	-109.1298*** (-3.5830)
EDL	956.9519*** (7.9950)	379.2400** (2.0383)	771.1248*** (5.6437)
IL	1.5516 (0.8045)	2.1896 (1.2659)	-2.2227* (-1.8717)
FDL	26.7103*** (3.6178)	79.7907*** (9.2051)	36.2169*** (4.7658)
CL	-1.6176 (-0.6403)	3.5351** (2.2551)	-0.3756 (-0.3505)
_cons	-5,422.0784*** (-6.2074)	-2,415.8535* (-1.8808)	-2,786.4673*** (-3.5590)
City fixed effects	control	control	control
Year fixed effects	control	control	control
Observations	834	845	585
R-squared	0.324	0.507	0.419

Table 8. Regression results of cities with different EDL.

Variables	(1)	(2)	(3)
	High EDL	Medium EDL	Low EDL
	Green innovation	Green innovation	Green innovation
EIDP	100.9234** (2.2437)	16.2756 (1.3365)	9.5630 (0.7948)
CS	123.7929* (1.7805)	-42.3860** (-1.9658)	23.0598 (1.1902)
EDL	669.9263*** (4.1169)	921.5848*** (7.7025)	161.1987** (2.3674)
IL	4.8032 (1.4325)	2.3730*** (2.6582)	0.2470 (0.3406)
FDL	7.4285 (0.7350)	32.4900*** (3.8498)	16.5472 (1.3116)
CL	3.8141 (0.9612)	3.3899*** (3.7576)	-0.1001 (-0.1460)
_cons	-5,899.4774*** (-4.3325)	-4,975.1511*** (-6.8474)	-1,326.6376*** (-2.9689)
City fixed effects	control	control	control
Year fixed effects	control	control	control
Observations	656	955	653
R-squared	0.443	0.506	0.455

on environmental protection administration to disclose local environmental information.

Heterogeneity Analysis Based on EDL

According to the actual per capita GDP level, in this paper, sample cities are divided into three groups with high, medium and low EDL and conducts regressions respectively. Table 8 explains the estimated results.

The regression result shows that the promotion effects of EIDP on green innovation in cities with high EDL are significantly positive, and effects on green innovation in cities with medium and low EDL are not significant. This result demonstrates that EIDP significantly promotes the green innovation in cities with high EDL. There are two potential reasons. First, the management goals vary across cities with different EDL [46]. In cities with high EDL, governments' focuses shift from GDP to green economic development. Therefore, government officials in these cities more emphasize the promotion of green innovation [47-48]. As for cities with low and medium EDL, local governments mainly pursue economic growth and ignore the importance of environmental protection, leading to relatively weak motivations for green innovation [49-50]. Second, supported by

abundant funds and advanced technologies, cities with high EDL are usually more capable of achieving green innovation. Therefore, EIDP's promotion effects on green innovation are more significant in cities with better economic development.

Heterogeneity analysis shows that, the impacts of EIDP on green innovation in low and medium EDL cities are greater than cities with high EDL, while effects on cities with low and medium EDL are much lower than cities with high EDL. Therefore, Hypothesis 3 is verified.

Conclusions

Innovation development is an essential path for China's economic transformation and upgrading. Under the background of increasing tightening ecological-environmental constraints, can informal environmental regulation effectively promote local green innovation? To answer this puzzle, this paper considered the EIDP as a quasi-natural experiment. Using panel data of 281 Chinese prefecture-level cities during 2003-2017, this paper evaluated the EIDP's effect, impact mechanism and heterogeneity on green innovation under the gradual DID model, and further

verified the conclusion's reliability by abundant robustness tests.

The result revealed that: first, EIDP can significantly promote green innovation. Second, the promotion effect of EIDP on green innovation is realized by three mediations including optimizing innovation environment, increasing innovation investment and gathering innovation talents. Third, more significant effects are behaved in cities with low or medium level of industrialization and economically developed cities.

According to above conclusions, several policy proposals are put forward in this paper: First, it is necessary to increase the number of cities implementing EIDP and strengthen this approach. The core conclusion of this study showed that EIDP can significantly promote green innovation. Therefore, it is of great importance to further expand the scope of EIDP and improve the quantity, quality and frequency of pollution source information disclosure. On the one hand, it is suggested to advocate social engagement in environmental protection, supervision and governance activities. On the other hand, the government should guide enterprises to disclose environmental information consciously, regularly, reasonably and legally, and lead them to adjust industrial structure and promote economic transformation by using disclosed environmental information appropriately.

Second, it is necessary to strengthen the guidance of consumers' demands for green products. The green innovation starts with consumers' consciousness and awareness, and there will be no successful transition for green consumption without the consumers' initiative to make the improvement. On one hand, government can arouse and deepen consumers' green awareness through advocating environmental protection concepts. On the other hand, enterprises can stimulate consumers' purchasing desire by various means of information dissemination, eventually achieving a promotion effect on green innovation from the demands side.

Third, it is necessary to emphasize the policies' achievements in cities with lower level of economic development or higher level of industrialization. Cities with poor economic development usually primarily target on economic growth, and citizens' awareness of environmental protection is relatively weak, so it is necessary to strive to the enhancement of public's awareness on environmental protection, improve resource utilization efficiency and avoid the double poverty on economy and environment. And it is necessary to encourage cities with high level of industrialization to conduct developing mode transition and optimize their industrial structure continuously.

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Conflict of Interest

The authors declare no conflict of interest.

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