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Does the Green Development of Cities Need High-Level Opening Up? A Quasi-Natural Experiment Based on China's Pilot Free Trade Zone

Bei Wang [1], Hong Chen [2,*], Ruiqi Chen [2], Weiting Zeng [2] and Lechuan Ye [2]

[1] School of Business, Jianghan University, Wuhan 430056, China; wangbei1989@jhun.edu.cn
[2] School of Economics and Management, Wuhan University, Wuhan 430072, China
* Correspondence: 00008567@whu.edu.cn

Abstract: The contradiction between urban open development and the environmental pollution of cities becomes increasingly serious. People begin to pay attention to the green development effect of Free Trade Zones. Based on 278 prefecture-level cities in China from 2009 to 2019, we use the time-varying DID method with the implementation of PFTZ establishment policy as a quasi-natural experiment to explore whether the green development of Chinese cities needs high-level opening up. The main findings of this paper are as follows: (i) Compared with cities without PFTZs, the environmental pollution composite index (EPI) of cities with PFTZs decreases significantly by 5.278% on average; that is, the establishment of PFTZs significantly improves the green development level of those cities. (ii) After the establishment of PFTZs, the green development level of Chinese coastal cities will be enhanced to a greater extent than that of inland cities. In addition, the higher Chinese cities are in the urban hierarchy, the more they can grasp the development opportunities from the establishment of PFTZs. (iii) The establishment of PFTZs effectively reduces the EPI and significantly improves the green development level of cities through three paths: the scale effect, the structure effect and the technology effect. This paper provides micro-empirical evidence for literature related to the environmental benefits and green development of PFTZ construction and provides a reference for most developing countries to learn from China's experience.

Keywords: China's Pilot Free Trade Zone; green development of cities; time-varying DID

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1. Introduction

After a long process of industrialization and economic opening up, developing countries have exchanged environmental sustainability for rapid economic development. However, in the current international situation, the global economy is facing a major systemic shock. It is difficult for most developing countries to adapt to the current international economic environment by relying only on low-level opening up and the inefficient development mode in the past. Those countries urgently need to adjust their strategies of opening up to obtain new impetus for economic growth. With the advancement of bilateral and multilateral free trade agreements, free trade zones built within a country are also becoming a booster of economic development, such as the Free Export Zone (Korea) and Foreign Trade Zone (U.S.), helping companies to enhance their international competitiveness through deeper participation in international markets (Rhee et al., 1990) [1]. Horn et al. (2010) point out that the quantities and depth of bilateral and free trade zones are growing at present [2]. As the world's largest developing country and the world's second largest economy, China is gradually adjusting its development strategy, and China's implementation of high-level opening up seems to have implications for most developing countries. The core of China's high-level opening up is an institutional opening up that gradually lowers the threshold of government restrictions on cross-border economic activities and dovetails with global high-standard economic and trade rules. One of the important elements is to promote the facilitation of trade and investment through the establishment of China's Pilot Free Trade Zone (PFTZ), thus leading the way to the gradual realization of China's high-level opening up. China's Pilot Free Trade Zone is subordinate to free trade zones in terms of customs attributes, usually defined as areas where goods are landed, handled, manufactured or reconfigured without customs intervention and are able to be re-exported (Teifenbrun, 2015; Akbari et al., 2018) [3,4], while being able to provide a more convenient and liberal policy environment for foreign investors to simplify the import and export procedures (Wan et al., 2014) [5]. Realistically, the construction of China's Pilot Free Trade Zone has always been based on local cities, so relevant ecological and environmental problems cannot be ignored. As Chen and Golley (2014) point out, sustainable urban development is facing the serious challenge of environmental pollution [6]. The construction of PFTZs ultimately takes local cities as the carrier, so the accordingly ecological and environmental problems cannot be ignored. The green development of cities is an important driving force for a country to promote sustainable economic development. More importantly, it is also an important topic concerning the quality of people's life. Cities themselves play a key role in promoting low-carbon development. In addition, while gradually achieving a high-level opening up in China, the construction of PFTZs is needed to better improve the green development level of cities (Liu et al., 2022) [7]. With PFTZs as the test platform, can China's high-level opening up improve the green development level of cities? What is the mechanism, and how does it work? The answers to the above questions can provide a reference basis and inspiration for developing countries to summarize the experience of China's high-level opening up and achieve the sustainable and healthy development of their own economy.

2. Literature Review

As important regions to promote trade liberalization and investment facilitation, PFTZs provide many convenient policies for the free flow of goods and labor, tax preferences, etc., create a good business environment (Ma et al., 2021) [8] and thus have received extensive academic attention. Existing literature is rich in studies on the spillover effects of PFTZs, but the conclusions obtained differ significantly. Some scholars argue that the establishment of PFTZs will lead to obstacles in the trade flow of resources due to inconsistent policies inside and outside the zone, thus making regional development more unbalanced (Jenkins and Kuo, 2017) and trade cost distortions more severe (Sirorn and Yucer, 2014) [9,10]. At the same time, as the reduction in transaction costs will drive down the prices of local products in the zone, it will also affect the welfare level of domestic producers (Hamiltion and Sevensson, 1982) [11]. However, the vast majority of scholars are positive about the spillover effects of PFTZs, such as Benton et al. (2016) [12] and Mohebi and Mirshojaee (2019) [13], who found that the construction of PFTZs attracts foreign direct investment, promotes the optimization and upgrading of the trade structure and thus strengthens the economic and trade ties with major countries in the world. Currently, scholars have also extensively discussed the spillover effects of PFTZs from various aspects, such as regional innovation development, economic growth, industrial development and knowledge spillover. In terms of regional development, Seyoum and Ramirez (2012) [14] and Díez-Vial and Fernández (2014) [15] pointed out that the institutional innovation effect generated by PFTZs can effectively promote the inflow of advanced knowledge and technology and lay a good foundation for industrial agglomeration and the improvement of regional innovation. In terms of economic growth, Waugh and Ravikumar (2016) studied the content of trade agreement policies and the measurement of trade openness, respectively, and concluded that PFTZs can promote regional economic development by introducing foreign investment and increasing the scale of trade [16]. Chen et al. (2018) examined the impact of PFTZs on regional economic development by establishing a development performance assessment system to evaluate the development performance of six typical free trade ports in coastal areas of China and concluded that the establishment of PFTZs can significantly affect regional production performance [17], while Zheng et al. (2016) and Cai et al. (2021) demonstrated that the construction of PFTZs would realize the release of institutional dividends and promote regional economic growth [18,19]. In terms of industrial development, Zhao et al. (2022) used the construction of PFTZs as a quasi-natural experiment to assess the industrial structure upgrading effect of PFTZs using the DID method and came up with the result that the construction of PFTZs exerted a significant positive influence on the upgrading of urban industrial structure [20]. Song et al. (2019) used a neural network model to study the influence of PFTZs on the development potential of Chinese environmental protection enterprises and concluded that the establishment of PFTZs created good development conditions for enterprises by changing their internal and external environment, which significantly enhanced the development potential of Chinese environmental protection enterprises [21]. In terms of knowledge spillover effects, there is a significant regional knowledge spillover effect of PFTZs (Li et al., 2020) [22], which facilitates the participation of Chinese enterprises in global value chains and knowledge exchange and favorably enhances their international competitiveness.

The existing literature rarely discusses the environmental effects and green development of PFTZ construction. In terms of the relationship between trade and the environment, scholars have gradually progressed from the macro level, such as international trade, to the micro level, such as urban openness, and have reached somewhat divergent conclusions. Through a study of North American PFTZs, Grossman and Krueger (1994) found that the acceptance of foreign investment in Mexico for economic development was accompanied by a corresponding increase in domestic atmospheric pollution, which proved the construction of PFTZs was detrimental to environmental protection [23]. By constructing a North–South trade model and decomposing the environmental effects of trade into the scale effect, structure effect and technology effect, Copeland and Taylor (1994) concluded that free trade increased environmental pollution in the world [24]. However, Antweiler et al. (2001) also used the same method and came to the opposite conclusion that free trade was beneficial to environmental protection [25]. Aloise and Macke (2017) argued that the construction of PFTZs should focus on the protection of the environment while using foreign investment to achieve sustainable and healthy development of the regional economy [26]. Some scholars have also explored the green development benefits of constructing China's PFTZs, and the reached conclusions are all positive. Jiang et al. (2021) used an integrated control approach to study the impact of establishing China's PFTZ (Shanghai) on green total factor productivity in Shanghai and concluded that the establishment of PFTZs promoted green total factor productivity in Shanghai through technological progress [27]. Similar conclusions were reached by Wang et al. (2022), who used the approach of regression discontinuity to study the radiation effect of China's PFTZs on urban development and concluded that the establishment of PFTZs effectively promoted the green development of China's Yangtze River Delta city cluster through technological progress [28]. Zhou et al. (2022) evaluated the green development path of China's PFTZs by constructing a green development index and concluded that the green development of China's PFTZs has played a positive role in China's green and high-quality development, which is the result of combining several factors such as green policy implementation, green productivity growth and foreign investment participation [29].

Through reviewing existing literature, this paper argues that there is still room for further expansion of the benefits of urban green development arising from high-level opening up with PFTZs as an important experimental platform.

First, most of the relevant literature uses the DID method to discuss the benefits of PFTZ establishment policy as a quasi-natural experiment, which may limit the number of samples due to the unicity of policy occurrence time in the DID model. The implementation of PFTZ establishment policy is a dynamic and continuous process in the practice of China's high-level opening up. In addition, as China's level of opening up continues to escalate, more eligible cities will undertake the construction of PFTZs. Thus, using the time-varying DID method can well put the dynamic effects of policy implementation under examination.

Second, the existing literature pays too much attention to the economic benefits of constructing PFTZs, while relatively little literature examines its environmental benefits, which fails to comply with the advanced concept of sustainable and healthy development strongly advocated by international organizations. As the test platform for China's high-level opening up, one of the important tasks of PFTZs is to achieve the liberalization and facilitation of trade and investment. Since the environmental impacts of free trade are widely divergent, the environmental benefits of constructing PFTZs and the impact mechanisms need to be clarified by more literature. Thus, we can provide reference for China to guide the future development path of high-level opening up and provide opportunities for developing countries to learn from China's experience.

Therefore, based on the balanced panel data of 278 prefecture-level cities in China from 2009 to 2019, we used the time-varying DID method with the implementation of PFTZ establishment policy as a quasi-natural experiment to explore whether the green development of Chinese cities needs high-level opening up. Compared with the existing literature, the contributions of this paper are as follows: (1) We explore the green development benefits of cities and realization mechanisms arising from high-level opening up, which further enriches the research on the environmental benefits of PFTZ construction. (2) The PFTZ establishment policy is a quasi-natural experiment with continuous implementation, and we use the time-varying DID method to examine its benefits for cities, which overcomes the limitations of the ordinary DID method.

3. Theoretical Analysis

The green development of cities proposed in this study is a mode of development that relies on industrial upgrading, innovation-driven and other means to promote cleaner production activities and a green living environment in cities and realize the gradual decoupling of urban economic growth and environmental pollution.

As the test platform for China's high-level opening up and an institutional highland for benchmarking international high-standard trade rules, PFTZs have produced an indispensable role in promoting high-quality trade development and enhancing the level of trade liberalization (Chen et al., 2022) [30]. The original purpose of establishing PFTZs is to provide experience for China to subsequently enhance higher-level opening up. In addition, the enhancement of the higher-level opening up needs to rely on the healthy development of the export-oriented economy with international trade as the main manifestation. Thus, expanding trade openness and enhancing trade liberalization have become some of the important tasks of PFTZs (Yao and Whalley, 2016a) [31].

While expanding trade liberalization through institutional innovation, PFTZs need to always adhere to the green development orientation to maintain the sustainable and healthy development of the open economy. The theoretical logic can be explained by the study of Copeland et al. (1994) based on the North–South trade model. In their study, the correlation between environmental pollution and international trade is discussed by the way of decomposing the impact of international trade on the environment into three effects: the scale effect, the structure effect and the technology effect. The decomposition equation is expressed as follows:

$$dD = \frac{\partial D}{\partial I}dI + \frac{\partial D}{\partial \tau}d\tau + \frac{\partial D}{\partial z}dz \tag{1}$$

In Equation (1), D is total pollution, I is total state revenue, τ is pollution tax, and z is industry type. Trade expansion can raise state revenue, restructure industry and use pollution tax to guide the clean technology progress, which in turn has three different types of effects on the environment. While PFTZs promote the green development of cities through trade expansion, the possible realization paths of the three effects are as follows:

(1) Scale effect. Through the implementation of negative lists, simplifying the approval process, cutting the scope of investment restrictions and so on, PFTZs can gradually approach the high standard and requirements of international trade rules, attract foreign investment and enterprises in an efficient way and expand the scale of trade.

Especially under the impact of COVID-19 and the anti-globalization wave, international capital and idle production elements are difficult to effectively utilize. The establishment of China's PFTZs provides good opportunities and channels for the whole world to invest in China, which will effectively promote the economic growth of local cities in China and expand the scale of the economy. With the expansion of the economic scale and stable economic growth, the cities belonging to PFTZs will accumulate more capital for pollution control, and people in cities will get better living standards and environment, ultimately enhancing their environmental awareness. Thus, the green development of cities will be eventually sustained.

(2) Structural effect. The relevant documents of Chinese officials guiding the development of PFTZs constantly emphasize the need to "promote the technological transformation and upgrading of traditional industries" and "support the development of strategic emerging industries". Those documents also further clarify the important task of PFTZs in promoting the renewal and upgrading of industrial structure. Through the institutional opening up of PFTZs, local governments in China support the entry of non-state enterprises into the relevant licensed and restricted areas, promote the free flow and optimal allocation of various factors, concentrate limited resources in high-end industries and service industries and promote the upgrading of the industrial structure of cities belonging to PFTZs. At the same time, in order to promote the transformation and upgrading of trade, the types of products traded need to be adjusted. China has to increase the production of trade products with high technological content, high economic added value and environmental protection. For the sake of gradually changing China's unfavorable position in the division of international trade, the corresponding industrial structure adjustment is indispensable. The change in industrial structure in local cities means that heavy industries and processing industries with higher pollution and lower economic added value are eliminated, while high-end industries with less pollution and higher economic added value are concentrated to survive and develop. Thus, the green and healthy development of China's urban economy is effectively promoted.

(3) Technology effect. The relevant documents of Chinese officials guiding the development of PFTZs also specify that PFTZs have the important goal of promoting innovation-driven development, i.e., to gather and utilize international innovation factors and promote the transfer and transformation of international advanced technologies to PFTZs. Therefore, the desirable approaches include improving the construction and configuration of research infrastructure, improving the intellectual property protection and management system in line with international standards and implementing policies for the introduction of research and innovation talents. At the same time, the expanded trade liberalization can effectively promote the exchange of international advanced technologies and facilitate the introduction of high-end clean production technologies in the cities belonging to PFTZs. It plays an important role in efficiency improvement and energy conservation in the production of products. Thus, the level of industrial pollutant emissions is reduced, and the green and healthy development of China's urban economy is effectively promoted.

The proposition that China's high-level opening up can enhance the green development of cities through the establishment of PFTZs is theoretically feasible. Will the proposition pass the test of empirical methods? Do the scale effect, structure effect and technology effect of this proposition exist in reality? In this paper, we will further explore this proposition through empirical analysis and a mechanism test.

4. Methodology and Data

The establishment of PFTZs provides a good quasi-natural experiment for the study of this paper, so we will use the time-varying DID model to examine whether the PFTZ establishment policy in China is beneficial to improve the green development of cities. Based on the quasi-natural experiment, the DID model is mostly used by scholars to study the effect of policy implementation. In addition, the method is widely applicable as it can effectively reduce the interference of other factors other than policy implementation variables.

4.1. Time-Varying DID Model

Since PFTZs are established in batches according to realistic conditions, there is some variation in the establishment time. Referring to the method of Fang and Wu (2020), this paper improves the ordinary DID model to the time-varying DID model [32]. In this paper, the time-varying DID model constructed with the establishment of China's PFTZs as a quasi-natural experiment is set as follows:

$$Y_{i,t} = \alpha_0 + \alpha_1 DID_{i,t} + \beta X_{i,t} + \eta_i + \gamma_t + \varepsilon_{i,t} \tag{2}$$

In Equation (2), subscripts i and t denote different Chinese cities and years, respectively. $Y_{i,t}$ is the explanatory variable, which denotes the green development level of Chinese cities. $DID_{i,t}$ is the core explanatory variable and also a dummy variable, which is equal to 1 when the PFTZ establishment policy is implemented in city i in period t, and it is equal to 0 otherwise. Thus, coefficient α_1 measures the average effect of the implementation of the PFTZ establishment policy on the green development level of Chinese cities. $X_{i,t}$ denotes the control variable, and β is the effect coefficient of the control variable. η_i and γ_t denote the model controls for city fixed effects and year fixed effects, respectively. $\varepsilon_{i,t}$ denotes the error term, and α_0 denotes the constant term.

4.2. Variables and Data Description

4.2.1. Dependent Variable

Green development level of cities: *EPI*. In this paper, we use the environmental pollution composite index (EPI) to measure the green development level of cities. Firstly, we collected data on the emissions of three common pollutants in Chinese cities, namely industrial wastewater emissions, industrial smoke emissions and industrial sulfur dioxide emissions. Then, we divide the data of the emissions of the above three pollutants by the GDP of each city per year to form the ratios. Finally, we apply the entropy method to those ratios to derive EPI. Since all factors are consistently negative indicators, there is no need to apply special positive standardization to them in the entropy method. The lower the value of the EPI, the higher the green development level of the city. Because economic growth is the final result of most positive factors and environmental pollution is the final result of most negative factors, the advantage of this index is that it takes both economic growth and environmental pollution into account and reflects the relative changes in pollution emissions in economic development of cities, which is in line with the definition of green development of cities in this paper. At the same time, the index takes the comprehensive emissions of three common pollutants into account, so it is more representative in measuring green development of cities.

4.2.2. Main Independent Variable

PFTZ establishment policy: *DID*. This variable is a dummy variable. In this paper, the expression of *DID* is obtained by multiplying the two dummy variables: treat_i (whether the city is in the treatment group) and post_t (whether the time is in or after the year of policy implementation). We can obtain the following expression: $DID_{it} = \text{treat}_\text{i} * \text{post}_\text{t}$. It means that the year in which the PFTZ is established in the local city and the subsequent years are recorded as 1; otherwise, it is 0. In order to better represent the effect of policy implementation and reduce the impact bias of too short a time interval, the next year is chosen as the year of policy implementation if the PFTZ is established in the second half of the year. Since the representative practice of China's high-level opening up is to carry out institutional innovation through the establishment of PFTZs, this paper takes the implementation of PFTZ establishment policy as a proxy variable for China's high-level opening up.

4.2.3. Control Variables

(1) Trade dependence (*FRE*): The construction of PFTZs will significantly change regional trade facilitation, which in turn affects the scale of regional imports and exports (Yao and Whalley, 2015b) [33]. In this paper, we use the ratio of total merchandise imports and exports per year in each city to the city's GDP to measure this variable. (2) International financing level (*FDI*): According to Rolfe et al. (1993), the construction of PFTZs provides important incentives for attracting foreign direct investment [34]. In this paper, we use the ratio of actual utilization of foreign direct investment per year in each city to the city's GDP to measure this variable. (3) Financial development level (*FIR*): Financial development has a significant impact on the efficiency of green development (Yang and Ni, 2022) [35]. This paper uses the ratio of the total deposits and loans of financial institutions to the GDP of each city per year at the prefecture level to measure this variable. (4) Government development level (*GOV*): A study by Aritenang (2009) concluded that government support has a significant impact on the economic performance of PFTZs [36]. This paper uses the share of local government budgetary expenditure in each city's GDP to measure this variable. (5) Reserve of talents (*EDU*): The construction of PFTZs promotes the cultivation of higher education talents, which in turn promotes the high-quality development of PFTZs' economy (Yu, 2018) [37]. In this paper, we use the proportion of general higher education students to the total local population per year in prefecture-level cities to measure this variable. (6) Informatization level (*INT*): Referring to Yi et al. (2022), the digital development of the economy has a significant impact on carbon emission reduction, so this paper uses the ratio of the number of households with Internet access to the total local population for each year to measure this variable [38]. (7) Environmental regulation (*ER*): Environmental regulation is an important initiative to coordinate economic development with environmental improvement (Tong et al., 2022) [39]. This paper uses the environmental concern of government work reports to measure this, which can be calculated by the proportion of the number of environmental words in the annual work report of each city's government in China to the total number of words in the annual work report of each city's government in China.

4.2.4. Intermediate Variables

(1) Economic scale (*lnGDP*): In this paper, we use the logarithm of GDP of Chinese prefecture-level cities after price adjustment with 2009 as the base period to measure. (2) Green innovation capacity (*lnGCRE*): Green patents, as a reflection of green innovation capacity, have an important impact on sustainable economic development (Wang, 2022) [40]. In this paper, we use the logarithm of the number of green patent applications in China's prefecture-level cities after matching the green list of WIPO's international patent classification with China's national IP database to measure it. It better reflects the effective innovation capacity of cities in promoting green economic development compared with the traditional number of ordinary patents granted. (3) Industrial structure (*TU*): Industrial structure is an important factor affecting the economy and the environment (Shao et al., 2016) [41]. In this paper, we use the industrial structure advanced index, which is the ratio of the output value of tertiary industry to secondary industry per year in Chinese prefecture-level cities, to measure the upgrading of industrial structure. The explanatory and measurement methods for the control and intermediate variables used in this paper are described in Table A1.

Considering the availability and timeliness of data, this paper uses balanced panel data of 278 prefecture-level cities in China during 2009–2019. Regarding the temporal dimension of the sample, this paper only uses the sample data of 11 years from 2009 to 2019 to avoid the systemic impact of the world financial crisis in 2008 and the adverse effects of COVID-19 starting in early 2020. Regarding the spatial dimension of the sample, considering the completeness of statistical data, this paper screens the data of 31 Chinese provinces and cities at the prefectural level excluding Hong Kong, Macao and Taiwan regions. The cities with serious data deficiencies were excluded, and finally, 278 individual prefecture-level cities were retained in the sample. The sources of the panel data on Chinese prefecture-level cities include EPS database, statistical yearbooks of each city and environmental statistical yearbooks. Some missing values in the variables are supplemented by the interpolation method. The descriptive statistical results of each variable are displayed in Table 1.

Table 1. Descriptive statistics of variables.

Variable	Obs	Mean	Std. Dev.	Min	Max	Unit
EPI	3058	0.096	0.101	0.001	0.845	unit
FRE	3058	18.559	35.668	0.001	813.391	%
FDI	3058	1.769	1.747	0.001	12.877	%
FIR	3058	94.209	58.098	13.218	745.017	%
GOV	3058	19.117	9.788	4.388	148.516	%
EDU	3058	1.872	2.438	0.006	14.458	%
INT	3058	20.607	19.339	0.006	367.861	%
ER	3058	0.549	0.229	0.025	1.811	%
lnGDP	3058	7.288	0.926	4.477	10.549	CNY 100 million
lnGCRE	3058	4.971	1.708	0	10.507	unit
TU	3058	0.944	0.522	0.027	5.168	%

The layout of China's PFTZs has formed a new quantitative pattern of "1 + 3 + 7 + 1 + 6 + 3" by 2020. According to the needs of the selected years, this paper only examines the cities in the 12 provinces where PFTZs are established by 2019 as the treatment group, and the rest of the cities are examined as the control group. The selection of the treatment group sample is shown in Table A2.

5. Empirical Results and Robustness Test

5.1. Main Results

The empirical results of the time-varying DID model are presented in Table 2. Column (1) shows the results without control variables, and column (2) shows the results with control variables. After controlling for city fixed effects and year fixed effects, the policy implementation variable *DID* has a significant negative effect on the *EPI* regardless of whether the control variables are included; that is, the establishment of PFTZs causes a significant decrease in the EPI of local cities. In column (2), the *EPI* of cities with PFTZs decreases by an average of 5.278% relative to cities without PFTZs. As we have emphasized in the previous section, when the *EPI* is lower, the green development level of the city is higher. Therefore, China's high-level opening up with PFTZs as the test platform can significantly improve the green development level of cities, and it is conducive to sustainable and healthy economic development.

For the control variables, except for the *FDI*, almost every control variable has a significant negative effect on the *EPI*. After adding control variables, although the absolute value of the influence coefficient of *DID* on the *EPI* decreased, the fitting accuracy of the model improved, indicating that the selection of control variables is more reasonable. As to the reason why the *FDI* is not significant, we suggest that it may be related to the foreign investment absorption policy oriented by the government of the city to which China's PFTZ belongs. Although PFTZs have the conditions for high-level opening up, the activities of attracting foreign investment are still closely controlled by the government. So it is difficult for the *FDI* to have a significant impact on the *EPI* in the short term, and thus the improvement of the green development level of Chinese cities is not significant.

Table 2. Baseline regression results.

	(1)	(2)
	EPI	***EPI***
DID	−0.11206 *** (−13.66)	−0.05278 *** (−3.27)
FRE		−0.00019 ** (−2.53)
FDI		0.00267 (1.36)
FIR		−0.00031 * (−1.89)
GOV		−0.00265 * (−1.88)
EDU		−0.02576 *** (−4.16)
INT		−0.00182 *** (−3.56)
ER		−0.11163 *** (−9.01)
Constant	0.10807 *** (503.67)	0.32506 *** (13.24)
Observations	3058	3058
R-squared	0.036	0.448
Number of Cities	278	278
Controls	No	Yes
City Effect	Yes	Yes
Year Effect	Yes	Yes

Note: The values in brackets are the t-values of the estimated coefficients of the explanatory variables; *, ** and *** denote 10%, 5% and 1% significance levels, respectively.

5.2. Robustness Test

5.2.1. Parallel-Trend Test

An important prerequisite for constructing a DID model for empirical analysis is that the sample data must pass the parallel-trend hypothesis test; that is, the trend of developmental changes in the treatment group and control group before the time of policy implementation is consistent. Referring to Beck et al. (2010) and She et al. (2019), in this paper, the treatment variable treat_i interacts with a series of time dummy variables, and the following equation is constructed to examine whether the parallel-trend hypothesis test is passed [42,43].

$$Y_{i,t} = \alpha_0 + \rho_1 \sum_{n=1}^{4} D_{t-n} + \rho_2 \sum_{n=1}^{5} D_{t+n} + \beta X_{i,t} + \eta_i + \gamma_t + \varepsilon_{i,t} \tag{3}$$

In Equation (3), D_{t-n} is a dummy variable with a value equal to 1 if the PFTZ is established or already exists in period $t - n$; otherwise, it is equal to 0. D_{t+n} is also a dummy variable with a value equal to 1 if the PFTZ is established or already exists in period $t + n$; otherwise, it is equal to 0. The results of the parallel-trend hypothesis test are shown in Figure 1. The dashed line indicates the 95% confidence interval, and the circles on the dashed line indicate the estimated coefficients of Equation (3).

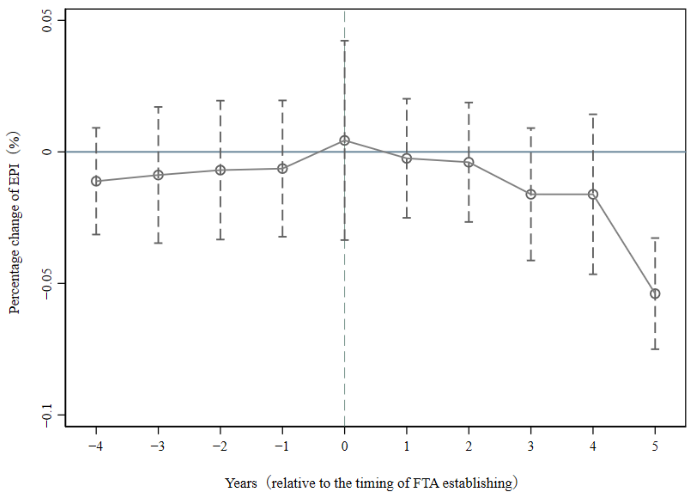

Figure 1. Parallel-trend hypothesis test results of time-varying DID model.

The results in Figure 1 illustrate two key points. Firstly, the estimated coefficients for the four periods before the policy implementation point 0 are not significant, indicating that the trend of change in the control and treatment groups before the policy implementation is consistent and the parallel-trend hypothesis test is passed. Secondly, starting from the fifth period after the policy implementation, the PFTZ establishment policy has a significant reduction effect on the *EPI*, indicating that the PFTZ establishment policy has a lagged effect on the green development level of local cities.

5.2.2. PSM-DID Test

The implementation of the PFTZ establishment policy divides the sample of prefecture-level cities into treatment and control groups. The baseline regression method examines all control and treatment group samples, which to some extent ignores the consistency of the characteristics of the treatment and control group samples and may lead to biased empirical results. In order to better match the similar characteristics of the control group samples with the treatment group samples, this paper uses the PSM method to reduce this error. Firstly we use the logit model to estimate the propensity score. Then, the nearest matching method of 1:2 and the radius matching method of 0.03 caliper value are used comprehensively. Finally, we get the control and treatment groups whose feature deviation is reduced. After matching the samples, this paper proceeds to the regression analysis of the effects of PFTZ establishment policy using the time-varying DID model. The empirical results of the PSM-DID method are displayed in Table 3.

Table 3. PSM-DID empirical results.

	(1)	**(2)**
	EPI	***EPI***
DID	−0.05278 *** (−3.27)	−0.08066 *** (−6.01)
Constant	0.32506 *** (13.24)	0.32603 *** (4.65)
Observations	3058	516
R-squared	0.448	0.366
Number of Cities	278	47
Controls	Yes	Yes
City Effect	Yes	Yes
Year Effect	Yes	Yes

Note: The values in brackets are the t-values of the estimated coefficients of the explanatory variables; *** denotes 1% significance level.

As shown in Table 3, column (1) shows the regression results of the time-varying DID model without the PSM method, while column (2) shows the regression results of the time-varying DID model using the PSM method. Comparing column (1) with column (2), it can be seen that both policy implementation variables' *DID* has a significant negative effect on the explanatory variable *EPI*. After propensity score matching, the *EPI* of cities with PFTZs will be reduced by 8.066% on average relative to cities without PFTZs. These results are consistent with the conclusion reached earlier. Therefore, the conclusion that China's high-level opening up with PFTZs as the test platform can effectively improve the green development level of cities is robust.

5.2.3. Placebo Test

One of the problems that arise from using the DID method is that certain unobservable and time-varying characteristics of the prefecture-level cities can have a biasing effect on the empirical results. While fixed effects are able to control for the effects of unobservable characteristics that do not vary over time, those unobservable characteristics that vary over time cannot be fully accounted for and added to the model. Therefore, the robustness of the empirical results can be examined here by means of placebo tests. Placebo tests generally include random assignment in control and treatment groups, the random setting of policy implementation time, the re-estimation of the model, etc. In this paper, we use the random setting of policy implementation time to conduct a placebo test. Specifically, we reconstruct the policy implementation variables DID_3 and DID_4 by advancing the time of PFTZ establishment by three and four years, respectively. If the estimated results of the reconstructed policy implementation variables are not significant in the model, it indirectly indicates that the empirical estimation results are still robust and credible, even if there are unobservable time-varying factors. The results of the placebo test are displayed in Table 4.

Table 4. Placebo test results.

	(1)	**(2)**	**(3)**
	EPI	***EPI***	***EPI***
DID	−0.05278 *** (−3.27)		
DID_3		−0.00753 (−0.68)	
DID_4			−0.01049 (−0.93)
Constant	0.32506 *** (13.24)	0.2457 *** (6.57)	0.2169 *** (6.46)
Observations	3058	3058	3058
R-squared	0.448	0.235	0.233
Number of Cities	278	278	278
Controls	Yes	Yes	Yes
City Effect	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes

Note: The values in brackets are the t-values of the estimated coefficients of the explanatory variables; *** denotes 1% significance level.

As shown in Table 4, column (1) shows the regression results for normal policy implementation time, and columns (2) and (3) show the regression results for three and four years earlier policy implementation time, respectively. After comparison, it can be seen that the policy implementation variables of three and four years ahead of time randomly are not significant, indicating that the establishment of PFTZs in the original year is the important reason why the green development level of cities is improved. Therefore, the conclusion that China's high-level opening up with PFTZs as the test platform can effectively improve the green development level of cities is robust.

6. Further Discussion

In the previous section, we have verified that China's high-level opening up with PFTZs as the test platform is beneficial to enhance the green development level of Chinese cities through the time-varying DID model, and the conclusion is also robust. In this section, we will further verify whether the differences in the geographic location and urban hierarchy of cities lead to heterogeneous effects and how the mechanism of China's high-level opening up improves the green development level of cities.

6.1. Heterogeneity Analysis

As is known, the geographical location of coastal and inland cities differs greatly, and cities at different urban hierarchies also vary widely in their ability to mobilize development resources and economic strength. Thus, the heterogeneity of effects may arise in terms of both urban hierarchy and geographical location.

In this paper, whether a province has a coastline or not is used as a criterion to classify coastal and inland provinces in China. In addition, cities in coastal provinces are considered as coastal city groups, and cities in inland provinces are considered as inland city groups. According to the latest list of the urban hierarchy published on China's official website, this paper classifies the sample cities into five major categories from high to low: first-tier, second-tier, third-tier, fourth-tier and fifth-tier. Generally speaking, the higher Chinese cities are in the urban hierarchy, the more development resources can be mobilized and the stronger the economic strength could be. According to the results of city classification, PFTZs exist in all cities except the fifth-tier cities. Therefore, this paper only discusses the heterogeneity of the urban hierarchy in all cities except the fifth-tier cities. The analysis results of the heterogeneity of city samples are shown in Table 5.

Table 5. Results of heterogeneity analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	EPI	***EPI***	***EPI***	***EPI***	***EPI***	***EPI***
DID	−0.05710 ***	−0.02585 *	−0.04500 **	−0.01140 *	−0.01048	−0.03365
	(−2.87)	(−1.72)	(−2.22)	(−1.87)	(−0.24)	(−0.96)
Constant	0.29518 ***	0.33532 ***	0.52563 ***	0.53271 ***	0.28059 ***	0.29919 ***
	(8.04)	(15.96)	(5.49)	(13.71)	(7.86)	(8.40)
Observations	1242	1804	208	330	759	869
Number of Cities	113	164	19	30	69	79
R-squared	0.438	0.504	0.602	0.680	0.450	0.557
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City Effect	Yes	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes	Yes

Note: The values in brackets are the t-values of the estimated coefficients of the explanatory variables; *, ** and *** denote 10%, 5% and 1% significance levels, respectively.

As shown in Table 5, columns (1) and (2) show the heterogeneity results for the coastal city samples and the inland city samples, respectively, while columns (3) to (6) show the heterogeneity results for the first-tier city to fourth-tier city samples, respectively. In column (1), the EPI of coastal cities with PFTZs is reduced by 5.71% on average relative to coastal cities without PFTZs. Column (2) shows that the EPI of inland cities with PFTZs is reduced by 2.585% on average relative to inland cities without PFTZs. By comparing column (1) with column (2), it can be found that coastal cities experience significantly stronger reductions in the EPI after PFTZs are established compared to inland cities; that is, the green development level of coastal cities is improved to a greater extent. This is consistent with the actual situation of China's economic development. Because coastal cities have a higher degree of economic openness, huge economic volume, complete infrastructure construction and supporting facilities, they have an inherent advantage in enjoying the policy dividends from the establishment of PFTZs. However, the inland cities have a relatively low degree of economic openness, infrastructure construction and geographical accessibility, so it is difficult to produce better results in those cities when accepting the policy of PFTZ establishment. As shown in columns (3) and (4), the EPI of first-tier and second-tier cities is significantly reduced by 4.5% and 1.14% after receiving the policy of PFTZ establishment, respectively. Moreover, the reduction in the EPI is stronger in first-tier cities compared to second-tier cities, which means that the green development level of first-tier cities is improved more effectively than second-tier cities. As shown in columns (5) and (6), the EPI of third-tier and fourth-tier cities does not decrease significantly after receiving the policy of PFTZ establishment, indicating that it is difficult for third-tier and fourth-tier cities in China to obtain the benefits of green development improvement from the implementation of PFTZ establishment policy due to their lower position in the urban hierarchy. Combining the empirical results in columns (3) to (5), we can draw the following conclusion: the higher Chinese cities are in the urban hierarchy, the more they can grasp the development opportunities from the high-level opening-up practice of PFTZ establishment. Thus, the green development level of cities is effectively improved.

6.2. Mechanism Analysis

6.2.1. Intermediary Effect Model

According to Baron and Kenny (1986), the intermediary effect model was originally widely used in psychological research to examine how explanatory variables affect the explained variables through intermediate variables [44]. Nowadays, the intermediary effect model is also widely used in the analysis of mechanisms in the field of economics. According to the theoretical analysis in the previous section, the establishment of PFTZs will likely achieve the goal of enhancing the green development of cities through the scale effect, structure effect and technology effect. Therefore, this paper uses the intermediary effect model to analyze the mechanism. The intermediate variables used for the scale effect, structure effect and technology effect are economic scale (lnGDP), industrial structure (TU) and green innovation capability (lnGCRE), respectively. The intermediary effect model constructed in this paper is shown bellow:

$$EPI_{i,t} = \alpha_0 + \alpha_1 DID_{i,t} + \beta X_{i,t} + \eta_i + \gamma_t + \varepsilon_{i,t} \tag{4}$$

$$M_{i,t} = \alpha_0 + \alpha_1 DID_{i,t} + \beta X_{i,t} + \eta_i + \gamma_t + \varepsilon_{i,t} \tag{5}$$

$$EPI_{i,t} = \alpha_0 + \alpha_1 DID_{i,t} + \beta_1 M_{i,t} + \beta_2 X_{i,t} + \eta_i + \gamma_t + \varepsilon_{i,t} \tag{6}$$

In Equations (5) and (6), M_{it} denotes the intermediate variable. The three variables including economic size (lnGDP), industrial structure (TU) and green innovation capacity (lnGCRE) will be added into the model and replace M_{it}.

6.2.2. Analysis of Intermediary Effect

The empirical results of the intermediary effects obtained in this paper are shown in Table 6. According to the results in Table 6, the policy implementation variables DID in columns (2)–(4) have significant positive effects on the economic scale (lnGDP), industrial structure (TU) and green innovation capacity (lnGCRE). This indicates that the establishment of PFTZs helps Chinese cities expand their economic scale, upgrade their industrial structure and significantly improve their green innovation capacity. Meanwhile, the results of coefficients in (5)–(7) columns of the economic scale (lnGDP), industrial structure (TU) and green innovation capacity (lnGCRE) are significant, indicating that the effect of the indirect influence of intermediate variables is significant. Observing the sign of the coefficients of DID in columns (5)–(7), we can find that after controlling lnGDP, TU and lnGCRE, DID has a significant negative effect on the EPI. This indicates three points: (i) Through the scale effect, the implementation of PFTZ establishment policy drives the economic scale growth of local cities by expanding trade and reduces the EPI. (ii) Through the structure effect, the implementation of PFTZ establishment policy drives the upgrading of the industrial structure of local cities by adjusting the trade commodity structure and reduces the EPI.

(iii) Through the technology effect, the implementation of PFTZ establishment policy drives the progress of environmental technology in local cities by promoting the exchange of international advanced technology and reduces the EPI. In summary, China's high-level opening up has achieved the purpose of improving the green development level of cities through the scale effect, structure effect and technology effect, and the green development of Chinese cities does need high-level opening up with PFTZs as the test platform.

Table 6. Results of intermediary effect model.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	EPI	*lnGDP*	*TU*	*lnGCRE*	*EPI*	*EPI*	*EPI*
DID	−0.05278 *** (−3.27)	0.27318 *** (4.78)	0.21362 *** (3.11)	0.57798 *** (4.54)	−0.00325 * (−1.79)	−0.03728 *** (−3.07)	−0.01608 ** (−2.53)
lnGDP					−0.17679 *** (−25.58)		
TU						−0.06678 *** (−5.20)	
lnGCRE							−0.06135 *** (−22.02)
Constant	0.32506 *** (13.24)	6.46938 *** (90.51)	0.18163 (1.36)	2.36999 *** (7.93)	1.46858 *** (32.98)	0.33697 *** (19.93)	0.47024 *** (39.93)
Observations	3058	3058	3058	3058	3058	3058	3058
Number of Cities	278	278	278	278	278	278	278
R-squared	0.448	0.431	0.405	0.496	0.734	0.483	0.679
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The values in brackets are the t-values of the estimated coefficients of the explanatory variables; *, ** and *** denote 10%, 5% and 1% significance levels, respectively.

7. Conclusions and Policy Implications

7.1. Conclusions

To investigate whether the green development of Chinese cities needs high-level opening up with PFTZs as an important experimental platform, this paper uses balanced panel data of 278 prefecture-level cities in China from 2009–2019, with the implementation of PFTZ establishment policy as a quasi-natural experiment, to conduct an empirical study using the time-varying DID method. The main conclusions drawn in this paper are as follows:

(1) From the perspective of the relationship between China's high-level opening up and the green development level of cities, compared with cities without PFTZs, the EPI of cities with PFTZs is significantly lower by 5.278% on average; that is, China's high-level opening up significantly improves the green development level of cities by establishing PFTZs. This finding still holds after the robustness test, indicating that the green development of Chinese cities does need China's high-level opening up.

(2) From the perspective of the heterogeneous effect of the PFTZ establishment policy, the EPI of Chinese coastal cities with PFTZs is significantly lower by 5.71% on average compared to those without PFTZs. In addition, the EPI of Chinese inland cities with PFTZs is significantly lower by 2.585% on average compared to those without PFTZs. This indicates that the reduction effect of the EPI is significantly stronger in Chinese coastal cities after the establishment of PFTZs; that is, the green development level of cities is improved to a greater extent. The average reduction in the EPI in China's first-tier and second-tier cities is 4.5% and 1.14%, respectively, after the implementation of the PFTZ establishment policy, while the reduction effect of the EPI in China's third-tier and fourth-tier cities is not significant. It indicates that the higher Chinese cities are in the urban hierarchy, the more they can grasp the development opportunities from the establishment of PFTZs. Then, the green development level of those cities is effectively improved.

(3) From the perspective of the mechanism of intermediate variables, as an experimental platform for high-level opening up in China, the establishment of PFTZs, with the important goal of promoting trade transformation and upgrading trade liberalization, effectively reduced the EPI through the three paths of the scale effect, structure effect and technology effect, and its direct and intermediary effects on the improvement of the green development level of cities are also significant.

7.2. Policy Implications

Chinese officials have given an important instruction for the construction of PFTZs, which requires each PFTZ to summarize the experience and achievements of reform and innovation in a timely manner. In addition, the Chinese central government will promote achievements that are effective, risk-controlled and replicable, which emphasizes the important role of PFTZs as the test platform for high-level opening up in China. As a pioneer among developing countries in promoting high-level opening up, China is gradually adjusting its development strategy and implementing high-level opening up. China's experience provides an important reference basis and experience inspiration for most developing countries to realize economic transformation and enhance the level of green urban development. In the process of learning from China's gradual realization of high-level opening up, developing countries need to give full play to the pioneering demonstration and driving effect of PFTZs, promote the improvement of the green development of cities and maintain sustainable and healthy economic development. This paper puts forward the following policy recommendations:

(1) Promote differentiated city development. Due to the differences in geographic location and urban hierarchy, it is impossible for developing countries to promote all cities to the same extent in the process of high-level opening up. Cities with developed economies and superior geographic locations can play a leading role as early demonstration areas. Thus, they can provide cities with less economically and geographically disadvantaged economies with meaningful experiences of opening up.

(2) Timely sum up the development experience and insist on high-level opening up. Since the construction of PFTZs has played a positive role in promoting the green development level of cities, developing countries should make full use of the experimental platform of PFTZs, overcome the heavy pressure during the difficult period of domestic economic transformation, firmly establish high-level opening up and speed up the construction of PFTZs in cities with economic strength. Meanwhile, governments of developing countries should summarize and learn from China's development experience of high-level opening up according to their actual situation and control the growth of economic activities with high pollution and high energy consumption by organizing negative lists and formulating environmental protection rules in the process of PFTZ construction. Thus, they can promote the improvement of the green development level of their cities with the high-quality construction of PFTZs.

(3) Strengthen the introduction of innovative elements and accelerate the optimization of industrial structure. Innovation capacity is an important reflection of a country's comprehensive strength. In the process of implementing high-level opening up, developing countries cannot be limited to imitating and following policies but need to make full use of the three paths of the scale effect, structure effect and technology effect of the construction of PFTZs to influence the green development level of cities. Thus, they can obtain the special development advantages belonging to their own countries. When establishing PFTZs, cities in developing countries should gather and utilize international innovation factors through the introduction of research talents, exchange of international technology and strengthening of research investment. Then they can make full use of the relative advantages of local technology and talents to adjust and optimize the city's industrial structure, eliminate backward industries in an orderly manner, vigorously cultivate core advantageous industries and promote the industrial structure to high-end, green and service-oriented industries.

There is still room for further expansion of this study. This paper only analyzes the heterogeneity of the geographical location and urban hierarchy of Chinese cities but fails to consider the policy differences in terms of environmental regulation. In addition, whether the implementation of PFTZ establishment policy has spatial spillover effects on the surrounding regions is also an important direction for expansion. Therefore, in the next step, we will further analyze the effect of environmental regulation policy differences on the green development level of cities and investigate whether there is a spatial spillover effect of PFTZ establishment policy. We hope to provide more informative Chinese experience and wisdom for the high-level opening up of developing countries.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1 shows the explanatory and measurement methods for the control and intermediate variables. Table A2 shows the summary of the urban sample in the treatment group.

Table A1. Description of control and intermediate variables.

Variable Type	Variable Name	Unit	Measurement Method
Control Variable	Trade dependence (*FRE*)	%	The ratio of the total merchandise imports and exports per year in each city at the prefecture level to the city's GDP.
	International financing level (*FDI*)	%	The proportion of actual utilization of foreign direct investment per year in each city to the city's GDP.
	Financial development level (*FIR*)	%	The ratio of the total deposits and loans of financial institutions to the GDP of each city per year.
	Government development level (*GOV*)	%	The share of local government budgetary expenditure in each city's GDP.
	Reserve of talents (*EDU*)	%	The proportion of general higher education students to the total local population per year in each city.
	Informatization level (*INT*)	%	The ratio of the number of households with Internet access to the total local population for each year.
	Environmental regulation (*ER*)	%	The proportion of the number of environmental words in the annual work report of each city's government in China to the total number of words in the annual work report of each city's government in China.
IntermediateVariable	Economic scale (*lnGDP*)	CNY 100 million	The logarithm of GDP of Chinese prefecture-level cities after price adjustment with 2009 as the base period.
	Green innovation capacity (*lnGCRE*)	unit	Logarithm of the number of green patent applications in China's prefecture-level cities after matching the green list of WIPO's international patent classification with China's national IP database.
	Industrial structure (*TU*)	%	The ratio of the output value of tertiary industry to secondary industry per year in each city.

Table A2. Summary of the urban sample in the treatment group.

Establishment Time	Established PFTZs	City
September 2013	Shanghai	Shanghai
April 2015	Guangdong	Guangzhou Shenzhen Zhuhai
	Tianjin	Tianjin
	Fujian	Xiamen Fuzhou
March 2017	Liaoning	Dalian Shenyang Yingkou
	Zhejiang	Zhoushan
	Henan	Zhengzhou Kaifeng Luoyang
	Hubei	Wuhan Xiangyang Yichang
	Chongqing	Chongqing
	Sichuan	Chengdu
	Shaanxi	Xianyang Xi'an
October 2018	Hainan	Sanya Haikou

Note: The whole province of Hainan is classified as a PFTZ. For the sake of completeness and accuracy of data, only Sanya and Haikou are selected as the cities in Hainan province for the establishment of the PFTZ.

Appendix B

Appendix B.1. details the calculation process of the entropy method, and Appendix B.2. provides a description of the environmental regulation measurements.

Appendix B.1. Entropy Method

In the selection of the index construction method, this paper uses the entropy method to construct the environmental pollution composite index (EPI) and then uses the EPI to measure the green development level of each prefecture-level city. This is mainly because the entropy method is more objective than other index construction methods, making the calculation results more scientific and more referential.

The construction of the EPI using the entropy method is based on the degree of dispersion of the indicators used. In order to solve the inconsistency of measurement units and directions of various indicators, it is necessary to standardize the data we used.

The standardization formula for positive indicators is as follows:

$$f_j(st) = \frac{x_j(st) - min_{1\leq s\leq n}min_{1\leq t\leq T}[x_j(st)]}{max_{1\leq s\leq n}max_{1\leq t\leq T}[x_j(st)] - min_{1\leq s\leq n}min_{1\leq t\leq T}[x_j(st)]} \tag{A1}$$

The standardization formula for negative indicators is as follows:

$$f_j(st) = \frac{x_j(st) - min_{1\leq s\leq n}min_{1\leq t\leq T}[x_j(st)]}{max_{1\leq s\leq n}max_{1\leq t\leq T}[x_j(st)] - min_{1\leq s\leq n}min_{1\leq t\leq T}[x_j(st)]} \tag{A2}$$

In Equations (A1) and (A2), j, s and t represent the indicator, city and year, respectively. $f_j(st)$ represents the standardized value of the jth indicator of city s in year t. $x_j(st)$ represents the original value of the jth indicator of city s in year t. T represents the number of years during the observation period, while n represents the number of cities.

Since all indicators are consistently negative, there is no need to apply special positive normalization to them in the entropy method. So, firstly, we use Equation (A2) to standardize the indicators.

Secondly, we need to determine the degree of contribution of each indicator by using the following equation:

$$y_j(st) = \frac{f_j(st)}{\sum\limits_{t=1}^{T}\sum\limits_{s=1}^{n} f_j(st)} \tag{A3}$$

In Equation (A3), $y_j(st)$ represents the degree of contribution of city s's jth indicator in year t.

Thirdly, we need to calculate the entropy level of the indicator j by using the following equation:

$$e_j = -\frac{1}{k}\sum_{t=1}^{T}\sum_{s=1}^{n} y_j(st) * \ln y_j(st) \tag{A4}$$

In Equation (A4), e_j represents the entropy level of the indicator j. $k = \ln(nT)$, while $k > 0$.

Fourthly, we have to calculate the information utility value of the indicator j, which is defined as g_j by using the following equation:

$$g_j = 1 - e_j \tag{A5}$$

Next, what we need to do is to calculate the objective weight of each indicator according to the variables in the equations above. The following equation is used:

$$w_j = \frac{g_j}{\sum\limits_{j=1}^{m} g_j} \tag{A6}$$

In Equation (A6), w_j represents the objective weight of the indicator j, and m represents the number of indicators.

Finally, by calculating the comprehensive score of m samples, we can obtain the EPI in the following equation:

$$EPI_{st} = \sum_{j=1}^{m} w_j f_j(st) \tag{A7}$$

The indicators we used in the paper are the ratios of the emissions of three common pollutants in each city per year to the GDP of each city per year. The three common pollutants in China are namely industrial wastewater emissions, industrial smoke emissions and industrial sulfur dioxide emissions. By substituting the indicators for $x_j(st)$ into the above process, we can obtain the EPI we used in our paper. In summary, this is the entropy method we used in this paper.

Appendix B.2. Environmental Regulation

This paper uses the environmental concern of government work reports to measure environmental regulation, which can be calculated by the proportion of the number of environmental words in the annual work report of each city's government in China to the total number of words in the annual work report of each city's government in China. The following are the detailed steps for measuring environmental regulations.

Firstly, we use the crawler function of Python to crawl the annual government work reports on the official government websites of various sample cities in China and measure the total number of words in the annual government work reports of each city, which is defined as α. Secondly, we use the vocabulary extraction function of Python, which we call the Jieba Library, to extract and count the number of words in government work reports that contain environmental classes, and we define the results as β. Thirdly, we use β to divide α and construct a ratio that is the frequency of using environmental words in the government's annual work report, which is the value of the environmental regulation variables used in this paper.

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