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How Does Green Investment Affect Environmental Pollution? Evidence from China

Siyu Ren[1] · **Yu Hao**[2,3,4,5,6] · **Haitao Wu**[2,3]

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Abstract

China is currently undergoing an important stage wherein it is adjusting its development mode and upgrading its industrial structure. Green investment has become a major driving force through which China can achieve green and sustainable development. Based on the panel data of 30 Chinese provinces for the 2006–2017 period, this paper uses a spatial Durbin model and a dynamic threshold model to empirically analyze the impact of green investment and institutional quality on environmental pollution. The research results show that China's environmental pollution is significantly characterized by spatial dependence. Local environmental pollution is negatively impacted by green investment, but it is not affected by green investment in neighboring areas; this conclusion remains valid after a series of robustness tests. Green investment can reduce environmental pollution by improving efficiency of energy conservation and emission reduction, expanding technological innovation capabilities and upgrading the industrial structure. The regression results of the dynamic threshold model show that green investment has a nonlinear impact on environmental pollution that is dependent on institutional quality. A higher degree of regional corruption can lead to a gradual decrease in the role of green investment in reducing environmental pollution. However, improvements in marketization and intellectual property protection can increase the positive influence of green investment in reducing environmental pollution. Significant regional heterogeneity is also found in the impact of green investment on environmental pollution, and this impact gradually decreases from the eastern coast to the western region.

Keywords Green investment · Environmental pollution · Institutional quality · Spatial Durbin model

✉ Yu Hao
haoyuking@gmail.com; haoyuking@bit.edu.cn
https://www.researchgate.net/profile/Yu-Hao-55

Extended author information available on the last page of the article

1 Introduction

Since the reform and opening-up, China's economic development has been world-renowned, and China has become the world's second largest economy (Wu et al., 2019). However, in the process of rapid growth, a series of environmental pollution problems have also arisen that not only cause devastating damage to the natural environment and ecological balance but also seriously threaten public health (Yang, et al., 2020). "Environmental Protection in China (1996–2005)" pointed out that China's extensive economic development mode may cause serious losses through environmental pollution and ecological damage that could account for approximately 10% of GDP. In the Environmental Performance Index Report (2018) released by Yale University and Columbia University, the comprehensive score for China is 50.74, placing it 120th overall and 177th in air quality ranking.[1] Another report from the bulletin on the state of China's ecological environment showed that among the 338 prefecture-level cities in China, 239 had excessive ambient air quality, representing 70.7% of China's cities. Increasingly serious environmental pollution and ecological damage have led China's government and public to realize the importance of environmental protection (Wang and Yang, 2016). To break resource and environmental constraints, the Chinese government has made comprehensive use of administrative regulations, economic means, and market mechanisms to limit pollutant emissions (Lan et al., 2012). Although these measures have achieved a certain level results, environmental pollution in China remains severe. In this context, if serious problems such as resource shortages, environmental pollution, and ecological destruction cannot be fundamentally solved, it will be difficult for China to achieve its goal of green and sustainable development (Wu et al., 2020).

To solve the environmental problems caused by economic development, the Chinese government and enterprises have continuously increased their investment in industrial pollution control. Green investment that emphasizes the coordinated development of the economy, society, and the environment has become an important force driving regional high-quality development and has attracted extensive attention from academic and government circles (Heinkel et al., 2001). The "China Industrial Green Development Plan 2016–2020" pointed out that it is necessary to increase green investment, build the basic framework of green financial system, and transfer social resources to the environmental protection industry. According to data from the National Bureau of Statistics, the environmental pollution control investment in China has been increasing annually, from 116.67 billion yuan in 2000 to 953.9 billion yuan in 2017, which demonstrates China's determination to control pollution (see Fig. 1). As an important carrier and method for realizing green development, green investment has been gradually incorporated into China's medium- and long-term development plan (Zhang and Yousaf, 2020). It can promote industrial upgrading and technological progress and control environmental pollution at its source.

However, the scale and structure of China's environmental investment still need to be further optimized and improved. On the one hand, the source of funds for green investment largely depends on government fiscal funds. The main direction of corporate green investment is industrial pollution control, while industrial pollution source control investment accounts for less than 10%. On the other hand, due to the long investment recovery period and low rate of return on green projects, coupled with the imperfect external institutional

[1] More details can be found at https://epi.yale.edu/downloads/epi2018policymakerssummaryv01.pdf.

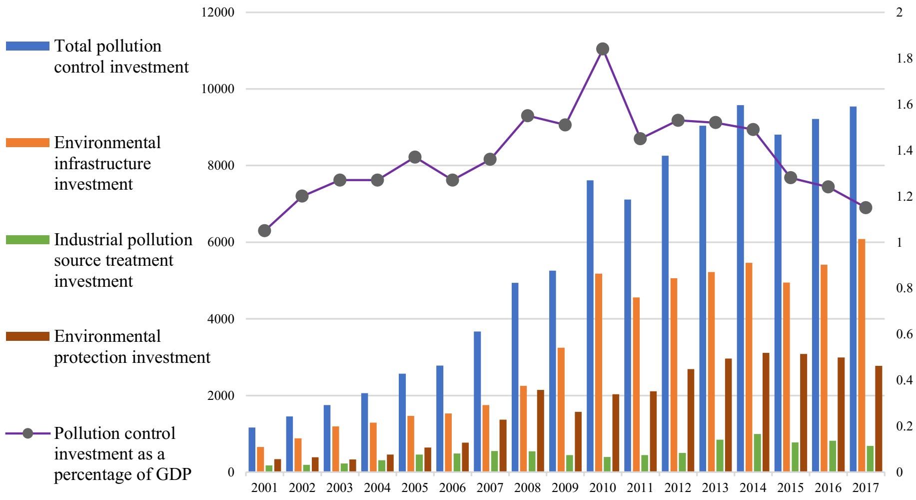


Fig. 1 China's environmental governance investment level (left scale) and proportion of GDP (right scale). Note: Environmental protection investment refers to environmental protection investment in accepted environmental protection projects in that year. *Source* The data are from the National Bureau of Statistics (http://www.stats.gov.cn/ztjc/ztsj/hjtjzl/2014/201609/t20160913_1399641.html)

environment and financial system in China, the implementation of green policies has failed to meet expectations. As external macro governance factors, institutional environments such as political corruption, intellectual property protection systems, and marketization processes can affect the allocation of factors and green technology R&D innovation (Arbatskaya and Mialon, 2020). Functions of the institutional environment include determining factor allocation, influencing transaction costs, and changing innovation incentives, which can not only directly guide the internal capital allocation of enterprises but also stimulate the enthusiasm of enterprises for green technological innovation and indirectly promote the development of green industries (Jennewein, 2006). Therefore, this article analyzes the relationship between green investment and environmental pollution from the perspective of institutional quality, thereby providing an important theoretical basis and policy reference for China's green and high-quality development.

The contributions and innovations of this study are as follows. First, green investment and environmental pollution are integrated in a unified analysis framework. Therefore, the research conclusions can help build understanding of the mechanism through which green investment impacts environmental pollution and provide a valuable reference for promoting sustainable development in China and other developing countries that are facing economic transformation and environmental problems. Second, considering the availability of data, this study defines and measures three aspects of green investment: environmental pollution control investment, renewable energy investment, and forestry construction investment. This approach can capture the status of China's environmental protection investment and provide a measurement method for related research on green investment. Third, in terms of research methods, given the significant spatial correlation of environmental pollution, this study selects the spatial Durbin model and the dynamic threshold panel model to determine the spatial spillover effect and endogeneity between variables.

The rest of the paper is organized as follows. Section 2 provides a literature review. The estimation methods and data are introduced in Sect. 3, and the empirical results are presented and discussed in Sect. 4. Section 5 proposes conclusions and corresponding policy implications.

2 Literature Review

2.1 Concept and Definition of Green Investment

There is no unified standard concept for green investment, and so the connotation of green investment first needs to be clearly defined. From a macroeconomic perspective, Eyraud et al. (2013) believe that green investment refers to the investment necessary to reduce greenhouse gas and air pollutant emissions, so green investment is also called environmental protection investment, ecological investment, etc. In the study of micro-corporate behavior, green investment is related to green management and corporate environmentalism, and it essentially aims to increase the company's capital expenditure on environmental governance, which can be regarded as a special activity in the domain of corporate social responsibility (Doval and Negulescu, 2014; Murillo-Luna et al., 2008; Martin and Moser, 2012). Ateş et al. (2012) regarded green investment as an internal investment involving environmental design, production and logistics. Voica et al. (2015) proposed including companies' climate adaptation or low-carbon investment in areas such as climate change, renewable energy, and clean technology in green investment. They suggested that only considering pollution control within environmental protection investment is green investment in a narrow sense, while a broader definition of green investment should consider multiple aspects of the environment, the economy, and society. It is worth noting that although the existing literature has inconsistent definitions of green investment, there is much intersection in the fields, commodities, technologies, services and processes involved in these different definitions (Inderst et al., 2012). Referring to existing research, this article defines green investment as the internal investment of government and enterprises in equipment, technology, materials, energy and purchased services to improve the companies' environmental performance, develop green management and reduce environmental risks.

2.2 Institutional Quality and Environmental Pollution

The definition of institutional quality usually includes government law enforcement efficiency, legalization, marketization and political stability (Dreher et al., 2009). It reflects the overall soft constraint of social development and is one of the comparative advantages that a country can hold (Dollar and Levin, 2005). In recent years, the relationship between institutional quality and environmental pollution has become a hot topic in the field of environmental economics. Institutional quality is considered a crucial factor for promoting economic transformation and alleviating pollution emissions, plays a critical role in environmental policy formulation, implementation and resource allocation, and has a positive effect on green innovative efficiency (Sarkodie and Adams, 2018; Sun et al., 2019; Zakaria and Bibi, 2019; Abduqayumov et al., 2020). Sun et al. (2019) surveyed the energy efficiency performance of 71 developed and developing countries and found that both green innovation and institutional quality have a significant positive impact on improvements in energy efficiency. Lau et al. (2018) analyzed the impact of institutional quality on the regional environment and found that controlling corruption significantly reduces carbon emissions in high-income countries, while the rule of law improves the environmental quality of middle-income and high-income countries. Hao et al. (2020) used a spatial measurement model to examine the impact of corruption on green total factor energy efficiency and found that more corruption can increase the inhibiting influences of labor resource misallocation on green total factor energy efficiency. Huynh and Ho (2020) studied 43 developing countries and found that improvements in institutional quality not only reduced air pollution but also alleviated the adverse impact of the shadow economy on air quality. In addition, some scholars believe that improvement in the institutional environment can increase the scale and quality of foreign investment, which facilitates the learning and absorption of foreign advanced environmental protection technology, knowledge and experience among the host countries' enterprises, thereby optimizing its industrial structure and improving its environmental quality (Buchanan et al., 2012; Huynh and Hoang, 2019; Mishra and Daly, 2007; Xin and Zhang, 2020).

2.3 Green Investment and Environmental Pollution

Given the importance of reducing traditional energy consumption and alleviating increasingly serious pollution, some studies in the environmental economics literature have addressed investment issues, especially green investment. Previous studies have tried to analyze the factors influencing green investment and found that economic growth, low interest rates, high fuel prices and environmental regulation promote green investment (Eyraud et al., 2013; Zhang et al., 2016). Liao and Shi found that public appeal can stimulate companies' green investment by improving the intensity of environmental regulations. Regarding the role of green investment, the available literature is not extensive. Green investment policy based on the debt capital market provides financial support for addressing climate challenges (Li et al. 2021). It affects the pattern of private capital mobilization for the evolution of clean energy and makes low pollution projects more cost-competitive (Heine et al., 2019). Green investment results in effective energy systems and climate markets, which play a significant role in reducing pollution emissions and promoting sustainable development (Lindenberg, 2014; Krushelnytska, 2019; Heine et al. 2019). Increasing capital investment in green technology can improve the production efficiency of enterprises and realize the replacement of nonrenewable with renewable energy, thereby alleviating the negative influence of enterprise production activities on the environment (Eyraud et al., 2013; Antonietti and Marzucchi, 2013). Karásek and Pavlica (2016) analyzed the effects of the green investment plan in the Czech Republic and found that the fiscal subsidy policy for biomass boilers and heat pumps reduced greenhouse gas emissions. Sachs et al. (2019) tried to assess the effect of implementing green projects and green investment on realizing the Sustainable Development Goals (SDGs) and found that green bonds and green funds are important tools for achieving SDGs and low-carbon development. Nassiry (2019) also proposed that the implementation of green investment can help achieve the SDGs. However, Zahan and Chuanmin (2021) found that although green investment has a positive impact on clean energy consumption, in the long run, it has little impact on carbon emissions.

3 Methodology and Data

3.1 Econometric Methodology

3.1.1 The Basic Model Construction

To test the impact of green investment on environmental pollution, based on the research of Grossman and Krueger (1995), the basic model is constructed based on the scale effect, technical effect, and structural effect:

$$P = Y \cdot T \cdot S \tag{1}$$

Here, P represents environmental pollution, and Y, T, and S indicate the scale effect, technical effect, and structural effect, respectively.

Scale effect. Economic development and urban scale expansion consume fossil energy and release a large amount of pollutants into the environment. Generally, more rapid economic growth and urban scale expansion result in more energy consumption and pollutant emissions. Therefore, economic development and urbanization are considered scale effects. The scale effect is constructed as follows:

$$Y = f(GDP, URB) \tag{2}$$

Technical effects. Technological progress can improve the productivity and energy efficiency of enterprises, upgrade pollutant treatment equipment, and weaken the negative externalities of economic development. Moreover, the application of green environmental protection technology can effectively promote the recycling of resources and reduce the damage to the environment caused by human production activities. Under the conditions of an open economy, in addition to increasing domestic R&D input, international technology spillover channels are also important ways to achieve technological progress. Considering that green investment can promote sustainable economic growth by improving green technology, the technology effect equation includes R&D capital, R&D personnel investment, green investment and trade openness.

$$T = f(OPEN, RD, RDP, GIN) \tag{3}$$

Structural effects. Economic development and technological progress usually lead to adjustments in the industrial structure. An industrial structure dominated by resource-intensive industries is characterized by increased resource consumption and aggravated environmental pollution. In contrast, an industrial structure dominated by knowledge- and technology-intensive industries will have comparatively reduced energy consumption and improved environmental quality. Therefore, the structural effect can be expressed by upgrading the industrial structure.

$$S = f(STR) \tag{4}$$

Substituting (2), (3), and (4) into Eq. (1), we obtain formula (5):

$$P(Pollution) = Y(URB, GDP) \cdot T(OPEN, RD, RDP, GIN) \cdot S(STR) \tag{5}$$

The basic model of this paper can thus be obtained:

$$pol_{it} = \beta_0 + \beta_1 gin_{it} + \beta_2 gdp_{it} + \beta_3 rd_{it} + \beta_4 rdp_{it} + \beta_5 open_{it} + \beta_6 str_{it} + \beta_7 urb_{it} + \alpha_i + v_t + \varepsilon_{it} \tag{6}$$

Here, pol_{it} represents environmental pollution, gin_{it} is green investment; i represents province, and t is time. α_i and v_t indicate the national effects and time effects, respectively. ε_{it} is called the idiosyncratic error term. The main control variables include economic development (gdp_{it}), R&D capital investment (rd_{it}), R&D personnel input (rdp_{it}), trade openness ($open_{it}$), industrial structure (str_{it}) and urbanization level (urb_{it}).

3.1.2 The Spatial Durbin Model

Due to the spatial correlation of regional environmental pollution, a spatial econometric model is used to examine the relationship between green investment and environmental pollution. Spatial measurement models include the spatial lag model (SLM), spatial error (SEM) model and spatial Durbin model (SDM). The spatial Durbin model introduces endogenous interaction effects and exogenous interaction effects, which makes the parameter estimation results more robust (Case et al., 2004). Therefore, we choose the spatial Durbin model to investigate the spatial spillover effect of green investment on environmental pollution. The spatial Durbin model is constructed as follows:

$$pol_{it} = \alpha_0 + \rho \sum_{j=1}^{N} W_{ij}pol_{jt} + \alpha_1 gin_{it} + \alpha_2 \sum_{j=1}^{N} W_{ij}gin_{jt} + \sum_{k=1}^{6} \delta_k X_{it} + \mu_i + v_t + \varepsilon_{it} \tag{7}$$

Here, ρ is the spatial spillover coefficient of environmental pollution;$\alpha_0, \alpha_1, \alpha_2, \delta_k$ are the estimated coefficients;W_{ij} is the spatial weight matrix; and μ_i and v_t indicate the national effects and time effects, respectively. ε_{it} is called the idiosyncratic error term.

The spatial matrix construction method used in this paper is the binary 0–1 matrix method: if province i has a common boundary with province j, then $W_{ij}=1$; otherwise, $W_{ij}=0$. To avoid possible measurement error of the distance between the complete sample, following Combes (2000) and Wu et al. (2020), local spatial weight matrices with thresholds of 200 km, 400 km, 800 km, 1000 km, 1500 km, and 2000 km are set to test the impact of green investment on environmental pollution at different distances. The Moran index (Moran's I) is used to test whether the attribute value of the spatial units has spatial correlation overall. The formula for Moran' I is as follows:

$$I_{morans} = \frac{\mathrm{n} \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} \tag{8}$$

where $S^2 = \sum_{i=1}^{n} \left(x_i - \overline{x}\right)^2, \overline{x} = \frac{1}{\mathrm{n}} \sum_{i=1}^{n} x_i$. n denotes the total number of geographic units (i.e., provinces). The spatial correlation between provinces can be tested by the local Moran's I, and the formula is as follows:

$$I_i = \mathrm{Z}_i \times \sum_{j=1}^{n} w_{ij} z_j \tag{9}$$

where $z_i = \mathrm{x}_i - \overline{x}$ and $z_j = \mathrm{x}_j - \overline{x}$ are the deviations between the observed value and the mean, respectively.

To further analyze the mechanism through which green investment indirect impacts environmental pollution, we use the method of Baron and Kenny (1986) and introduce mediation variables. The mediation effect model is as follows:

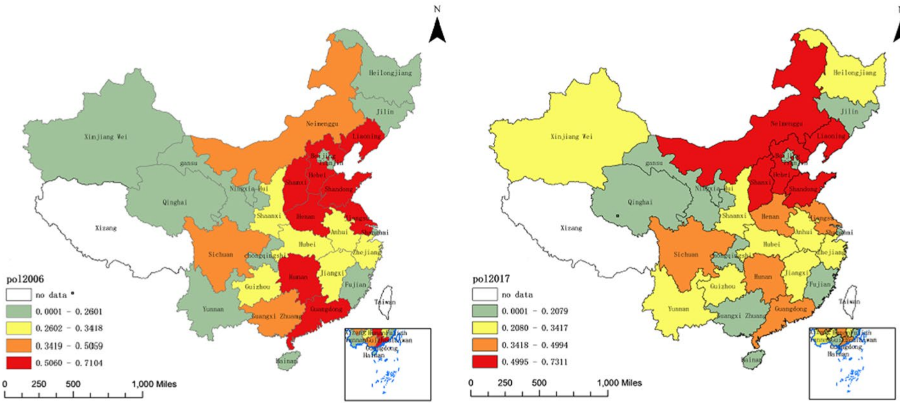


Fig. 2 China's comprehensive environmental pollution index in 2006 and 2017

$$pol_{it} = \gamma_0 + \gamma_1 gin_{it} + \sum_{k=2}^{6} \gamma_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{10}$$

$$med_{it} = \vartheta_0 + \vartheta_1 gin_{it} + \sum_{k=2}^{6} \vartheta_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{11}$$

$$pol_{it} = \varphi_0 + \varphi_1 gin_{it} + \varphi_2 med_{it} + \sum_{k=3}^{7} \varphi_k X_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{12}$$

Here, med_{it} is a mediation variable, including government energy savings and emission reduction efficiency $\left(eser_{it}\right)$, industrial structure upgrading $\left(str_{it}\right)$, and technological innovation $\left(invo_{it}\right)$. Formula (10) tests the impact of green investment on environmental pollution, formula (11) tests the impact of green investment on the mediation variables, formula (12) tests the impact of green investment and the mediation variables on environmental pollution, and formula (10), formula (11) and formula (12) jointly constitute the mediation effect model.

3.2 Explanation of Variables

1. Environmental pollution (pol_{it}). Referring to the method of Zhao et al. (2019a, b), a comprehensive environmental pollution index was constructed using the basic data of industrial wastewater, exhaust gas (SO2), smoke, dust and solid waste emissions. The entropy method is used to calculate the comprehensive index of China's environmental pollution (see Fig. 2).
2. Green investment. Most of the methods for measuring green investment are concentrated at the micro level of the enterprise, and there are few studies on measurement methods of provincial green investment. At present, many scholars directly use environmental pollution control investment as a substitute variable for green investment. However, in addition to environmental pollution control investment, the construction of infrastructure that can effectively prevent pollution is also an important aspect of green investment.

Referring to the method of Liao and Shi, three aspects of green investment are included in this study: environmental pollution control investment, water conservancy construction investment and forestry investment. Among them, environmental pollution control investment includes investments in industrial pollution control, urban environmental infrastructure construction and environmental components for new construction projects. This study sums the three aspects of investment and uses the fixed asset investment index to deflate them. *According to the statistical methods and dimensions, investment in urban environmental infrastructure construction comes entirely from government investment, industrial pollution control investment comes from government subsidies and internal corporate funds, and investment in environmental components for new construction projects comes entirely from corporate investment.*

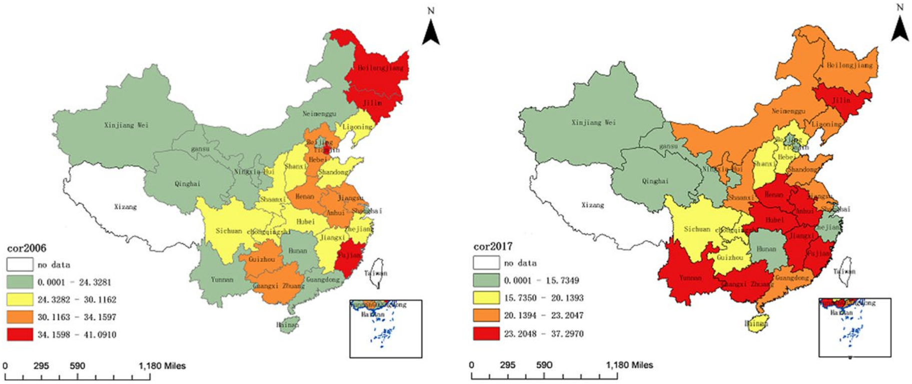
3. Mediation Variables. Energy savings and emission reduction efficiency $\left(eser_{it}\right)$, innovation efficiency $\left(invo_{it}\right)$ and industrial structure upgrading $\left(str_{it}\right)$ are selected as mediation variables to analyze the path through which green investment impacts environmental pollution. The Malmquist-Luenberger productivity index proposed by Chung et al. (1997) is used to measure regional energy savings and emission reduction efficiency. Among them, the input variables include capital stock (k), labor force (L) and energy consumption (EU) (Zhang et al., 2011). The desirable output is measured by the GDP of each province. To ensure the comparability of the data, we chose 2000 as the base year for price conversion. The undesirable output variables include wastewater discharge (WW), exhaust gas discharge (WG) and solid waste production (WS) (Wu et al., 2020). The specific measurement methods of each variable are shown in Table 1. This study refers to Han et al. (2019) and also summarizes the patent value released by the China Intellectual Property Office to represent the provincial technology innovation index. The upgrading of industrial structure is characterized by the ratio of the output value of tertiary and secondary industry (Yang et al., 2020).
4. Institutional Quality. Regional corruption (cor). Corruption can indirectly affect the environmental pollution of a country. On the one hand, corruption distorts environmental policies and weakens the "innovative compensation effect" of environmental regulation, which affects the governance effect on environmental regulation policies addressing pollution (Fredriksson and Svensson, 2003). On the other hand, corruption increases the rent-seeking cost of enterprises and has an adverse impact on green technology R&D and innovation (Pellegrini and Gerlagh, 2006). Considering the availability of data, this paper refers to Hao et al. (2020) and uses the number of public officials involved in corruption per 10,000 as a proxy variable for regional corruption (Fig. 3).

   Marketization level (mar). The degree of marketization is important because it affects the flow of factors. The degree of marketization can improve the efficiency of the allocation of innovative resources in the product and factor markets and reduce the potential for the misallocation of market resources. This paper draws on the research of He and Wu (2017) and mainly uses the marketization level, measured by the proportion of nonstate-owned enterprise employees (Fig. 4).

   Intellectual property protection (ipp). The intellectual property protection system can ensure the exclusive possession of R&D results, help companies achieve long-term competitive advantages, and stimulate competitors' enthusiasm for green technological innovation. Referring to the practice of Awokuse and Yin (2010), this study uses the ratio of technology market transaction volume to GDP to measure the level of intellectual property protection (Fig. 5).
5. Control Variables. Trade openness ($open_{it}$) is measured by the ratio of total imports and total exports in RMB and the GDP of each province (Kong et al., 2020). The level

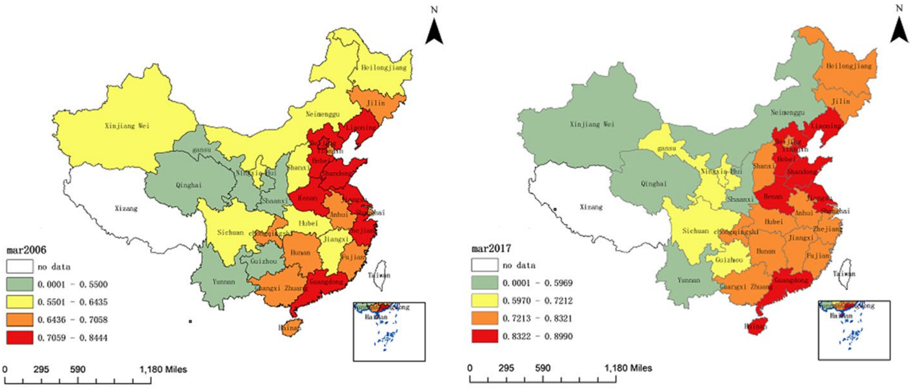
Table 1 Measurement of input and output variables

Attribute layer	First-class index level	Explanation of indicators	Measurement method
Input variable	Capital stock (K)	Reflect the construction of fixed assets	"Perpetual inventory method" applied to total fixed asset investment and price index of fixed asset investment data
	Labor (L)	Measure the number of laborers	Provincial employment data
	Energy consumption (EU)	Measure energy consumption	Total energy consumption data of each province
Desirable outputs variable	GDP	Reflect the level of interprovincial economic development	GDP data of each province
Undesirable output variable	Wastewater (WW)	Reflect wastewater discharge	Industrial wastewater discharge of each province
	Waste gas (WG)	Reflect the industrial waste gas emission	Industrial waste gas emission of each province
	Solid waste (WS)	Reflect the output of general industrial solid waste	Industrial waste gas production and general industrial solid waste production of each province



Cor Year 2006 Cor Year 2017

Fig. 3 China's regional corruption index in 2006 and 2017

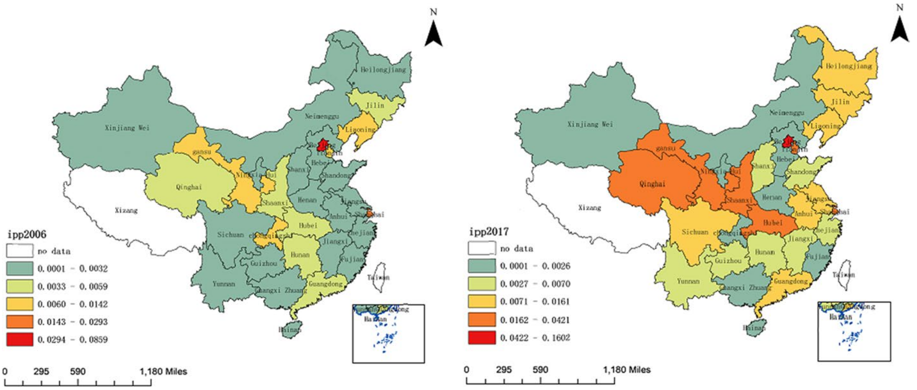


Mar Year 2006 Mar Year 2017

Fig. 4 China's marketization level in 2006 and 2017

of regional urbanization is measured by the proportion of the urban population in the total. Economic development (gdp_{it}) is represented by the GDP of each province. The R&D capital investment and R&D personnel investment in each province are used to measure R&D capital (rd_{it}) and R&D personnel (rdp_{it}), respectively (Wu et al., 2020).

This study selects panel data of 30 provinces in China from 2006 to 2017 (excluding data from Hong Kong, Macau, Taiwan and Tibet) as the research object. The relevant data in this study are from the "*China Statistical Yearbook*", "*China Hydropower Statistical Yearbook*", "*China Environmental Statistics Yearbook*", "*China Forestry Statistical Yearbook*", "*China Science and Technology Statistical Yearbook*", and China's provincial statistical yearbooks. See Table 2 for the descriptive statistics of the sample.



Ipp Year 2006 Ipp Year 2017

Fig. 5 China's intellectual property protection level in 2006 and 2017

Table 2 The statistical description of variables

Variable	Definition	Obs	Mean	SD	Min	Max	Unit
pol	Environmental pollution	360	0.3099	0.1877	0.0051	0.7610	-
gin	Green investment	360	0.3479	0.2782	0.0114	1.4764	Hundreds of billions yuan
rdp	R&D personnel investment	360	6.2481	8.9534	0.0085	45.7342	Ten thousand
rd	R&D capital investment	360	2.1496	3.2228	0.0040	18.6503	Ten billion yuan
gdp	Economic development	360	1.4276	1.2059	0.0638	6.6918	Trillion yuan
open	Trade openness	360	0.3122	0.3750	0.0086	1.7215	%
invo	Technological innovation	360	0.0974	0.1868	0.0006	1.3229	Ten thousand
str	Industrial structural upgrade	360	0.9980	0.5556	0.4996	4.2367	%
urb	Urbanization level	360	0.5353	0.1371	0.2745	0.8961	%
eser	Energy saving and emission reduction efficiency	360	0.6106	0.1687	0.2990	1.0000	-
cor	Regional corruption	360	24.7129	6.8828	7.8750	46.3227	Per 10,000 people
mar	Marketization level	360	0.7077	0.1059	0.4401	0.8990	%
ipp	Intellectual property protection	360	0.0105	0.0230	0.0002	0.1602	%

4 Empirical Results and Discussion

4.1 Estimation Result of the Basic Model

To test the relationship between green investment and environmental pollution, we first use the ordinary least squares (OLS) model, fixed effects (FE) model and random effects (RE) model to estimate the basic model formula (6). The regression results from the OLS, FE and RE models in Table 3 show that the regression coefficient of the core

Table 3 Estimation result of the basic model

Variable	OLS	FE	RE	FGLS	SYS-GMM
pol_{it-1}					0.923***
					(56.328)
gin	– 0.067**	– 0.038**	– 0.055***	– 0.062***	– 0.051***
	(– 2.053)	(– 2.347)	(– 3.075)	(– 10.879)	(– 5.361)
rdp	– 0.010***	– 0.005***	– 0.003**	– 0.010***	– 0.002*
	(– 3.707)	(– 3.475)	(– 2.288)	(– 21.414)	(– 1.940)
rd	– 0.042***	0.025***	0.007	– 0.042***	– 0.003
	(– 4.990)	(5.113)	(1.416)	(– 31.071)	(– 1.477)
gdp	0.278***	– 0.108***	– 0.018	0.277***	0.028***
	(14.445)	(– 5.769)	(– 0.964)	(93.947)	(3.906)
open	– 0.021	– 0.050**	– 0.021	– 0.016*	– 0.042***
	(– 0.726)	(– 2.243)	(– 0.903)	(– 1.855)	(– 3.318)
str	– 0.079***	0.002	– 0.003	– 0.081***	– 0.020**
	(– 5.455)	(0.153)	(– 0.217)	(– 13.528)	(– 2.524)
urb	– 0.327***	0.257***	– 0.097	– 0.333***	0.145***
	(– 4.111)	(2.782)	(– 1.048)	(– 16.404)	(2.904)
_cons	0.352***	0.327***	0.420***	0.353***	– 0.033**
	(9.517)	(9.478)	(10.207)	(33.896)	(– 2.147)
R2/Wald Test	0.5978	0.3487	0.2974	20,624.13***	48,952.23***
AR (1) /P-Value					– 3.30 (0.001)
AR (2) /P-Value					0.15 (0.877)
Hansen Test /p-Value					24.83 (0.991)
N	360	360	360	360	360

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Figures in () are the t-values or z-values or p-values

explanatory variable (gin) is negative, indicating that green investment can significantly reduce China's environmental pollution. To correct for any impact on the estimation results of possible heteroscedasticity and autocorrelation of the provincial individual perturbation terms, the feasible generalized least squares (FGLS) method is used to estimate the basic model formula (6). We found that the regression coefficients of the core explanatory variable (gin) are consistent with the results of the OLS, FE and RE models. Given that endogeneity problems between variables may lead to biased regression results, the generalized moment estimation method (two-step system GMM (SYS-GMM)) is selected to address endogeneity problems (Blundell and Bond, 1998). The regression results show that the P-values of AR(2) and the Hansen test are both greater than 0.1, indicating that there is no second-order serial correlation and that all instrumental variables are valid. The estimation results of SYS-GMM show that the lag term coefficient of environmental pollution is significantly positive, indicating that environmental pollution has significant path dependence characteristics. Moreover, the SYS-GMM estimate shows that for every 1% increase in green investment, environmental pollution will be reduced by 0.051%.

Table 4 Spatial correlation test

Time	0–1 adjacent matrix			Geographic distance matrix		
	I	z	p-value	I	z	p-value
2006	0.178**	1.764	0.039	0.125**	1.648	0.050
2007	0.175**	1.746	0.040	0.126**	1.657	0.049
2008	0.187**	1.841	0.033	0.132**	1.728	0.042
2009	0.195**	1.910	0.028	0.129**	1.696	0.045
2010	0.152**	1.555	0.060	0.125**	1.653	0.049
2011	0.167**	1.712	0.043	0.156**	2.012	0.022
2012	0.149*	1.556	0.060	0.158**	2.033	0.021
2013	0.135*	1.438	0.075	0.160**	2.050	0.020
2014	0.168**	1.708	0.044	0.161**	2.053	0.020
2015	0.194**	1.920	0.027	0.169**	2.128	0.017
2016	0.141*	1.496	0.067	0.137**	1.824	0.034
2017	0.099	1.126	0.130	0.125**	1.675	0.047

* *, * *, and * are significant at the 1%, 5% and 10% levels, respectively

4.2 Estimation Results of the Spatial Econometric Model

4.2.1 Spatial Correlation Test

Based on the spatial weight matrix, this paper further adopts the Moran index (Moran's I) in the global autocorrelation analysis to test the spatial correlation of environmental pollution. Table 4 shows the results of the global spatial correlation test of China's environmental pollution under the 0–1 adjacency matrix and geographic distance matrix. It shows that the global Moran's I of China's environmental pollution is positive and fluctuates in the range of 0.099–0.195, which indicates that environmental pollution in various provinces has significant positive spatial autocorrelation and spatial agglomeration.

4.2.2 Estimation Results of the Spatial Effect of Green Investment on Environmental Pollution

To ensure the robustness of the regression results, we report the regression results of different distance threshold matrices based on the adjacent weight matrix. From the perspective of the spatial autoregressive coefficient (rho), the spatial autoregressive coefficient of environmental pollution under the 0–1 adjacency matrix is positive and significant at the 1% level. This shows that environmental pollution has spatial effects in various provinces in China. Therefore, it is reasonable to choose a spatial measurement model in this study. The regression results in Table 5 show that the core explanatory variable green investment (gin) is significantly negative at the 1% level, indicating that as the total amount of green investment increases, regional environmental pollution will be alleviated to a certain extent. Green productivity formed by green investment is an essential input to realize the coordinated development of society and the environment (Hu et al., 2020). The impact of green investment on environmental pollution is mainly achieved through pollution control. On the one hand, green capital can be directly invested in "end-of-pipe treatment" by industry, such as sewage treatment plants and solid waste treatment companies, which can

Table 5 The regression results of the spatial Durbin model

Variables	W_1	W_{200km}	W_{400km}	W_{600km}	W_{800km}	W_{1000km}	W_{1500km}	W_{2000km}
gin	− 0.023*	− 0.045***	− 0.035**	− 0.029*	− 0.031**	− 0.032**	− 0.026*	− 0.024
	(− 1.648)	(− 3.026)	(− 2.294)	(− 1.820)	(− 2.039)	(− 2.149)	(− 1.774)	(− 1.630)
rdp	− 0.004***	− 0.002*	− 0.003**	− 0.004***	− 0.004***	− 0.005***	− 0.004***	− 0.003**
	(− 3.535)	(− 1.853)	(− 2.515)	(− 2.989)	(− 3.160)	(− 3.538)	(− 2.784)	(− 2.123)
rd	0.030***	0.018***	0.022***	0.023***	0.023***	0.024***	0.023***	0.022***
	(6.792)	(3.604)	(4.763)	(4.558)	(4.575)	(5.078)	(4.699)	(4.551)
gdp	− 0.108***	− 0.100***	− 0.107***	− 0.099***	− 0.095***	− 0.098***	− 0.105***	− 0.107***
	(− 6.113)	(− 5.632)	(− 6.068)	(− 5.079)	(− 5.099)	(− 5.322)	(− 5.531)	(− 5.810)
open	− 0.014	− 0.039*	− 0.022	− 0.043**	− 0.054**	− 0.046**	− 0.040*	− 0.035
	(− 0.676)	(− 1.710)	(− 1.026)	(− 1.961)	(− 2.558)	(− 2.218)	(− 1.868)	(− 1.645)
str	− 0.009	0.007	0.003	0.011	0.010	0.008	− 0.002	0.007
	(− 0.867)	(0.627)	(0.262)	(0.803)	(0.748)	(0.589)	(− 0.160)	(0.472)
urb	0.278**	0.192**	0.092	0.325***	0.450***	0.436***	0.300**	0.286**
	(2.322)	(2.142)	(1.004)	(3.027)	(3.677)	(3.749)	(2.089)	(2.015)
W*gin	0.010	0.061	0.002	− 0.001	0.015	0.010	0.005	0.048
	(0.332)	(1.022)	(0.069)	(− 0.038)	(0.492)	(0.308)	(0.091)	(0.769)
W*rdp	0.001	− 0.014***	− 0.005**	− 0.001	− 0.003	− 0.012***	− 0.002	− 0.001
	(0.515)	(− 3.272)	(− 2.275)	(− 0.294)	(− 0.931)	(− 3.441)	(− 0.407)	(− 0.196)
W*rd	− 0.017**	− 0.004	− 0.011	− 0.009	− 0.005	0.017	− 0.018	− 0.030
	(− 1.991)	(− 0.533)	(− 1.357)	(− 0.954)	(− 0.528)	(1.458)	(− 1.132)	(− 1.579)
W*gdp	0.019	0.083*	0.116***	0.040	0.011	− 0.035	0.029	0.092
	(0.642)	(1.818)	(3.498)	(1.263)	(0.307)	(− 0.830)	(0.486)	(1.338)
W*open	− 0.128***	− 0.053	− 0.141***	− 0.059	− 0.045	− 0.133**	− 0.068	− 0.074
	(− 2.876)	(− 1.088)	(− 3.420)	(− 1.383)	(− 0.939)	(− 2.432)	(− 1.055)	(− 0.990)
W*str	0.021	− 0.013	− 0.014	− 0.009	− 0.022	− 0.092***	0.001	0.030
	(1.061)	(− 0.345)	(− 0.837)	(− 0.377)	(− 0.898)	(− 3.028)	(0.020)	(0.616)
W*urb	0.048	0.113	− 0.392*	− 0.315	− 0.082	0.516	0.311	− 0.296
	(0.276)	(0.491)	(− 1.940)	(− 1.342)	(− 0.279)	(1.535)	(0.693)	(− 0.571)
Spatial rho	0.384***	− 0.051	0.060	0.091	0.187**	0.210**	0.364***	0.398***
	(6.344)	(− 0.510)	(0.942)	(1.369)	(2.559)	(2.451)	(3.596)	(3.824)
Variance sigma2_e	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(13.253)	(13.411)	(13.409)	(13.403)	(13.375)	(13.384)	(13.353)	(13.359)
Log− like	733.7967	706.9062	712.0126	698.6244	705.5189	715.9756	712.3422	714.5125
R^2	0.4317	0.3955	0.4125	0.3660	0.3843	0.4164	0.3926	0.3987
N	360	360	360	360	360	360	360	360

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Figures in () are the z-values of the coefficients

help reduce the generation of wastewater and solid waste at the source and reduce environmental pollution. On the other hand, green investment can also be used to invest in technology research and development enterprises, thereby catalyzing new processes and new products and improving the efficiency of pollutant treatment (Wang et al., 2020). Under different distance matrices, we find that the regression coefficient of green investment in the matrix range of W_{200km} to W_{2000km} gradually decreases and is not significant in the W_{2000km} matrix, indicating that as the distance increases, the emission reduction effect of green investment gradually weakens. In addition, except for the W_{600km} matrix, the regression coefficient of W*gin is estimated to be positive but not significant. This shows that there is no significant relationship between local green investment and the environmental pollution of neighboring areas. The possible reason is that the scale of green investment in China's provinces is relatively low, which makes the diffusion effect of green technological innovations not obvious (Li et al., 2020). Moreover, given that economic performance is an important criterion for the selection of Chinese officials, local officials often sacrifice the environment in exchange for economic benefits to obtain political promotion (Deng et al., 2019). This also makes it difficult for green technologies formed by green investment to spread on a large scale.

4.3 Estimation Results of the Mediation Effect

The influence of green investment on environmental pollution is complex and dynamic. To analyze whether green investment can reduce environmental pollution by improving the regional industrial structure, technological innovation capability, energy savings and emission reduction efficiency, this paper introduces the analysis of mediation effects. The regression results are shown in Table 6. The results of Model 1 show that green investment can reduce environmental pollution, which is consistent with the above research results.

Model 2 and Model 3 present the estimated results, with technological innovation as a mediation variable. Model 2 shows that green investment has a positive impact on regional technological innovation, which is consistent with the research conclusions of Shen et al. (2020). The results of Model 3 show that the coefficients capturing the influence of green investment and technological innovation ability on environmental pollution are both significantly negative. Therefore, green investment can reduce environmental pollution by improving regional technological innovation capability. Model 6 and Model 7 present the estimated results with energy conservation and emission reduction efficiency as mediation variables. Model 6 shows that green investment can significantly promote regional energy conservation and emission reduction efficiency (0.112); this result is consistent with the research conclusions of Li et al. (2020). The results of Model 7 show that the influence coefficients of energy conservation and emission reduction efficiency on environmental pollution are both significantly negative. Therefore, green investment can reduce environmental pollution by improving regional energy conservation and emission reduction efficiency. The reasons for the above results are as follows. First, green investment encourages enterprises to realize clean energy through substitution for fossil energy and optimize the energy consumption structure. Second, green investment has a technology spillover effect, enabling producers to improve production technology and reduce energy consumption per unit of output, thereby reducing energy consumption intensity (Sueyoshi and Wang, 2014). Finally, increased investment in green technology innovation will promote the continuous improvement of green emission reduction technology innovation, which can reduce the intensity of pollution emissions per unit of output value and reduce environmental pollution. In summary, green investment can optimize the energy consumption structure, reduce energy consumption intensity, and improve pollution treatment technology to reduce the intensity of pollution emissions during the entire production process (Wang et al., 2020).

Model 4 and Model 5 present the estimated results with industrial structural upgrades as a mediation variable. Model 4 shows that the coefficient of green investment is positive, indicating that green investment can promote the upgrading of the regional industrial structure. The results of Model 5 show that the influence coefficients of green investment

Table 6 The regression results of the mediation effect model

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	pol	invo	pol	str	pol	eser	pol
invo			− 0.255*** (− 4.529)				
str					− 0.079*** (− 5.455)		
eser							− 0.327***
							(− 4.295)
gin	− 0.103***	0.057*	− 0.089***	0.452***	− 0.067**	0.024**	− 0.100***
	(− 3.09)	(1.849)	(− 2.718)	(3.860)	(− 2.053)	(2.041)	(− 3.072)
rdp	− 0.008***	− 0.000	− 0.009***	− 0.024**	− 0.010***	− 0.003***	− 0.006**
	(− 2.94)	(− 0.153)	(− 3.055)	(− 2.345)	(− 3.707)	(− 3.214)	(− 2.282)
rd	− 0.049***	0.047***	− 0.037***	0.091***	− 0.042***	0.007**	− 0.052***
	(− 5.70)	(5.938)	(− 4.220)	(3.016)	(− 4.990)	(2.111)	(− 6.174)
gdp	0.297***	− 0.035*	0.288***	− 0.233***	0.278***	− 0.028***	0.304***
	(15.05)	(− 1.929)	(14.918)	(− 3.366)	(14.445)	(− 2.969)	(15.735)
open	− 0.058**	0.024	− 0.052*	0.469***	− 0.021	− 0.110***	− 0.006
	(− 1.99)	(0.902)	(− 1.826)	(4.560)	(− 0.726)	(− 13.675)	(− 0.179)
urb	− 0.045***	0.353***	− 0.360***	1.548***	− 0.327***	0.806***	− 0.293***
	(− 5.67)	(4.828)	(− 4.514)	(5.545)	(− 4.111)	(20.782)	(− 3.419)
_cons	0.340***	− 0.168***	0.297***	0.149	0.352***	0.451***	0.421***
	(8.86)	(− 4.750)	(7.712)	(1.109)	(9.517)	(16.704)	(10.035)
N	360	360	360	360	360	360	360

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Figures in () are the t-values of the coefficients

Table 7 The threshold value of different threshold variables and the confidence interval

Threshold variable	Dynamic threshold model	Threshold value	Wald statistics	P-value	BS	95% confidence interval	
						Lower	Higher
Cor	SYS-GMM	20.9547	0.0426***	0.0000	1000	14.2270	37.9846
Mar	SYS-GMM	0.8047	1.3787***	0.0000	1000	0.53072	0.8653
Ipp	SYS-GMM	0.0267	0.9565***	0.0000	1000	0.0005	0.0307

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The probability is evaluated based on 1,000 replications of the regression. The confidence interval estimation of the threshold parameter is based on the method of Hansen (1999)

and industrial structure upgrades on environmental pollution are significantly negative. Therefore, green investment can reduce environmental pollution by upgrading the industrial structure. Green investment can achieve low carbon upgrading of the industrial structure. First, the government, as the main body of green investment, can not only increase financial support for green industries by formulating financial policies such as loans, taxes, and subsidies but also send consumers a signal to prioritize environmental protection and stimulate their environmental awareness. In particular, certain tax reductions and subsidies are given to consumers for buying green products so that they are more inclined toward environmentally friendly products and thereby promote the development of green industries. Second, green investment can reduce the financing costs of environmental protection industries, guide capital flow to green industries, and increase financial support for green industries and those engaged in environmental protection (Liao, 2018). Finally, to adapt to more stringent environmental regulation policies, companies will inevitably choose to increase environmental investment, develop green industries, eliminate polluting industries and achieve green upgrading of industrial structure (He et al., 2019). In summary, green investment can not only directly reduce environmental pollution but also indirectly improve it by improving technological innovation, energy savings, emission reduction efficiency and industrial structure upgrades.

4.4 The Estimation Results of the Dynamic Threshold Panel Model

To test whether the impact of green investment on environmental pollution is affected by regional corruption, the marketization level and the intellectual property protection level, referring to the study of Wu et al. (2019), this paper establishes a dynamic threshold panel model to test for a nonlinear relationship. Table 7 shows the results with the threshold and confidence interval. According to Wald statistics and the P values, we find that all threshold variables pass the threshold significance test, and the impact of green investment on environmental pollution is affected by regional corruption, the level of marketization and intellectual property protection. The p-value of AR (2) and the Hansen test in Table 8 show that there is no serial correlation in the model error term and that the instrumental variables are effective.

Corruption is treated as a threshold variable to analyze the impact of green investment on environmental pollution. The result shows that with the increase in corruption, the inhibitory influence of green investment on environmental pollution becomes smaller. The possible reason is that regional corruption suppresses the willingness of

Table 8 Regression results of the dynamic threshold panel models

Variable	Cor SYS-GMM	Mar SYS-GMM	Ipp SYS-GMM
pol_{it-1}	0.9173***	0.9347***	0.8440***
	(21.77)	(30.78)	(17.40)
rdp	− 0.0019***	− 0.0020***	− 0.0066***
	(− 5.59)	(− 6.06)	(− 8.12)
rd	− 0.0015	0.0003	− 0.0032
	(− 0.39)	(0.10)	(− 0.79)
gdp	0.0299*	0.0239*	0.0796***
	(1.72)	(1.83)	(4.46)
open	− 0.0283***	− 0.0280***	− 0.0311**
	(− 6.81)	(− 5.29)	(− 2.29)
urb	0.0261**	0.0385	0.1092*
	(0.83)	(1.31)	(1.66)
$\boldsymbol{gin}(\boldsymbol{q} \leq \boldsymbol{C})$	− 0.0406**	− 0.0312***	− 0.0912***
	(− 2.04)	(− 3.13)	(− 5.17)
$\boldsymbol{gin}(\boldsymbol{q} > \boldsymbol{C})$	− 0.0335***	− 0.0355***	− 0.3753***
	(− 2.91)	(− 2.80)	(− 3.46)
_cons	0.0007	− 0.0073	− 0.0316
	(0.04)	(− 0.44)	(− 0.96)
AR(1)	− 3.22	− 3.26	− 3.17
	[0.001]	[0.001]	[0.002]
AR(2)	0.13	0.05	0.01
	[0.900]	[0.961]	[0.995]
Hansen test	27.09	27.36	26.09
	[0.964]	[0.961]	[0.974]
Wald test	485,724.65***	456,183.27***	7230.17***
	[0.000]	[0.000]	[0.000]
N	360	360	360

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Figures in () are the z-values of the coefficients, and those in [] are the p-values of the corresponding test statistics

enterprises to invest in production activities, increases their preference for inputs in nonproductive activities, and causes distortions in the allocation of enterprise factors (Wu et al., 2020). Since the reform and opening up, China has established a market economy system through a series of market-oriented reforms. However, local governments still dominate the allocation of resources, which inevitably become a tool for local officials to seek personal gain. In particular, the government's excessive regulation and corruption often drive companies to spend excessive time and money dealing with officials, which in turn squeezes their capital investment in production and green technology innovation (Arbatskaya and Mialon, 2020). It is predictable that given a serious level of regional corruption, the scale of green investment by enterprises will be further reduced, which will have an adverse impact on environmental pollution.

Improvement of the marketization level can increase the negative influence of green investment on environmental pollution. An important reason is that green investment is affected by many factors, among which the market environment is particularly important. In theory, an increase in marketization can improve the efficiency of regional resource allocation and also diversify corporate green investment risk, which is conducive to increasing corporate willingness to make green investments (Leitch and Davenport, 2005). The improvement of marketization can reduce the information asymmetry faced by enterprises, which not only enables them to obtain investment information in a timely and comprehensive manner but also can reduce the cost of financing information search (Zhao et al., 2019a, b). Second, the improvement of marketization will reduce the degree of government intervention in enterprise production. Higher economic freedom, lower barriers to entry and less government intervention can guide enterprises to allocate more factors to production and technology R&D activities and improve their level of green technology (Yuan et al., 2020). Finally, an increase in the degree of marketization can improve the efficiency of capital allocation in the financial market and promote free competition among financial institutions, which is conducive to reducing the cost of green financing for enterprises and stimulating their enthusiasm to innovate in environmental protection technology (Callon, 2017).

When the level of marketization and financial development exceeds the threshold, green investment will gradually increase its inhibitory effect on environmental pollution. The main reason is that the legal environment can significantly affect the investment behavior of enterprises, and a higher level of intellectual property protection is conducive to protecting the innovative achievements of investors (Pisano, 2006). Moreover, a higher level of intellectual property protection reduces the risk of information asymmetry and infringement. The intellectual property protection system can ensure the exclusive possession of R&D project results to a certain extent, help companies gain long-term market competitive advantages, and stimulate companies to improve the efficiency of green technology innovation activities (Jennewein, 2006).

4.5 Regional Heterogeneity

The above empirical results show that green investment can significantly reduce China's environmental pollution. However, due to China's vast land area, different regions have different technological innovation capabilities, economic gaps, climate change effects, and environmental pollution (Bao et al., 2011). These objective conditions may cause the impact of green investment on environmental pollution to vary greatly in different regions. Referring to Wu et al. (2020), the research samples are divided into eastern, central and western regions. The regression results of the different regions in Table 9 show that green investment has the greatest inhibitory effect on environmental pollution in the eastern region, followed by the central region, while the western region has the least impact. Combined with the actual situation in different regions of China, a possible reason is that green investment has different characteristics from ordinary investment, and its main goal is to obtain environmental benefits. The current level of economic development in the western region of China is still far lower than that in the eastern region, and the investment demand for economic development is greater. Once green investment in the western region occupies too many investment resources, it will weaken the financial support for other industries, resulting in insufficient economic growth momentum. Moreover, the ecological environment in the western region is relatively fragile, and it undertakes the transfer of polluting industries from the eastern region, which leads to

Table 9 The estimation results for regional heterogeneity

Variable	SYS-GMM Eastern Region	SYS-GMM Central Region	SYS-GMM Western Region
L.pol	0.915***	0.932***	0.854***
	(75.575)	(94.008)	(89.731)
East_gin	− 0.040***		
	(− 6.164)		
Middle_gin		− 0.029***	
		(− 3.215)	
West_gin			− 0.019***
			(− 3.695)
rdp	− 0.003***	− 0.001***	− 0.007***
	(− 7.605)	(− 5.615)	(− 14.486)
rd	− 0.003***	− 0.003*	0.005***
	(− 2.684)	(− 1.760)	(7.102)
gdp	0.038***	0.025***	0.050***
	(7.763)	(4.366)	(12.483)
open	0.005	− 0.026***	− 0.008
	(0.683)	(− 2.832)	(− 0.947)
urb	0.003	0.009	− 0.183***
	(0.108)	(0.554)	(− 4.323)
_cons	− 0.008	0.002	0.104***
	(− 0.606)	(0.225)	(4.530)
AR(1)	− 3.26	− 3.23	− 3.13
	[0.001]	[0.001]	[0.002]
AR(2)	0.03	− 0.08	− 0.19
	[0.979]	[0.938]	[0.849]
Hansen test	26.37	23.75	23.62
	[0.335]	[0.741]	[0.909]
Wald test	989,150.21***	252,860.29***	91,721.26***
	[0.0000]	[0.0000]	[0.0000]
N	360	360	360

***, **, and * indicate significance at the 1%, 5%, and 10% levels; standard errors are in parentheses. Figures in () are the z-values of the coefficients, and those in [] are the p-values of the corresponding test statistics

a smaller effect of green investment in reducing pollution. In contrast, the eastern region is superior to the central and western regions in its economic development, talent concentration, technological innovation, pollution treatment technology, and industrial structure. Therefore, the environmental and economic benefits per unit of green investment are more significant than those of the whole country.

4.6 Robustness Test

To further improve the reliability of the above research conclusions, we also conducted the following robustness tests. (1) Considering that economic factors are important factors affecting

Table 10 Regression results of robustness test

Variable	pol	waste water	PM2.5	Smoke and dust	So_2
	Economic matrix		Geographic distance matrix		
gin	– 0.034**	– 3.735***	– 0.154***	– 0.086*	– 0.013
	(– 2.265)	(– 3.967)	(– 4.758)	(– 1.710)	(– 0.285)
rdp	– 0.005***	0.144*	0.007**	– 0.003	0.008*
	(– 3.637)	(1.858)	(2.524)	(– 0.683)	(1.901)
rd	0.030***	0.034	0.028***	0.025	– 0.025
	(6.350)	(0.116)	(3.574)	(1.607)	(– 1.589)
gdp	– 0.140***	4.644***	– 0.220***	– 0.070	– 0.138**
	(– 7.786)	(3.959)	(– 10.747)	(– 1.111)	(– 2.120)
open	– 0.040*	1.276	0.078**	– 0.073	– 0.121*
	(– 1.914)	(0.979)	(2.212)	(– 1.036)	(– 1.806)
urb	0.504***	– 0.944	– 0.733***	– 0.420	– 0.643
	(3.807)	(– 0.100)	(– 6.577)	(– 0.988)	(– 1.426)
Spatial_rho	0.083	– 0.210*	1.558***	0.626***	0.605***
	(0.980)	(– 1.924)	(37.360)	(11.292)	(9.721)
sigma2_e	0.001***	3.962***	0.012***	0.014***	0.011***
	(13.411)	(13.351)	(15.099)	(12.360)	(12.227)
R^2	0.4304	0.5737	0.0446	0.2945	0.6798
N	360	360	360	360	360

***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. Figures in () are the z-values of the coefficients

environmental pollution and green investment, we replaced the spatial weight matrix and used the economic distance weight matrix to re-estimate the relationship between green investment and environmental pollution. The relevant results are shown in Table 10. The estimation results show that under the economic distance weight matrix, the direction and significance of the impact of green investment on environmental pollution are basically the same as in the adjacent weight matrix, indicating that the estimation result of the spatial Durbin model is reliable. (2) The new dependent variables selected include wastewater, haze pollution (PM2.5), smoke and dust and sulfur dioxide (So_2). The estimated coefficient of green investment is significantly negative, indicating that the increase in green investment can reduce the emissions of the three pollutants. In terms of the degree of impact, the coefficients of green investment under different pollutants are different, and green investment has the greatest inhibitory effect on wastewater. However, we also found that the effect of green investment on reducing sulfur dioxide (So_2) is not obvious. In summary, we believe that the regression results of this article are robust.

5 Conclusion and Policy Recommendations

Based on China's provincial panel data from 2006 to 2017, a spatial econometric model is used to analyze the impact of green investment on environmental pollution. The research conclusions are as follows. Green investment can significantly reduce local environmental pollution, but it has no impact on environmental pollution in neighboring areas. This conclusion is still valid after a series of robustness tests. Green investment can reduce environmental pollution by improving technological innovation, upgrading the industrial structure, enhancing energy conservation and increasing emission reduction efficiency. In addition, the relationship between green investment and environmental pollution is affected by regional corruption, the level of marketization and intellectual property protection. With the further improvement of the marketization and intellectual property protection levels, the restraining effect of green investment on environmental pollution becomes more obvious. A higher degree of regional corruption can lead to a gradual decrease in the role of green investment in reducing environmental pollution. According to the above empirical results, we propose some policy recommendations.

1. China's economy is developing rapidly, but the environmental effects are being ignored, which leads to frequent environmental pollution incidents. However, the green economy in China is still in its infancy, and it is far behind that of developed countries. Green innovation is crucial in promoting the green transformation of the economy, and expanding green investment requires the government to play its role. Local governments need to increase expenditures on environmental protection and perform their functions well. Communication and cooperation between local governments and administrative departments should be strengthened so that green capital can be invested in reasonable industries. It is necessary to established relevant green funds to increase the scale of green investment throughout society and reduce the green financing costs of enterprises to provide financing guarantees for the development of environmental protection-related industries. In addition, companies should take the initiative to strengthen green investment, increase investment in green technology, promote cleaner production, focus on environmental issues and increase investment in this area in the investment decision-making process. Citizens should also pay attention to environmental protection in daily consumption and other economic activities and support products from green industries in the consumption process.
2. Green investment should be made rationally according to local conditions. The research in this paper finds that green investment has a positive effect on China's environmental quality overall, but there is significant regional heterogeneity. Therefore, when the government specifies green investment policies, it is necessary that it formulate corresponding policies based on the economic development of different regions and local conditions and conduct green investment rationally to ensure green, healthy and efficient economic development in the various regions. According to the empirical results of this article, green investment in China can reduce environmental pollution, but the efficiency of green investment is still low, especially in western China. Therefore, local governments can actively learn from the advanced experience of foreign environmental protection investment based on national conditions, formulate a reasonable green investment plan, create a good environment for green investment, and improve investment efficiency.
3. The research in this paper finds that the corrupt behavior in government gradually weakens the inhibitory effect of green investment on environmental pollution. There-

fore, to avoid distortions in the allocation of green resources, it is necessary to actively promote market-oriented reforms and give full play to the leading role of the market in the allocation of energy resources. In terms of political system reform, it is necessary to promote the transformation of government functions and cancel the administrative approval items that hinder the development of green industries. Establishing and improving preventive, punitive and supervisory mechanisms can also increase the cost of corruption and reduce its incidence and benefits. In addition, the government should actively promote financial system processes, actively guide financial capital and social capital toward green industries, and form a diversified green capital investment system. Financial institutions should increase environmental protection awareness and improve laws and standards for green credit, green securities and green insurance. Moreover, according to the 2014–2015 Global Competitiveness Report, China ranks 53rd in the world in the intellectual property protection index. Therefore, local government departments can improve the legal environment for enterprise innovation by strengthening the enforcement of intellectual property rights protection, thereby enhancing the enthusiasm of enterprises for green technology innovation and realizing the transformation of regional economic development methods.

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Authors and Affiliations

Siyu Ren[1] · Yu Hao[2,3,4,5,6] · Haitao Wu[2,3]

Siyu Ren
rensiyuking@126.com

Haitao Wu
haitao.kungfuer@gmail.com

1 Present Address: School of Economics, Nankai University, Tianjin 300071, China

2 Present Address: School of Management and Economics, Beijing Institute of Technology, Zhongguancun South Street, Haidian District, Beijing 100081, China

3 Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China

[4] Sustainable Development Research Institute for Economy and Society of Beijing, Beijing 100081, China

[5] Yangtze Delta Region Academy of Beijing Institute of Technology, Jiaxing 314001, China

[6] Beijing Key Lab of Energy Economics and Environmental Management, Beijing 100081, China