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Pollution heaven or pollution halo? Assessing the role of heterogeneous environmental regulation in the impact of foreign direct investment on green economic efficiency

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Abstract

As the main engine of the global economy, China has been attracting increasing foreign direct investment (FDI) since the 1980s. The frequent occurrence of pollution incidents by multinational companies and the continuous deterioration of the environment have prompted China to attach importance to environmental regulations and attempt to avoid the potential pollution heaven effect of FDI on green development. To assess the effectiveness of these environmental regulations,this paper investigates the moderating effect of environmental regulation, in particular, the heterogeneous environmental regulatory tools, on the relationship between FDI and green economic efficiency. In addition, the spatial performance of these moderating effects is examined through the Spatial Durbin Model (SDM), using China's provincial panel data from 2004 to 2018. The results show that environmental regulation has an overall positive moderating effect, exacerbating the pollution heaven effect of FDI on green economic efficiency. In the meantime, the moderating effects of heterogeneous environmental regulations are obviously different, i.e., command-and-control and public-participation-based environmental regulations have positive moderating effects, while market-based environmental regulation has a negative moderating effect. In addition, in terms of spatial performance, the market-based environmental regulation has a positive spillover effect, thereby promoting green economic efficiency in surrounding regions, which is contrary to command-and-control and public-participation-based environmental regulations. Based on the above findings, this paper makes some recommendations for policymakers.

Keywords: green economy efficiency; FDI; environmental regulation; moderating effect; SDM model

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1 Introduction

Since 1978, China has created an unprecedented growth miracle, and gradually become a key engine of world economic growth. As of 2020, China has made the largest contribution to the world economic growth for 15 consecutive years and it was expected that the contribution would reach 25% in 2021 (The Beijing News 2022; Paper net 2022). During the process, China has attracted increasing FDI with its vast market and abundant resources. In 2021, China attracted $173.48 billion in FDI, up 20.2% from last year, ranking second in the world in terms of inward FDI (MOC Ministry of Commerce 2021). It is noteworthy that the increasing FDI can be a double-edged sword. On the one hand, it has promoted China's rapid economic growth by contributing capital, technology and so on (Hu and Xu 2020; Fu and Lin 2021). However, on the other hand, it can worsen the ecological environment through reckless production. Several incidents have shown that FDI may bring a "pollution heaven" effect[1] to China's green development, for example, the illegal discharge of Jiangsu Prince Paper[2], the pollution of the production line of Apple's supply chain in China[3], *etc*. The pollution incidents of these multinational companies have caused growing

[1] The "pollution heaven" effect refers to pollution-intensive industries that tend to move to countries or regions with relatively low environmental standards, resulting in waste of resources and environmental degradation in the host country.

[2] Paper net. 2009. Prince paper pollution threatens 1.14 million people in Qidong. Available from: http://www.paper.com.cn/news/daynews/2009/091013134728904760.htm. Accessed 06 May 2022

[3] Sohu net. 2011. Workers in Apple's supply chain have been crippled by n-hexane poisoning. [Online]. Available from: http://news.sohu.com/20110218/n279399190.shtml. Accessed 06 May 2022

concern to the Chinese government. FDI may achieve the win-win of promoting economic growth and improving the environment in the presence of favorable institutional environment (Chaudhry et al. 2021).

Consequently, in recent years China has launched a number of environmental regulation policies to avoid the possible negative effect of FDI. In 2017, the General Office of the State Council issued a *ban on the entry of foreign garbage to promote the implementation of the reform of the solid waste import management system,* which completely prohibits the entry of foreign waste. In 2019, the Standing Committee of the National People's Congress (NPC) passed the first *Resource Tax Law of the People's Republic of China* imposing resource taxes on any Sino-foreign cooperation that exploits land or offshore oil resources. In 2020, the Standing Committee of the NPC revised for the second time *the Solid Waste Pollution Prevention and Control of the Environment Law* with an aim to protect the ecological environment via strengthening the system and tightening the law.

The implementation of these environmental regulation policies may affect the size, industrial distribution, entry mode, and location selection of FDI (Yu and Li 2020). However, it has been questioned whether these policies can successfully guide FDI to bring about a "pollution halo" effect[4]on China’s green development. Can environmental regulation moderate the effectiveness of FDI on green economic efficiency[5] ? How do the moderating effects of heterogeneous environmental regulatory tools differ? Furthermore, given the spatial characteristics of the environment, what is the spatial performance of the moderating effect of environmental regulation on FDI and green economic efficiency? It is necessary to answer all these questions in order to optimize the source structure of FDI, enhance China's environmental regulation system, realize a green transformation of China's economy, and contribute China's strength to the green development of the world economy.

The remainder of the paper is organized as follows: Section 2 reviews the related literature; Section 3 describes the theoretical framework and establishes the research hypothesis; Section 4 introduces the methodology and the data; followed by the empirical results presented in Section 5; Section 6 discusses the findings and the last section concludes the paper with some recommendations.

2 Literature Review

2.1 Foreign direct investment and green economic efficiency

The technological spillover effects of FDI on host countries’ productivity have been demonstrated in many counties, such as the UK (Liu et al. 2000), Zambia (Bwalya 2006), and China (Du et al. 2012). Since the emergence of the concept of sustainable development, the impact of FDI on the host country’s environment has received increasing attention. Whether this influence is positive or negative depends on the combined effects of scale, structure, and technology[6] (Grossman and Krueger 1991). Recently, FDI has been shown to have a more complex impact on

[4] The "pollution halo" effect refers to the inflow of FDI with advanced production processes, technology levels, management concepts, etc., contributing to host country efficiency and environmental improvements.

[5] Green economic efficiency is a comprehensive index to measure economic, social, and environmental development, which is an important indicator to measure the level of green development (Shuai and Fan 2020; Zhao et al. 2020; Zhao et al. 2021).

[6] The scale effect means that FDI promotes the host country's economic growth, but also consumers a lot of resources, thus affecting the environmental situation (Chandio et al. 2020; Xie et al. 2020; Zeng et al. 2020).

the environment. Based on the panel data of 76 countries, Muhammad et al. (2021) concluded that FDI from developed countries improved the environment in the low and low-middle income countries, nonetheless FDI from developing countries damaged the environment in the low, low-middle, and high-middle income countries. Especially in China, Yang et al. (2019) found that FDI and industrial environmental efficiency had a U-shaped relationship and FDI was located on the left side of the U-shape, which weakens the industrial environmental efficiency. Both using the spatial Durbin model, Zhao et al. (2020) indicated that FDI had a significant positive impact on green economic efficiency, but Feng et al. (2021) concluded that the effect was not obvious.

2.2 Environmental regulation and green economic efficiency

Environmental regulation also affects regional productivity, which was originally named the "cost of compliance argument" (Boyd and Mcclelland 1999; Gray and Shadbegian 2003). The positive effect of environmental regulation on regional productivity is established when the phenomenon of technological innovation stimulated by environmental regulation offsets or even exceeds costs, as stated in the "Porter Hypothesis" (PH) (Porter 1991; Porter and Van der Linde 1995). With the deepening of research, the concept of green economic efficiency began to be used to analyze the actual impact of environmental regulation on economic productivity (Qian and Liu 2015; Song et al. 2017). Qiu and Wang (2018) used the Super-SBM model with undesired outputs to calculate green economic efficiency, pointing out that environmental regulation has a positive impact on industrial eco-efficiency, and the spatial spillover effect of environmental regulation on industrial eco-efficiency is significant, which is consistent with the findings of Li and Du (2020). Zheng et al. (2020) also supported the presence of the PH in China's marine economy. More recently, however, a few scholars have found that there are significant differences in the impact of heterogeneous environmental regulations on green economic efficiency. Zhang and Song (2021) found that market-based environmental regulation was more effective than command-and-control environmental regulation in improving the energy and environmental efficiency of metal industries in China. Yin et al. (2022) indicated that command-and-control environmental regulation had a positive effect on the green economic efficiency of the manufacturing industry in the Yangtze River Economic Zone, while public-participation-based environmental regulation did not.

2.3 Environmental regulation, foreign direct investment, and green economic efficiency

Many existing studies on the relationship between FDI and environmental regulation have provided theoretical support for China's continuous efforts to strengthen environmental regulation and avoid the negative impact of FDI on green economic efficiency (Santos and Forte 2021). These studies show that while harsh environmental regulations sometimes deter foreign investment (Wu 2007; Fu and Li 2010), they do prevent the entry and expansion of high-emitting multinational companies (Tang 2019; Lv and Mao 2020). It is also worth noting that if the host country's environmental regulations are more relaxed, it will attract FDI from polluting industries (Dong et al. 2021). In

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The structural effect means that FDI promotes the development of clean industries or the expansion of polluting industries in the host country and thus changes its industrial structure, which brings about environmental improvement (Ayamba et al. 2019; Zhou and Zhang 2021) or deterioration (Liu et al. 2021; Nejati and Taleghani 2022).

The technology effect means that FDI brings about more advanced pollution control technologies and clean production processes, which might improve the environment (Demena and Afesorgbor 2020; Wu et al. 2021).

addition, Yu and Li (2020) provided more direct evidence that strict environmental regulations could improve the quality of FDI, thereby preventing China from becoming a “pollution heaven”. However, there are clear differences in the impact of heterogeneous environmental regulations on FDI’s quality upgrading. Lei et al. (2021) showed that command-and-control environmental regulation inhibited FDI’s technological spillover and exacerbated FDI pollution, while market-based environmental regulation reduced FDI pollution.

Recently, a few studies have attempted to integrate FDI, environmental regulation, and green economic efficiency into one framework to test whether environmental regulation affects the impact of FDI on green economic efficiency, nonetheless no consensus has been reached. Fu et al. (2018) argued that environmental regulation always increased the contribution of FDI to green total factor productivity, whereas Wang et al. (2020) showed that FDI could only promote green economic efficiency when environmental regulation was more stringent.

After reviewing the related literature, we found that: firstly, the existing studies have assessed environmental regulation based on a single indicator (Wu 2007; Zheng et al. 2020) or a comprehensive indicator (Fu et al. 2018; Wu et al. 2020; Zhang and Song 2021), which cannot avoid the defects such as one-sidedness of a single indicator or over-generalization of comprehensive indicators. Secondly, in the very limited literature (Fu et al. 2018; Wang et al. 2020), there is a lack of systematic studies on the moderating effects of environmental regulation on the relationship between FDI and green economic efficiency. Thirdly, most existing studies using non-spatial econometric models ignore the role of inter-regional factor mobility[7] and thus lead to biased estimates.

Therefore, the main contributions of this paper are as follows: firstly, the index system of environmental regulation is designed to fully reflect the intensity of environmental regulation in China. We integrate FDI, environmental regulation, and green economic efficiency into one framework by constructing an interaction term of FDI and environmental regulation, so as to preliminary determine the moderating effect of environmental regulation on the relationship between FDI and green economic efficiency. Secondly, we further divide environmental regulation into three types: command-and-control environmental regulation, market-based environmental regulation, and public-participation-based environmental regulation, and analyze the differences in the effects of heterogeneous environmental regulations. Thirdly, a spatial econometric model is adopted to capture the spatial correlation between FDI, environmental regulation, and green economic efficiency to reduce the bias in estimates in the existing studies.

3 Theoretical framework and research hypothesis

[7]The implementation of environmental policies among local governments faces a game of "race to the top" or "race to the bottom". Meanwhile, FDI not only has an impact on local environmental efficiency, but also has an impact on the surrounding areas' environmental efficiency by spillover effects (Long et al. 2020).

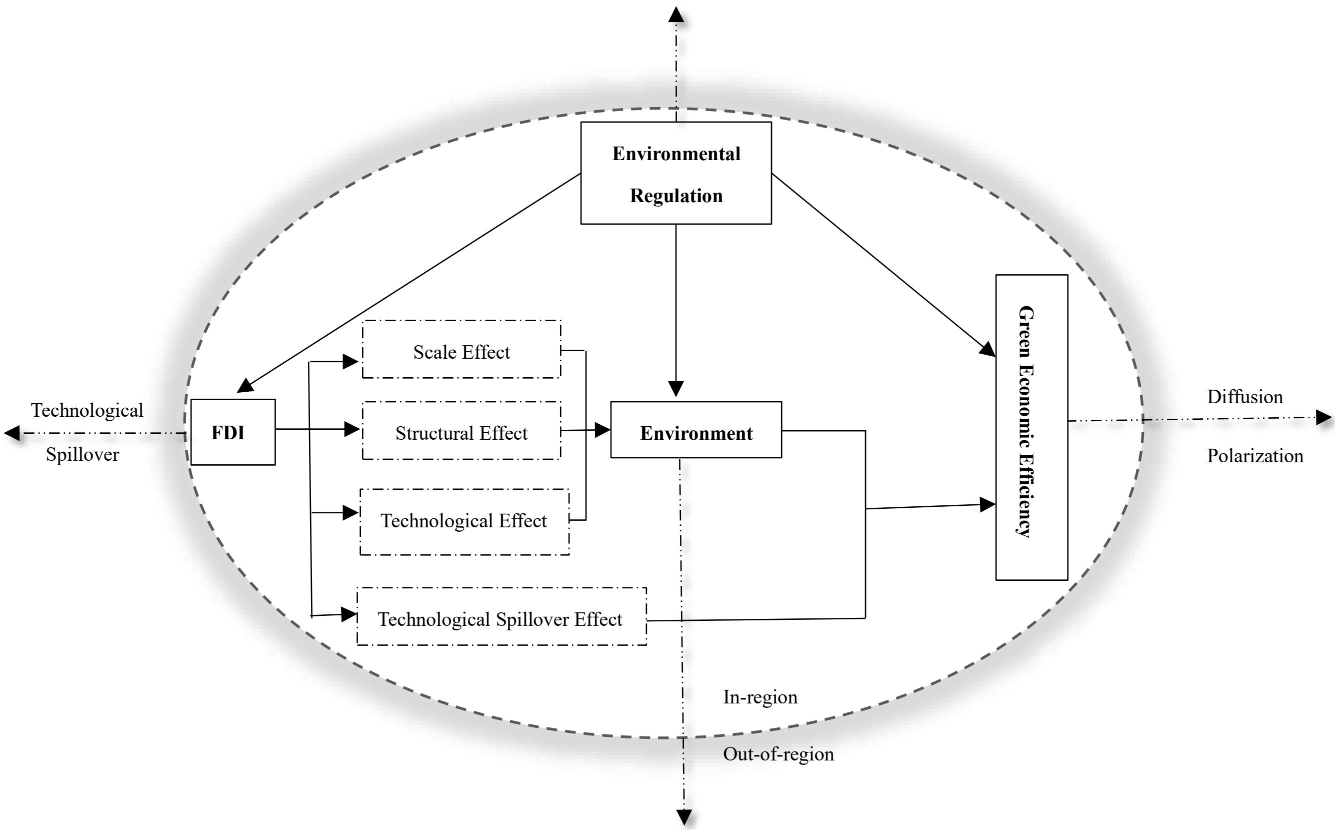

Fig. 1 Mechanism of FDI, environmental regulation, and green economic efficiency

Source: Author's own

As shown in Fig.1, FDI improves green economic efficiency through technological spillover, that is, domestic companies acquire advanced technologies through competition, human mobility, and industrial linkages with multinational enterprises, which affects the environment through scale, structural, and technological effects, and in turn affects the green economic efficiency, resulting in the "pollution heaven" or "pollution halo". Moreover, environmental regulation not only influences green economic efficiency via compliance costs and technological innovation, but also affects FDI’s size, quality, entry patterns, and industrial distribution. Furthermore, it may also affect the technological spillover and environmental impact of FDI on green economic efficiency. Therefore, we propose the following hypothesis:

H1: Environmental regulation has a moderating effect on the relationship between FDI and green economic efficiency.

China has initially established a three-dimensional system, that is, command-and-control, market-incentive, and public-participation-based environmental regulatory tools. And each tool has significant differences in application conditions, mechanism of action, implementation costs, *etc*. In particular, command-and-control environmental regulation is mandatory and implemented quickly, but their low flexibility imposes high compliance costs for multinational companies. Market-based environmental regulation induces multinational companies to internalize the externalities of pollution emissions, thereby incentivizing them to innovate in green technologies, but it requires a robust market to be effective. Public-participation-based environmental regulation relies on public awareness of environmental protection and is relatively inexpensive to implement, but it is not mandatory. Therefore, we propose the following hypothesis:

H2: Heterogeneous environmental regulations have varying moderating effects on the relationship between FDI and green economic efficiency.

In addition, environmental regulation may promote the spatial linkage of green economic efficiency with the "diffusion effect" and "polarization effect" through the screening effect, and internal or external technological spillover (Qian and Liu 2014). Meanwhile, given the strong externalities and spatial diffusion of the environment, many of China's environmental policies are implemented collaboratively between regions. For instance, the *Action Plan for the Comprehensive Treatment of Air Pollution in Beijing, Tianjin, Hebei, and Surrounding Areas in Autumn and Winter 2019-2020* was jointly issued by sixteen authorities in 2019; the *Yangtze River Delta Regional Ecological Environment Co-Protection Plan* was issued by the Ministry of Ecology and Environment in 2020. Therefore, we propose the following hypothesis.

H3: The moderating effects of environmental regulation on the relationship between FDI and green economic efficiency have spatial spillover effects.

4 Methodology and data

4.1 Super-SBM model

Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are two common methods to measure economic efficiency (Sun et al. 2020; Sun et al. 2021). The DEA model has been adopted by many scholars because it does not require artificial preset weights and production functions (Shuai and Fan 2020; Zhao et al. 2020; Ma and Liu 2021; Zheng et al. 2021; You and Xiao 2022). Meanwhile, the Super-SBM model with undesired output, attached to the DEA model, can solve not only the radial and angular size deviations of the traditional DEA model (BBC model and CCR model), but also the unrankable problem of the SBM model for simultaneous efficient decision-making units (DMUs) (Asmild et al. 2004). Thus, we adopt the Super-SBM model with undesired output to measure green economic efficiency. The formula is given as follows:

$$\vartheta^* = \min \frac{\frac{1}{m}\sum_{i=1}^{m} \bar{x}_i / x_{i0}}{\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \frac{\bar{y}_r^g}{y_{r0}^g} + \sum_{j=1}^{s_2} \frac{\bar{y}_j^b}{y_{j0}^b}\right)}$$

$$\text{s.t.} \quad \begin{cases} \bar{x} \geq x_0\,, \bar{y}^g \leq y_0^g\,, \bar{y}^b \geq y_0^b \\ S^- \geq 0,\ S^g \geq 0,\ S^b \geq 0,\ \bar{y}^g \geq 0,\ \lambda \geq 0 \\ x_0 = X\lambda + S^-\,, y_0^g = Y^g\lambda - S^g,\ y_0^b = Y^b\lambda + S^b \\ \bar{x} \geq \sum_{j=1,\neq 0}^{n} \lambda_j x_j\,,\ \bar{y}^g \leq \sum_{j=1,\neq 0}^{n} \lambda_i y_j^g,\ \bar{y}^b \geq \sum_{j=1,\neq 0}^{n} \lambda_j y_j^b \end{cases} \tag{1}$$

There are n DMUs, each of which has m inputs ($x = (x_1, x_2, \dots, x_m) \in R^m$), s_1 desired outputs ($y^g = \left(y_1^g, y_2^g, \dots, y_{s_1}^g\right) \in R^{s_1}$) and s_2 undesired outputs ($y^b = \left(y_1^b, y_2^b, \dots, y_{s_1}^b\right) \in R^{s_1}$). S^-, S^g and S^b are the slack variables of input vectors, desired output vectors, and undesired output vectors, respectively. λ is the weight vector.

ϑ^* is the measured efficiency of the DMUs. It is relatively inefficient as $0 < \vartheta^* < 1$and efficient as $\vartheta^* \geq 1$.

Input-output indices of green economic efficiency (*lnecc*) are presented in Table 1. Following the existing literature (Zhou et al. 2019; Shuai and Fan 2020; Xin et al. 2020, Sun et al. 2020), inputs include labor, capital, and resources, which are represented by the number of employees, fixed capital stock, and total energy consumption, respectively. Outputs are both desired and undesired. The desired output is generally referred to the GDP. And we adopt the entropy method to integrate the total sulfur dioxide emissions, industrial wastewater discharge, and common industrial solid waste generation as a proxy of the undesired output.

Table 1 Input-output indices

Indicators	Statistical variables						
	Inputs			Outputs			
	Labor	Capital	Resources	Desired output	Undesired outputs		
	Employees (10^6 persons)	Fixed capital stock[8] (10^9 CNY)	Total energy consumption (10^6 tons standard coal)	GDP (10^9 CNY)	Total sulfur dioxide emissions (10^6 tons)	Industrial wastewater discharge (10^6 tons)	Common industry solid waste generation (10^6 tons)
Mean	2601.88	20768.01	12816.30	13322.65	65.46	70330.82	8715.56
Max	6767.00	73882.45	38899.00	71091.60	200.30	296318.00	48445.00
Min	296.60	1945.19	742.48	466.10	0.99	3544.00	112.00
Median	2079.74	15482.73	10595.50	9968.43	55.66	44821.50	6227.00
Standard deviation	1714.83	16232.01	8161.22	12230.23	44.14	61416.10	8284.11

4.2 Spatial econometric model

Spatial econometric models mainly include the spatial lag model (SLM), spatial error model (SEM), and spatial Durbin model (SDM). The SDM model is more general because it not only captures the spatial correlation between dependent variables and spatial spillover effects of independent variables, but also considers the interaction effects of endogenous, exogenous, and autocorrelated terms (Lesage and Pace 2009; Zhao et al. 2020). Its normal form is given as follows.

$$Y = \rho WY + \alpha l_n + X\beta + WX\theta + \varepsilon \quad (2)$$

where $Y \in R^{n\times 1}$ is the dependent variable matrix; $W \in R^{n\times n}$ is the spatial weight matrix; $\alpha l_n \in R^{n\times 1}$ is the constant term matrix; $X \in R^{n\times k}$ is the independent variable matrix; β is the independent variable coefficient; ρ、θ are the spatial lag term coefficients; and ε is the random error term.

4.2.1 Spatial weight matrix

A suitable spatial weight matrix is the basis of a spatial econometric model, and there are three common matrices as 0-1 matrix, economy-distance matrix, and geography-distance matrix. With the booming development of

[8] The fixed capital stock was calculated by the perpetual inventory method of Shan (2008), and the depreciation rate was taken as 10.96%.

transportation, Internet 5G+ and big data in China, inter-regional factors flow and knowledge spillovers are more subject to economic gaps rather than geographical distance. Hence, we construct a nested economy-information matrix considering the difference in economic development and informatization levels[9] among regions. The formulae are given as follows.

$$W = W_F \times diag(\bar{I}_1/\bar{I}, \bar{I}_2/\bar{I}, \dots\dots\dots, \bar{I}_n/\bar{I}) \qquad (3)$$

$$W_F = \begin{cases} \frac{1}{|\bar{Y}_i - \bar{Y}_j|} & , i \neq j \\ 0 & , i = j \end{cases} \qquad (4)$$

Where W_F is the economy-distance matrix; $\bar{Y}_i$、$\bar{Y}_j$ are the average value of GDP per capita of the regions *i* and *j* from 2004 to 2018, respectively; $\bar{I}$ is the average value of postal service per capita in 30 provinces in China from 2004 to 2018; and $\bar{I}_i$ is the average value of postal service per capita in region *i* from 2004 to 2018.

4.2.2 Spatial Durbin model

We initially construct the SDM models (5) and (6) [10] to identify the moderating effect of environmental regulation on the relationship between FDI and green economic efficiency as well as its spatial performance. In these models, green economic efficiency (*lnecc*) is set as the explained variables, while the FDI (*lnfdi*), environmental regulation (*lner*), and its interaction term (*lnfdi*lner*) as the explanatory variables. If the coefficient of the interaction term passes the significance test, it indicates moderating effect exists.

$$ln\, ecc_{it} = \alpha + \rho \sum_{j=1}^{n} w_{ij}\, ln\, ecc_{jt} + \beta_1\, ln fdi_{it} + \beta_2\, ln\, er_{it} + \beta_\tau\, ln\, Z_{it} +$$

$$\theta_1 \sum_{j=1}^{n} w_{ij}\, lnfdi_{jt} + \theta_2 \sum_{j=1}^{n} w_{ij}\, ln\, er_{jt} + \theta_\tau \sum_{j=1}^{n} w_{ij}\, ln\, Z_{jt} + \varepsilon_{it} \quad (5)$$

$$ln\, ecc_{it} = \alpha + \rho \sum_{j=1}^{n} w_{ij}\, ln\, ecc_{jt} + \beta_1\, ln fdi_{it} + \beta_2\, ln\, er_{it} + \beta_3\, ln fdi_{it} * ln\, er_{it} + \beta_\tau\, ln\, Z_{it} +$$

$$\theta_1 \sum_{j=1}^{n} w_{ij}\, lnfdi_{jt} + \theta_2 \sum_{j=1}^{n} w_{ij}\, ln\, er_{jt} + \theta_3 \sum_{j=1}^{n} w_{ij}\, ln fdi_{jt} * ln\, er_{jt} + \theta_\tau \sum_{j=1}^{n} w_{ij}\, ln\, Z_{jt} + \varepsilon_{it} \quad (6)$$

Given the heterogeneity of the regulatory effects of the three environmental policies, we further extend models (5) and (6) to models (7) and (8).

$$ln\, ecc_{it} = \alpha + \rho \sum_{j=1}^{n} w_{ij}\, ln\, ecc_{jt} + \beta_1\, ln fdi_{it} + \beta_2\, ln\, er\eta_{it} + \beta_\tau\, ln\, Z_{it} +$$

$$\theta_1 \sum_{j=1}^{n} w_{ij}\, lnfdi_{jt} + \theta_2 \sum_{j=1}^{n} w_{ij}\, ln\, er\eta_{jt} + \theta_\tau \sum_{j=1}^{n} w_{ij}\, ln\, Z_{jt} + \varepsilon_{it} \quad (7)$$

$$ln\, ecc_{it} = \alpha + \rho \sum_{j=1}^{n} w_{ij}\, ln\, ecc_{jt} + \beta_1\, ln fdi_{it} + \beta_2\, ln\, er\eta_{it} + \beta_3\, ln fdi_{it} * ln\, er\eta_{it} + \beta_\tau\, ln\, Z_{it} +$$

$$\theta_1 \sum_{j=1}^{n} w_{ij}\, lnfdi_{jt} + \theta_2 \sum_{j=1}^{n} w_{ij}\, ln\, er\eta_{jt} + \theta_3 \sum_{j=1}^{n} w_{ij}\, ln fdi_{jt} * ln\, er\eta_{jt} + \theta_\tau \sum_{j=1}^{n} w_{ij}\, ln\, Z_{jt} + \varepsilon_{it} \quad (8)$$

where *i* and *j* represent provinces; *t* represents the year; α denotes a constant term; η is the type of environmental

[9] Referring to Zhang et al. (2018a), Li and Yang (2019), and Jiang (2019), this paper used the total postal and telecommunication services/number of population (postal and telecommunication services per capita) to indicate the level of informatization in each region.

[10] Referring to Fang et al. (2015), we constructed the interaction terms after decentering *lnfdi, lner, lner*η respectively to guarantee the coefficient of FDI and environmental regulations are still meaningful after adding the interaction term together with weakening the multicollinearity.

regulation (η=1, 2, 3); Z is the control variable.

4.3 Data

Based on the existing studies and the availability of data, we build an environmental regulation index system considering government, market, and public (see Table 2), to which the weights are objectively assigned by the entropy method to synthesize the composite index of environmental regulations (*lner; lnerη*). More specifically, command-and-control environmental regulation, i.e. the government protects the environment by promulgating laws and regulations and other mandatory means, is mainly measured by the amount of investment in industrial pollution control, the number of environmental laws and regulations, and the emission of pollutants (Shen et al. 2019; Zhang and Li 2021; Chen and Leng 2022). Market-incentive environmental regulation, i.e. the government uses the invisible hand of the market to stimulate enterprises to carry out environmental governance, is mainly captured by the sewage charges, and environmental protection taxes (You and Ooyang 2020; Zhang and Song 2021; Wang et al. 2022). Public-participation-based environmental regulation that relies on public environmental awareness to protect the environment, is generally measured by the education level, the population structure, the number of CPPCC proposals, and so on (Yuan and Xie 2014; Gao et al. 2019; Chen and Leng 2022).

Table 2 Environmental regulation index system

	Types	Indicator Compositions	Unit
Environmental regulation (*lner*)	Command-and-control environmental regulation (*lner1*)	Completed investment in the treatment of industrial pollution/Added values of industries	%
		Common industrial solid waste comprehensive utilization rate	%
		COD discharged/Total volume of wastewater discharged	%
	Market-incentive environmental regulation (*lner2*)	Pollution discharge fees/GDP	%
		Resource tax/Tax revenue	%
		Tax on vehicles and boat operation/Tax revenue	%
	Public-participation-based environmental regulation (*lner3*)	Population ratio of 15-64 years old[11]	%
		Number of NPC suggestions and CPPCC proposals undertaken	piece
		Percentage of employees with education level of college or above[12]	%

In addition, we use the ratio of actual utilization of FDI to GDP as a proxy of the FDI variable (*lnfdi*). Then, the interaction terms of FDI and environmental regulations (*lnfdi*lner, lnfdi*lnerη*) are formed to capture the moderating effects of environmental regulations on the relationship between FDI and green economic efficiency. According to the Environmental Kuznets Curve (EKC) (Panayotou 1993), several factors may influence the environment, which are selected as control variables. We use the per capita GDP to indicate economic development level (*lngdpper*), the ratio of industrial output to GDP to indicate industrial structure (*lnis*), and the ratio of urban population to the total regional population to indicate urbanization (*lnurban*) (Wu et al. 2020; Wen and Zhang 2020; Wu 2021).

Taking full account of the availability and comparability of data, we use the panel data of 30 provinces in China

[11] The 15-64 years old population ratio was used to measure the capability of the public to participate.

[12] The percentage of employed persons with education level of college or above was used to reflect the education level of the public. Generally, the higher the education level of the public, the stronger the environmental awareness (Yuan and Xie 2014).

(excluding Tibet, Hong Kong, Macau, and Taiwan) from 2004 to 2018 as the sample[13]. All the data is from the China Statistical Yearbook (2005-2019), the China Environmental Statistical Yearbook (2005-2019), the China Energy Statistical Yearbook (2005-2019), the China Labor Statistical Yearbook (2005-2019), and the Statistical Yearbooks, as well as the National Bureau of Statistics and the WIND database. All variables are adopted as their natural logarithm for processing potential heteroscedasticity. Moreover, the variables with price factors are converted to constant prices in 2004 by the GDP price index.

5 Empirical Results

5.1 Green economic efficiency

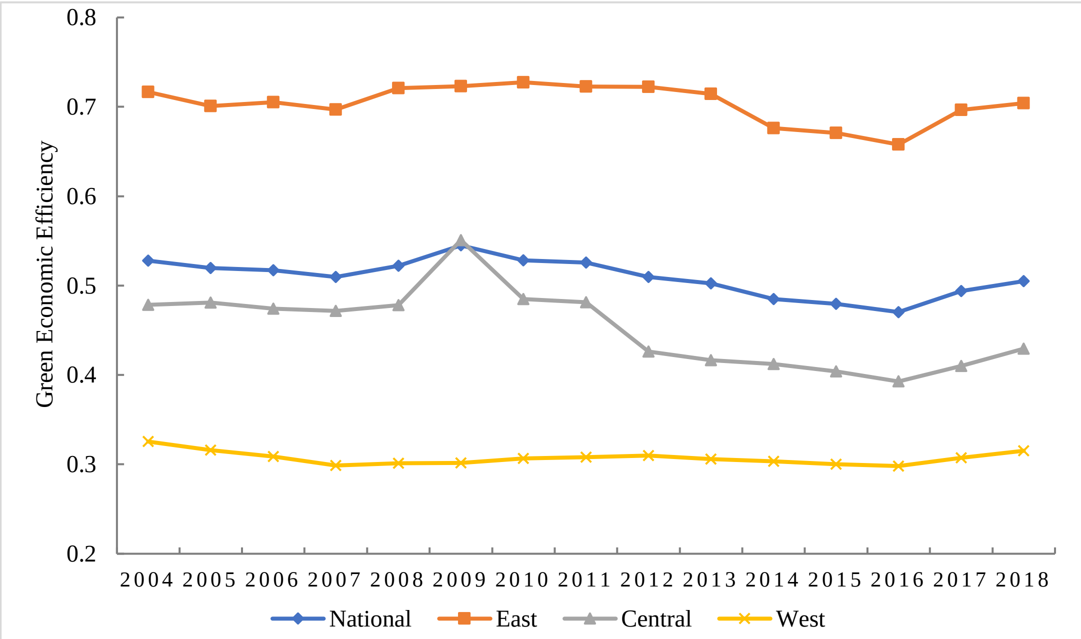

Fig. 2 Time-series chart of green economic efficiency in China, 2004-2018.

In the time dimension (see Fig. 2), green economic efficiency presents a trend of first downward and then upward. During the early period, China's resource-for-growth development model pulled down the green economic efficiency. With the formulation of the five development concepts of innovation, coordination, green, openness, and sharing in the *13th Five-Year Plan for National Economic and Social Development of the People's Republic of China (2016-2020)*, China's resource and the environmental situation has improved, and green economic efficiency began to pick up in 2016.

[13] Since the statistical standards of many Chinese environmental regulation indicators have changed significantly in 2018, such as the pollution discharge fees were implemented in July 2003 and abolished in January 2018, etc., thus we selected data from the time interval of 2004-2018 for empirical analysis to maintain the continuity and comparability of data.

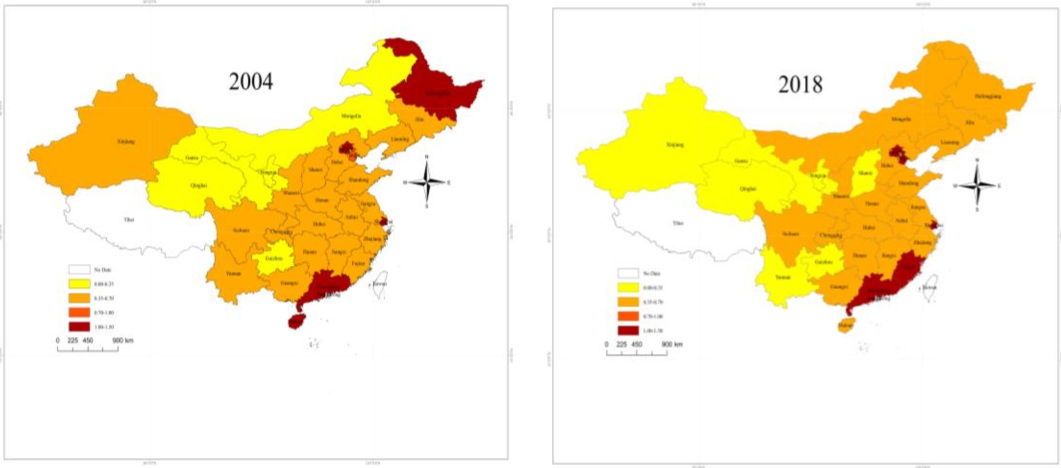

Fig. 3 Spatio-temporal maps of green economic efficiency in China, 2004 and 2018

In the spatial dimension (see Fig. 3), the trend of green economic efficiency ladder is the highest in the eastern region, the middle in the central region, and the lowest in the western region. With the continuous advancement of China's regional economic integration process, the green economic efficiency of the three regions shows a trend of convergence, i.e., club convergence, but the ladder-like trend of Eastern-Central-Western decreasing is more noticeable.

5.2 Spatial correlation tests

Based on the 0-1 matrix, geographic-distance matrix, economic-distance matrix, and economic-information matrix, we first measure the global Moran's I of green economic efficiency in China and all show positive at the significance level of 1% (see Table 3), indicating green economic efficiency has a significant positive spatial correlation. In addition, thanks to the rapid development of big data, the Internet, and transportation in China, the temporal and spatial barriers of factor flow have been broken, and the setting of economic information matrix is more reasonable.

Table 3 Global Moran'I of green economic efficiency in China from 2004 to 2018

Year	0-1 Matrix		Geography-distance Matrix		Economy-distance Matrix		Economy-information Matrix	
	Moran'I value	P-value	Moran'I value	P-value	Moran'I value	P-value	Moran'I value	P-value
2004	0.421***	0.000	0.238***	0.004	0.261***	0.005	0.309***	0.001
2005	0.411***	0.000	0.234***	0.005	0.243***	0.008	0.290***	0.002
2006	0.425***	0.000	0.254***	0.002	0.258***	0.005	0.307***	0.001
2007	0.424***	0.000	0.257***	0.002	0.267***	0.004	0.315***	0.001
2008	0.456***	0.000	0.306***	0.000	0.284***	0.002	0.334***	0.001
2009	0.384***	0.001	0.266***	0.002	0.238**	0.010	0.279***	0.004
2010	0.456***	0.000	0.313***	0.000	0.288***	0.002	0.337***	0.001
2011	0.390***	0.001	0.306***	0.000	0.322***	0.001	0.384***	0.000
2012	0.415***	0.000	0.324***	0.000	0.393***	0.000	0.469***	0.000
2013	0.406***	0.000	0.321***	0.000	0.393***	0.000	0.470***	0.000
2014	0.408***	0.000	0.342***	0.000	0.418***	0.000	0.500***	0.000
2015	0.403***	0.000	0.338***	0.000	0.421***	0.000	0.505***	0.000
2016	0.388***	0.001	0.328***	0.000	0.418***	0.000	0.503***	0.000

2017	0.378***	0.001	0.303***	0.000	0.363***	0.000	0.444***	0.000
2018	0.366***	0.001	0.305***	0.000	0.363***	0.000	0.443***	0.000

Note: ***, **, * indicate passing the significance test of 1%, 5%, 10%, respectively.

We calculate the local Moran's I of green economic efficiency based on the economy-information matrix and drew its LISA (Local Indicators of Spatial Association) clustering chart. As shown in Fig.4, the overall high-high and low-low spatial agglomeration dynamics of green economic efficiency in China are becoming increasingly significant. In addition, high-high agglomeration is in the eastern regions, and low-low agglomeration is in the mid-western regions.

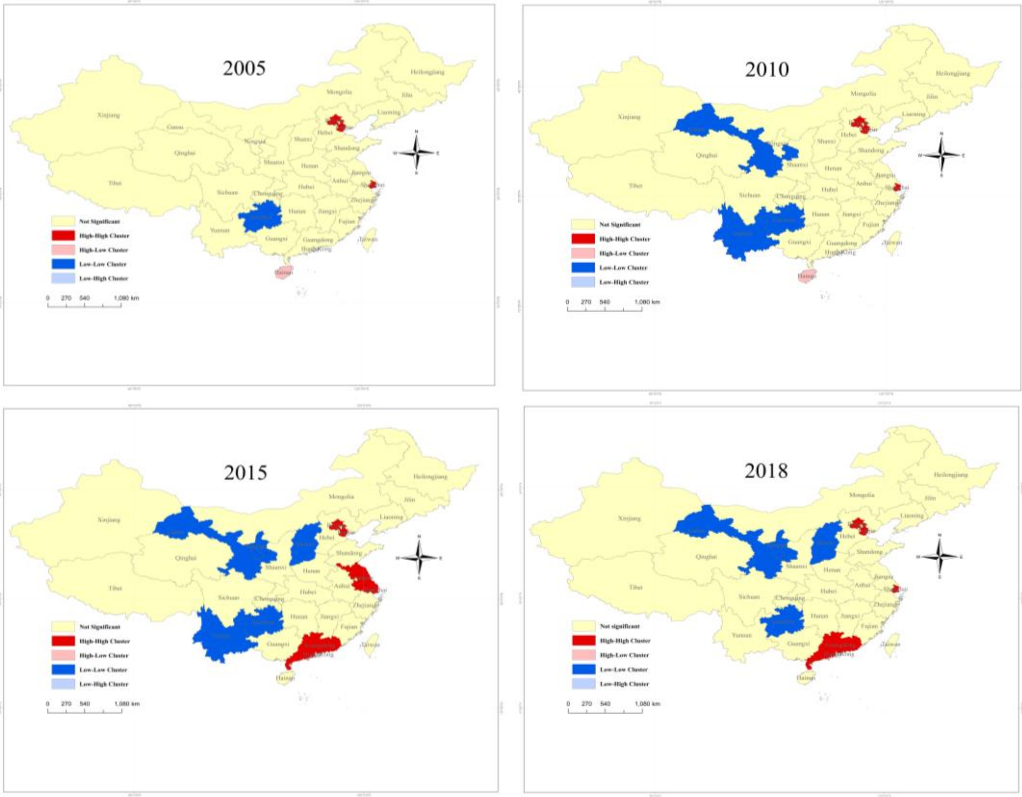

Fig. 4 LISA clustering chart of green economic efficiency in China[14]

Finally, the LM (Lagrange Multiplier), Wald, and LR (Likelihood-ratio) tests are adopted to identify the specific form of the spatial econometric model, all of which reject the null hypothesis and the SDM model degrades to the SEM model and SLM model at the 1% significance level (see Table 4). Hence, the SDM model is established. The SDM model of random effects and fixed effects are selected according to Hausman statistics for estimating the models (5)-(8). The regression results are presented in Table 4.

[14]Areas with no data for Tibet, Taiwan, Hong Kong, and Macau are classified as Not Significant.

5.3 Regression of the SDM model

Table 4 SDM model regression results

Variables	Models (5) and (6)				Models (7) and (8)			
	(*lner*)		(*lner1*)		(*lner2*)		(*lner3*)	
	Non-interactive item	Plus-interactive item	Non-interactive item	Plus-interactive item	Non-interactive item	Plus-Interactive item	Non-interactive item	Plus-interactive item
lnfdi	-0.034***	-0.029***	-0.045***	-0.041***	-0.036***	-0.061***	-0.043***	-0.058***
	(0.011)	(0.010)	(0.013)	(0.012)	(0.010)	(0.017)	(0.014)	(0.015)
lner	-0.068**	-0.093***						
	(0.032)	(0.027)						
*lnfdi*lner*		-0.011***						
		(0.004)						
lner1			-0.045**	-0.058***				
			(0.019)	(0.019)				
*lnfdi*lner1*				-0.011***				
				(0.003)				
lner2					-0.041	-0.008		
					(0.056)	(0.057)		
*lnfdi*lner2*						0.021**		
						(0.008)		
lner3							-0.043*	-0.031
							(0.024)	(0.024)
*lnfdi*lner3*								-0.051**
								(0.024)
lngdpper	0.380**	0.347**	0.747***	0.400**	0.398**	0.923***	0.793***	0.918***
	(0.171)	(0.160)	(0.221)	(0.178)	(0.191)	(0.220)	(0.240)	(0.240)
lngdpper2	0.032*	0.035*	0.034**	0.022	0.029	0.039**	0.039**	0.042**
	(0.018)	(0.018)	(0.017)	(0.015)	(0.019)	(0.018)	(0.019)	(0.018)
lnis	0.409***	0.393***	0.383**	0.398***	0.410***	0.416***	0.408**	0.429***
	(0.138)	(0.137)	(0.157)	(0.136)	(0.149)	(0.157)	(0.161)	(0.148)
lnurban	0.824**	0.855***	0.541*	0.804**	0.869**	0.477	0.564*	0.436
	(0.321)	(0.327)	(0.314)	(0.332)	(0.353)	(0.315)	(0.331)	(0.288)
*W*lnfdi*	-0.026	-0.035	-0.019	-0.039	-0.028	-0.064*	-0.019	-0.053
	(0.042)	(0.041)	(0.041)	(0.037)	(0.042)	(0.034)	(0.039)	(0.034)
*W*lner*	0.005	0.010						
	(0.022)	(0.034)						
*W*lnfdi*lner*		0.000						
		(0.006)						
*W*lner1*			-0.011	-0.018				
			(0.014)	(0.014)				
*W*lnfdi*lner1*				-0.005				
				(0.004)				
*W*lner2*					0.048	0.129**		
					(0.066)	(0.061)		
*W*lnfdi*lner2*						0.026**		
						(0.011)		
*W*lner3*							-0.019	-0.024
							(0.036)	(0.034)
*W*lnfdi*lner3*								-0.058**
								(0.024)
*W*lngdpper*	-0.307*	-0.315**	-0.662***	-0.363**	-0.309*	-0.794***	-0.696***	-0.887***
	(0.161)	(0.143)	(0.237)	(0.161)	(0.186)	(0.249)	(0.257)	(0.265)
*W*lngdpper2*	0.031	0.036	0.008	0.029	0.028	-0.001	0.006	-0.000
	(0.022)	(0.023)	(0.018)	(0.018)	(0.022)	(0.020)	(0.018)	(0.018)
*W*lnis*	-0.221	-0.195	-0.190	-0.169	-0.161	-0.004	-0.201	-0.095

	(0.135)	(0.129)	(0.145)	(0.118)	(0.137)	(0.135)	(0.143)	(0.112)
*W*lnurban*	-1.350***	-1.258***	-1.121**	-1.216***	-1.269***	-0.631	-0.979**	-0.574
	(0.426)	(0.391)	(0.457)	(0.416)	(0.385)	(0.406)	(0.442)	(0.406)
ρ	0.315***	0.311***	0.272***	0.271***	0.336***	0.249***	0.284***	0.222***
	(0.062)	(0.060)	(0.067)	(0.058)	(0.063)	(0.062)	(0.068)	(0.055)
R^2	0.480	0.486	0.495	0.496	0.460	0.504	0.481	0.511
N	450	450	450	450	450	450	450	450
fe/re	re	re	fe	re	re	fe	fe	fe
LM-lag	233.16***	232.71***	256.06***	256.84***	194.04***	168.58***	245.37***	235.07***
LM-error	93.53***	93.69***	122.74***	123.30***	85.81***	82.78***	129.98***	144.84***
R-LM-lag	149.21***	148.54***	138.82***	139.02***	110.86***	86.13***	116.73***	90.56***
R-LM-error	9.58***	9.52***	5.50**	5.48**	2.63	0.32	1.34	0.34
LR-lag	141.15***	139.72***	161.64***	135.22***	135.20***	181.04***	155.07***	171.34***
LR-error	124.63***	125.72***	146.45***	128.61***	120.40***	165.57***	138.86***	160.38***
Wald-lag	160.74***	157.46***	195.48***	149.54***	148.64***	222.79***	186.37***	208.64***
Wald-error	77.34***	76.51***	90.39***	81.47***	73.11***	110.30***	84.35***	108.67***
Hausman	9.50	2.09	12.07*	10.11	8.43	30.02***	12.90**	32.83***

Note: ***, **, * indicate passing the significance test of 1%, 5%, 10%, respectively. Parentheses are standard errors.

Table 4 shows that the spatial lag terms (ρ) are positive at the significance level of 1%. To some extent, it indicates the SDM models have good applicability. However, the coefficients of the explanatory variables estimated by the SDM model are often biased due to the spatial lag term (Lesage and Pace 2009). Therefore, we further decompose the SDM models (6) and (8) (see Table 5), in which the interaction coefficients of environmental regulations and FDI in the direct effect are used to test the moderating effects of environmental regulation on the relationship between FDI and green economic efficiency, and they are used to examine the spatial performances of these moderating effects in the indirect effect.

5.4 Decomposition of the SDM model

Table 5 SDM model decomposition results

Variables	Direct effect				Indirect effect			
	Model (6)	Model (8)			Model (6)	Model (8)		
	(*lner*)	(*lner1*)	(*lner2*)	(*lner3*)	(*lner*)	(*lner1*)	(*lner2*)	(*lner3*)
lnfdi	-0.031***	-0.043***	-0.065***	-0.061***	-0.059	-0.063	-0.107**	-0.084*
	(0.011)	(0.013)	(0.017)	(0.016)	(0.056)	(0.052)	(0.048)	(0.045)
lner	-0.095***				-0.024			
	(0.027)				(0.044)			
*lnfdi*lner*	-0.011***				-0.004			
	(0.004)				(0.008)			
lner1		-0.061***				-0.044**		
		(0.018)				(0.019)		
*lnfdi*lner1*		-0.011***				-0.010*		
		(0.003)				(0.005)		
lner2			-0.004				0.165**	
			(0.054)				(0.071)	
*lnfdi*lner2*			0.023***				0.041**	
			(0.009)				(0.016)	
lner3				-0.033				-0.035
				(0.024)				(0.044)
*lnfdi*lner3*				-0.052**				-0.082**
				(0.025)				(0.033)

Note: ***, **, * indicate passing the significance test of 1%, 5%, 10%, respectively. Parentheses are standard errors.

In the direct effect of the model (6), the coefficients of FDI and its interaction term with environmental regulation (*lnfdi*, *lnfdi*lner*) are both negative at the significance level of 5%, which indicates that environmental regulation has a positive moderating effect on the relationship between FDI and green economic efficiency, expanding FDI's negative influence on green economic efficiency. As such, Hypothesis 1 is confirmed. Meanwhile, the indirect effect of the model (6) shows that the interaction coefficient of environmental regulation with FDI is insignificant. It implies that overall environmental regulation has no spatial spillover effect on green economic efficiency.

In the direct effect of model (8), the interaction coefficients of command-and-control environmental regulation and public-participation-based environmental regulation with FDI (*lnfdi*lner1*, *lnfdi*lner3*) are significantly negative, while the interaction coefficient of market-based environmental regulation with FDI (*lnfdi*lner2*) is significantly positive. The results suggest that contrary to command-and-control and public-participation-based environmental regulations, market-based environmental regulation has a negative moderating effect on the relationship between FDI and green economic efficiency, reducing the negative impact of FDI on green economic efficiency. As such, Hypothesis 2 is empirically supported.

In the indirect effect of the model (8), the interaction coefficients of three environmental regulations with FDI all pass the significance test, indicating that their moderating roles have a spatial spillover effect. Specifically, the moderating roles of command-and-control and public-participation-based environmental regulations have a negative spillover effect, inhibiting green economic efficiency in the surrounding areas. This contrasts with market-based environmental regulation. Therefore, Hypothesis 3 is valid.

Besides, the results of control variables (see Table 4) show that economic development level (*lngdpper*, *lngdpper2*) has a significant U-shaped relationship with green economic efficiency, supporting the EKC. And its spatial effect (*W*lngdpper*) is significantly negative, confirming a strong "siphon effect"[15]. China, as the world's largest industrialized country, has been effective in promoting industrial green transformation to achieve the strategic goal of full industrialization by 2035. As a result, industrial structure (*lnis*) has a significant positive effect on green economic efficiency. But its spatial lag term (*W*lnis*) is insignificant. Although urbanization (*lnurban*) can improve the efficiency of regional resource utilization (Wu 2021), it (*W*lnurban*) deteriorates the environment of the surrounding areas (Lv and Gao 2021).

5.5 Robustness tests

We adopted three approaches to conduct robustness tests. Firstly, on the basis of the existing literature, we replaced two-index measures for three types of environmental regulations, respectively. Among them, command-and-control environmental regulation is represented by the cumulative number of local environmental standards promulgated ($lner1_1$), the number of administrative punishment cases ($lner1_2$) (Li 2013; Zhang and Song 2021; Liu et al. 2022; Chen and Leng 2022). Market-incentive environmental regulation is represented by the ratio of local financial environmental protection expenditure to local fiscal general budget revenue ($lner2_1$), and the ratio of

[15] The siphon effect means that well-developed economic regions may attract talents, technology and other factors from around regions to gather locally, which inhibits green economy efficiency around regions.

investment in urban environmental infrastructure construction to local fiscal general budget revenue (*lner2*$_2$) (Wang 2016; Xu 2022). Public participation-based environmental regulation is represented by the per capita education level[16] (*lner3*$_1$), and the Baidu index of "environmental pollution" (*lner3*$_2$) (Xiong et al. 2020; Yuan et al. 2014; Wu et al. 2022). Subsequently, we used the entropy method to synthesize the above indicators as a proxy for comprehensive environmental regulation (*lner*)[17]. Finally, we re-estimated model (8) and model (10), and the results are presented in Table 6. The signs of variables in Table 6, especially the interaction terms between FDI and environmental regulations, are highly consistent with those in Table 5.

Table 6 SDM model decomposition results of robustness tests[18]

	Variables	Model (8)	Model (10)					
			(*lner1*)		(*lner2*)		(*lner3*)	
		(*lner*)	*lner1*$_1$	*lner1*$_2$	*lner2*$_1$	*lner2*$_2$	*lner3*$_1$	*lner3*$_2$
Direct Effect	*lnfdi*	-0.060***	-0.047***	-0.065***	-0.045***	-0.042***	-0.063***	-0.030**
		(0.018)	(0.014)	(0.019)	(0.014)	(0.013)	(0.016)	(0.012)
	lner	-0.019						
		(0.020)						
	*lnfdi*lner*	-0.029*						
		(0.015)						
	lner1		-0.001	-0.016*				
			(0.006)	(0.009)				
	*lnfdi*lner1*		-0.007*	-0.018***				
			(0.004)	(0.007)				
	lner2				-0.053	-0.006		
					(0.032)	(0.019)		
	*lnfdi*lner2*				0.012	0.013**		
					(0.011)	(0.006)		
	lner3						0.049	-0.036
							(0.298)	(0.050)
	*lnfdi*lner3*						-0.225**	-0.021**
							(0.090)	(0.009)
Indirect Effect	*lnfdi*	-0.083*	-0.058	-0.074	-0.071	-0.056	-0.094**	-0.056
		(0.049)	(0.043)	(0.051)	(0.061)	(0.058)	(0.044)	(0.045)
	lner	0.023						
		(0.043)						
	*lnfdi*lner*	-0.053**						
		(0.026)						
	lner1		0.001	0.009				
			(0.015)	(0.017)				
	*lnfdi*lner1*		-0.014**	-0.030**				
			(0.006)	(0.014)				
	lner2				0.038	0.042		
					(0.042)	(0.036)		
	*lnfdi*lner2*				0.037*	0.025*		
					(0.020)	(0.014)		

[16] The per capita education level (years) = (6P1+9P2+12P3+16P4) / P0. P1, P2, P3, and P4 are the number of people aged six years or older in elementary school, middle school, high school, and specialist and above, respectively, and P0 is the total population aged six years or older.

[17] Google and Baidu were the two major search engines commonly used by Chinese residents before 2010, but Google withdrew from mainland China in 2010. Therefore, to ensure data continuity and comparability, we adopt the Baidu index with the time interval of 2011-2018; the indicator is also excluded when synthesizing the comprehensive environmental regulation with the time interval of 2004-2018.

[18] Only the results of the core variables are shown for conciseness and clarity.

lner3						-0.225	-0.063
						(0.391)	(0.091)
*lnfdi*lner3*						-0.380**	-0.038**
						(0.162)	(0.017)
N	450	450	450	450	450	450	240

Secondly, we re-estimated and decomposed models (8) and (10) using the dynamic spatial Durbin model to avoid the interference of endogeneity on the results. As shown in Table 7, the signs of the coefficients of the interactions between FDI and environmental regulations are consistent with those in Table 5 in the short and long term.

Table 7 Dynamic SDM model Decomposition results

	Variables	Short-term				Long-term			
		Model（8）	Model（10）			Model（8）	Model（10）		
		(*lner*)	(*lner1*)	(*lner2*)	(*lner3*)	(*lner*)	(*lner1*)	(*lner2*)	(*lner3*)
Direct Effect	*lnfdi*	-0.039***	-0.049***	-0.063***	-0.061***	-0.040***	-0.051***	-0.065***	-0.062***
		(0.012)	(0.014)	(0.018)	(0.015)	(0.013)	(0.015)	(0.018)	(0.015)
	lner	-0.074***				-0.080***			
		(0.028)				(0.030)			
	*lnfdi*lner*	-0.009**				-0.010**			
		(0.004)				(0.004)			
	lner1		-0.047**				-0.052***		
			(0.019)				(0.020)		
	*lnfdi*lner1*		-0.008**				-0.009**		
			(0.003)				(0.004)		
	lner2			-0.008				-0.005	
				(0.062)				(0.063)	
	*lnfdi*lner2*			0.021**				0.023**	
				(0.010)				(0.010)	
	lner3				-0.013				-0.012
					(0.023)				(0.023)
	*lnfdi*lner3*				-0.060**				-0.063**
					(0.025)				(0.026)
Indirect Effect	*lnfdi*	0.006	-0.014	-0.027	-0.018	-0.021	-0.049	-0.049	-0.033
		(0.049)	(0.040)	(0.042)	(0.040)	(0.080)	(0.063)	(0.052)	(0.047)
	lner	-0.015				-0.100			
		(0.025)				(0.070)			
	*lnfdi*lner*	-0.006				-0.017			
		(0.007)				(0.012)			
	lner1		-0.033*				-0.078**		
			(0.018)				(0.031)		
	*lnfdi*lner1*		-0.007				-0.015*		
			(0.004)				(0.008)		
	lner2			0.073				0.088	
				(0.078)				(0.100)	
	*lnfdi*lner2*			0.027**				0.039**	
				(0.013)				(0.018)	
	lner3				0.011				0.010
					(0.057)				(0.067)

*lnfdi*lner3*				-0.068***				-0.092***
				(0.023)				(0.031)
N	420	420	420	420	420	420	420	420

Note: ***, **, * indicate passing the significance test of 1%, 5%, 10%, respectively. Parentheses are standard errors.

Thirdly, considering the green economic efficiencies are all greater than 0, we adopted the Tobit model to estimate models (8) and (10) without spatial lag to solve the problem of a limited dependent variable. As shown in Table 8, most of the variables keep their signs and significance as compared to those in Table 4. Taken together, from the results in Tables 6, 7 and 8, no matter which method is used to estimate models (8) and (10), the moderating effect of environmental regulation on the relationship between FDI and green economic efficiency does exist, and the effect of heterogeneous environmental regulation does have different manifestations. This, to some extent, demonstrates the robustness of our empirical results.

Table 8 Tobit model regression results

	Model (8)	Model (10)		
	(*lner*)	(*lner1*)	(*lner2*)	(*lner3*)
lnfdi	-0.038***	-0.046***	-0.051***	-0.051***
	(0.013)	(0.012)	(0.013)	(0.013)
lner	-0.086***			
	(0.023)			
*lnfdi*lner*	-0.014***			
	(0.005)			
lner1		-0.066***		
		(0.014)		
*lnfdi*lner1*		-0.014***		
		(0.004)		
lner2			-0.021	
			(0.022)	
*lnfdi*lner2*			0.008	
			(0.006)	
lner3				-0.065***
				(0.022)
*lnfdi*lner3*				-0.035***
				(0.013)
lngdpper	-0.064*	-0.048	-0.041	0.017
	(0.034)	(0.033)	(0.041)	(0.033)
lngdpper2	0.063***	0.046***	0.053***	0.051***
	(0.008)	(0.008)	(0.008)	(0.008)
lnis	0.406***	0.414***	0.462***	0.463***
	(0.050)	(0.048)	(0.050)	(0.049)
lnurban	0.100	0.090	0.129	0.112
	(0.114)	(0.114)	(0.114)	(0.111)
_cons	-2.670***	-2.669***	-2.787***	-3.516***
	(0.315)	(0.312)	(0.326)	(0.376)
sigma-u	0.500***	0.503***	0.495***	0.494***
	(0.066)	(0.066)	(0.065)	(0.065)
sigma-e	0.117***	0.115***	0.118***	0.116***
	(0.004)	(0.004)	(0.004)	(0.004)
LR-test	786.97***	813.96***	678.52***	754.85***
N	450	450	450	450

Note: ***, **, * indicate passing the significance test of 1%, 5%, 10%, respectively. Parentheses are standard errors.

6 Discussion

As a major economy in the world, China has not yet established a complete environmental regulatory system (Bo et al. 2018). Overall, low environmental costs have prompted developed countries to relocate pollution-intensive industries to China through FDI, which currently accounts for less than 30% of high-tech industries (MOC Ministry of Commerce 2020). In the meantime, with the continuous strengthening of the environmental regulations, the competitiveness of multinational companies has surpassed that of domestic companies. In 2018, China established 60,533 foreign-invested companies with an average annual growth rate of 69.8%, of which 50,106 were foreign-invested companies with an average annual growth rate of 85.5% (MOC Ministry of Commerce, 2019). This trend of the wholly-owned multinational companies has limited FDI's technological spillover and industrial structure upgrading effects. As a result, the overwhelming scale effect of FDI has made China a "pollution haven" for developed countries.

In particular, the high cost of implementing command-and-control environmental policy has frequently led to problems of lax enforcement, improper prosecution, and so on. Therefore, it cannot effectively prevent the inflow of pollution-intensive FDI. Different from the environmental regulation mandated by the government, market-based environmental regulation can motivate companies to continuously innovate environmental technologies (Hu et al. 2020; Xu et al. 2022). Confronted with China's increasingly stringent pollution charges and environmental taxes, multinational companies will adopt cleaner production processes and apply innovative pollution abatement technologies to exceed compliance costs, thereby giving full pay to the "pollution halo" effect of FDI. In addition, compared with developed countries with well-developed public environmental protection organizations, Chinese public awareness of environmental protection is relatively poor (Xie et al. 2017; Wu et al. 2020). It hardly regulates the production process of multinational companies, thus creating the pollution heaven effect of FDI.

In addition, command-and-control environmental regulation often leads to a vicious circle of "race to the bottom"[19] among regions, while market-based environmental regulation tends to bring about a "race to the top"[20] competitive game among regions (Xiao and Zhao 2020). While command-and-control environmental regulation can rapidly improve the environment, compliance costs are prohibitive (Yu 2017). Therefore, local governments tend to free-ride on the surrounding areas, that is, to relax the environmental regulation of regional boundaries[21], resulting in the pollution paradise effect of FDI on green economic efficiency of the surrounding regions. However, the negative moderating effect of market-based environmental regulation on the relationship between FDI and green economic

[19] The "race to the bottom" indicates that to gain comparative advantage under fierce market competition, local governments will compete to relax their environmental regulations to attract FDI inflows. While FDI inflows may drive the short-term growth of regional economies, it may also degrade the regional environment.

[20] The "race to the top" indicates that as the central government is increasingly strict with local environmental inspectors, local governments will compete to raise environmental regulation intensity to introduce high-quality FDI that can exert a positive effect on the regional environment.

[21] Such as in the treatment of river pollution; provincial governments, responding to orders to reduce pollution, will reduce environmental enforcement in the most downstream counties, which causes it 20% more water pollution incidents than other counties (Cai et al. 2016).

efficiency will have an exemplary effect on surrounding local governments. It encourages local governments to imitate each other in developing and implementing environmental regulations (Li et al. 2014; Fan 2021). For example, after Shenzhen launched China's first carbon emissions trading market in 2013, Beijing, Tianjin, Shanghai, and other cities competed to launch pilot carbon emissions trading. This will help attract cleaner FDI to flow into the region. In addition, public-participation-based environmental regulation takes a long time to show effect (Zhang and Liu 2019), and it is difficult to form an attractive "race to the top" in the short term. As public-participation-based environmental regulation tightens in one region, pollution-intensive FDI will shift to surrounding regions with poorer public-participation-based environmental regulation, inhibiting those regions' green economic efficiency.

7 Conclusions and Suggestions

Using China's provincial panel data from 2004 to 2018, this paper first calculates the green economic efficiency by adopting the Super-SBM model with undesired output, and then establishes an environmental regulation index system that incorporates command-and-control environmental regulation, market-based environmental regulation, and public-participation-based environmental regulation. Finally, this paper uses the SDM model to examine the moderating effect of environmental regulation, especially heterogeneous environmental regulation, on the relationship between FDI and green economic efficiency, as well as spatial manifestations of these moderating effects. The following conclusions are drawn:

(1) Generally speaking, China's environmental regulation has a positive moderating effect on the relationship between FDI and green economic efficiency. FDI and its interaction with environmental regulation have a negative impact on green economic efficiency, i.e. environmental regulation exacerbates the negative impact of FDI on green economic efficiency.

(2) It has been verified that these moderating effects of heterogeneous environmental regulations differ. Specifically, command-and-control and public-participation-based environmental regulations have positive moderating effects, while market-based environmental regulation has a negative moderating effect, correcting the pollution heaven effect of FDI on green economic efficiency.

(3) Although the overall moderating effect of environmental regulation has no significant spatial spillover effect, the moderating effect of command-and-control and public-participation-based environmental regulations have significant negative spatial spillover effects, which inhibits the regional green economic efficiency. By contrast, the moderating effect of market-based environmental regulation has a significant positive spatial spillover effect on green economic efficiency.

Based on the above conclusions, the following countermeasures are proposed: ① Environmental protection and governance require concerted efforts from the government, the market, and the public. To give play to the filtering effect of environmental regulation on FDI, policymakers should not only continuously strengthen emission standards, but also continuously optimize the objects and tax standards of environmental protection as well as national environmental protection education so as to improve the comprehensive ability of environmental protection. ② Since the environment has significant properties of public goods, it is necessary to gradually increase the proportion of ecological indicators in the local government performance appraisal system. This will not only help alleviate the free-rider behavior of local governments, but also help guide them to pay attention to the quality of FDI. ③ Although China has initially adopted some effective approaches such as the national carbon trading rights market, it is still necessary to explore continuous trading and collective auction trading of carbon emission right in order to foster enthusiasm for trading, which helps to maintain the virtuous interaction of the “Race to the top” among local governments and reduce the negative impact of FDI on green development. ④ It is indeed a long-term task to enhance the public’s environmental awareness and stimulate the enthusiasm of the public to participate in environmental regulation. We suggest that the government can first try to clarify the public's right to know and supervise through laws, proactively disclose the environmental information of multinational companies, and then focus on establishing a broad and effective public interest litigation system to shorten the time lag.

Statements and Declarations

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

Hui Zheng, Li Zhang, and Weiling Song conceptualized the study, synthesized the data analysis plan, analyzed the data, interpreted the findings, and have been the leading contributors to this paper. Hairong Mu made further contributions at a later stage. All the authors have read and approved the final version of the paper.

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Competing Interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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