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To cite this article: Shuangpeng Yang, Zhonglu Chen, Muhammad Umar & Ambreen Khursheed (2022) Environmental regulation and high-quality sustainable development of China's economy – an empirical study based on a spatial durbin model and threshold model, Economic Research-Ekonomika Istraživanja, 35:1, 5699-5718, DOI: [10.1080/1331677X.2022.2035243](https://doi.org/10.1080/1331677X.2022.2035243)

To link to this article: <https://doi.org/10.1080/1331677X.2022.2035243>



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Published online: 16 Feb 2022.



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Environmental regulation and high-quality sustainable development of China's economy – an empirical study based on a spatial durbin model and threshold model

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ABSTRACT

Coordinating and managing the contradictions among the environment, resources and economy is an urgent problem in China. Based on the panel data of 30 provinces and cities in China from 2004 to 2017, this paper empirically studies the impact of environmental regulation on China's high-quality economic development and the mediating effect mechanism through the spatial Durbin model and threshold model. The results show that China's high-quality economic development shows a fluctuating upward trend, and the east is higher than the middle and west. Environmental regulation significantly inhibits high-quality economic development, but its impact is moderated by accelerating industrial upgrading, promoting technological innovation, and enhancing foreign direct investment. As the primary driving force, technological innovation has a significant spatial spillover effect. The results show that industrial upgrading has no threshold effect, and technological innovation and foreign direct investment have the characteristics of a 'U' single threshold.

ARTICLE HISTORY

Received 22 November 2021
Accepted 24 January 2022

KEYWORDS

High-quality economic development; environmental regulation; spatial durbin model; threshold model

JEL CODES

C55; O10; O21; O31; P23

1. Introduction

China has made remarkable achievements in industrialization, but for a long time, the industrial process has not been able to break free from middle and low-end constraints. The fundamental reasons for these constraints can be attributed to the slow transformation and upgrading of the industrial structure and the lack of follow-up power for the conversion of new and old kinetic energy (Ielasi et al., 2018). The extensive development driven mainly by investment and other factors has directly led to serious environmental pollution and resource waste (Zhang et al., 2019). According to a report released by the WHO in 2017, 6 out of the 30 most polluted

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cities in the world are in China. The realization of a refined green economic development model brooks no delay (Ji et al., 2021; Tao et al., 2022). How to use reasonable policies to improve high-quality economic development and thereby alleviate the contradiction between the environment and economic development is a key issue that China urgently needs to solve (Umar et al., 2021).

Environmental regulation is a key measure to solve environmental pollution and improve resource utilization (Rizvi et al., 2021). In the context of changes in international economic and trade patterns and domestic economic development strategies and direction adjustments, potential restraints are used to directly affect the transaction costs, benefits, and management of economic entities. Efficiency in turn promotes changes in high-quality economic development (Cai & Zhou, 2017). However, in practice, in the underdeveloped central and western regions, local governments will deregulate and devote themselves to creating 'policy depressions' to increase the attraction of external investment, to encourage the transfer of industries from foreign or eastern coastal areas, thereby leading to increasing local environmental pollution. Pollution and industrial spatial transfer caused by environmental regulatory gradients are an important reason for not only the healthy ecological environment in some areas of China but also the uneven distribution of overall quality. Therefore, does environmental regulation policy have a significant impact on high-quality economic development? If so, what is the mechanism of environmental regulation policies affecting green productivity? Are there any regional differences? Is there a threshold effect? Based on these questions, this article uses the intermediary effect as the starting point to investigate the impact of environmental regulations on the high-quality development of the regional economy and its mediating effect mechanism, as well as spatial spillover effects and threshold characteristics. Effective governance has important research significance.

2. Related literature

For the relationship attribute and influence mechanism between environmental regulation and high-quality economic development, the main viewpoints are as follows: Porter hypothesis theory believes that there is an explicit positive relationship between them, and the 'forced' effect is an important mechanism. He, (2018) supports this conclusion. They constructed China's economic growth quality system based on China's provincial panel data and empirically studied the relationship between environmental regulation and economic growth. The results show that environmental regulation significantly promoted economic development and social welfare levels overall but also indirectly led to the expansion of the income gap. Qi et al. (2016) points out, based on data of 113 key environmental protection cities, that the 'emission reduction' effect of environmental regulation is conducive to economic development, and a good institutional environment will amplify the positive effect and slow down the distortion effect of regulatory policies to realize the 'win-win' of environment and economy. Hamamoto (2006) studied the Japanese manufacturing industry and found that the increase in R&D investment stimulated by strict regulation has a significant positive impact on the growth rate of total factor production.

Yang et al. (2012) show that environmental regulation not only improves the production cost of enterprises but also promotes technological innovation. In the long run, the benefits brought by innovation will greatly offset the increased cost, improve the productivity of enterprises and form a competitive advantage.

The 'cost compliance' hypothesis holds that there is a linear inverse relationship between environmental regulation and high economic quality. The 'cost' effect is the realization mechanism, and regulatory policy has characteristics of lag, which not only inhibits high-quality economic development and growth but also induces enterprises to accelerate polluting behaviors to increase economic output as a means of compensating for the cost of emission reduction, which results in environmental deterioration (Lobato et al., 2021). Ling et al. (2013), based on the input-output data of 36 industrial industries in China, showed that China's industrial green total factor productivity regressed from 2001 to 2010, resulting in a reduction or even negative contribution rate to the industrial economy, creating a threshold effect. Based on the data of 27 manufacturing industries, Yinea al. (2012) found that the overall level of environmental regulation intensity and green total factor productivity of the manufacturing industry conform to a U-shaped relationship, and there is heterogeneity between clean sectors and pollution-intensive sectors. Ling and Tao (2012) calculated the environmental regulation and green total factor productivity of 28 manufacturing sectors and found that the intensity of environmental regulation in heavily polluting industries is relatively reasonable and significantly promotes the green total factor productivity of industries, while the relationship between moderately polluting and slightly polluting industries is 'U'.

In addition, some scholars believe that there is a nonlinear relationship between environmental regulation and high economic quality. The economic effect of environmental regulation depends on whether the 'forced effect' or 'cost effect' is more dominant. The relationship between environmental regulation and high-quality economic development may have a U-shaped relationship (He, 2018; Xiong, 2011) or an inverted U-shaped relationship (Cha, 2015; Liu et al., 2016). Wang and Lu (2018) and others also concluded that environmental regulation has a significant inhibitory effect on the quantity of economic growth, but it has significantly improved the quality of economic growth and regional heterogeneity, especially in the central and western regions.

In summary, although sufficient research has shown that reasonable environmental regulations can promote high-quality economic development, opposing views still exist (Naqvi et al., 2021). The reason for opposing views can be attributed to 'regional differences', 'threshold effect' and so on. In addition, most studies focus on a single analysis of the impact of environmental regulations on high-quality economic development without delving into the specific impact mechanism. Based on this, this paper studies the impact mechanism of environmental regulation on green total factor productivity and regional differences at three levels: industrial upgrading, technological innovation and foreign direct investment. By constructing a spatial Durbin model and a panel threshold model, we will empirically test environmental regulations. The mediating effect mechanism and spatial spillover and threshold effect affect high-quality economic development.

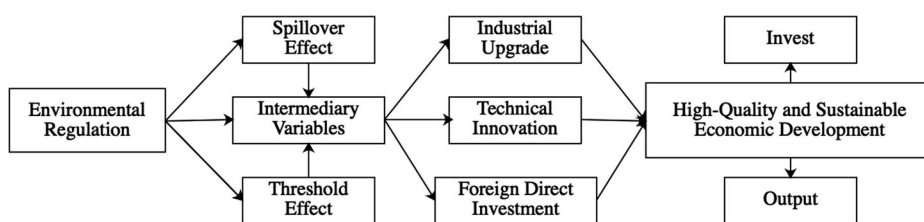


Figure 1. Analysis diagram of the intermediary effect mechanism.

3. Analysis of the mediating effect mechanism

As shown in Figure 1, environmental regulation policy is the key factor that affects the sustainable development of the green economy. In addition to its formulation and implementation, it can also have a far-reaching impact on high-quality economic development, such as industrial upgrading, technological innovation and foreign direct investment.

3.1. Industrial upgrading effect

Industrial structure is not only an important carrier impacting economic activities but also an important factor affecting the ecological environment. It has the dual functions of ‘resource converter’ and ‘environmental regulator’ (Yu, 2020). At present, the transformation and upgrading of China’s industrial structure is characterized by a strong planned economy and a lack of intrinsic incentives. Nonmarket intervention regulatory policies are a government-led means for effectively solving the externalities of environmental pollution compensates for this incentive. Scientific environmental policies force industries with high pollution and high energy consumption, such as resource-based industries, to eliminate backward production capacity, increase green management and green improvement, and transform them into green and clean industries to realize the high-end rise of the industrial value chain (Xiao & Liu, 2014). However, the tightening of regulatory policies amplifies the ‘cost compliance effect’ in areas dominated by pollution-intensive manufacturing industries, and pollution emissions increase with the increase of regulatory intensity. It is inefficient or even ineffective to reduce green productivity through environmental regulations.

3.2. Technological innovation effect

Technology, as an intermediary variable, acts on environmental regulation to influence high-quality economic development. There may be two effects. First, the ‘innovation compensation effect’, that is, reasonable environmental regulation, can encourage enterprises to internally digest the regulation cost, and the government encourages enterprises to increase R&D investment and carry out technological innovation activities through policy subsidies and actively introduce or develop green technologies and advanced management tools, which can effectively offset or even surpass the environmental compliance cost caused by the formulation of regulatory policies and ultimately promote high-quality economic development. (Boyd & Curtis,

2014). Second, the ‘cost effect’, that is, the implementation of environmental regulation policies, can lead to an increase in the external environmental costs and pollution control costs of enterprises. In pursuit of income optimization, enterprises can increase the number of products to compensate for the additional production costs, resulting in increased pollution emissions, which seriously restricts the development of technological innovation of enterprises.

3.3. Foreign direct investment effect

To attract more foreign direct investment to promote local economic growth, local governments have implemented blind and disorderly ‘bottom-to-bottom competition’ behavior, resulting in some symbolic or passive implementation of regulatory policies. Trade-induced investment often ignores the quality of foreign direct investment and easily leads to low-quality investment dominated by pollution-intensive enterprises, which makes the region a ‘pollution paradise’ of developed countries and regions, so foreign direct investment may worsen the development of high-quality economic development. However, some scholars believe that high-quality foreign direct investment provides the host country with excellent management tools, environmentally friendly production standards, green technologies, and sufficient funds. Through the spatial correlation effect and demonstration effect, it can effectively encourage enterprises to invest in R&D and technological innovation spillover, further promote clean technologies, improve resource utilization and reduce pollutant emissions (Kim et al., 2015).

4. Model setting and variable selection

4.1. Parameter design

Suppose i and t represent provinces and cities and observation years, respectively. α_0 indicates the intercept item, β_1 , \varnothing indicates the estimation coefficient, X_{it} indicates the control variable, and ε_{it} indicates the error term. Referring to the research of Wu and He (2017), $W_{ij} = 1/d_{ij}$ (d_{ij} represents the actual distance of the straight line between the centers of the two provincial capitals). Second, the adjacent weight matrix is established by using the adjacent method, that is, the adjacent distance is 1 and the nonadjacent distance is 0. Other parameters are shown in Table 1:

Table 1. Parameter design.

Explained variable	High quality and sustainable economic development	$Gtfp$
	Technical efficiency	Ec
	Technical progress	Tc
Explanatory variable	Environmental regulation	Er
Mediating variable	Industrial upgrading	Ts
	Technological innovation	Inn
	Foreign direct investment	Fdi
Control variable	Foreign trade dependence	$Trade$
	Marketization index	$Market$
	Urbanization	$Urban$
	Investment in fixed assets	$Invest$

Source: completed by the authors.

4.2. Model setting

This paper focuses on the impact of local and surrounding areas and their mediating effect mechanism on green total productivity. According to Elhorst (2014), the direct effect is the influence of the explanatory variables in the region on their own explanatory variables, and the indirect effect is the influence of each pair of explanatory variables in the region on the explanatory variables in adjacent areas. Total area is the sum of the direct effect and spatial spillover, that is, the impact of explanatory variables on the explained variables is analyzed at the overall level. New economic geography holds that spatial distance is an important factor affecting regional economic ties. Similarly, Er and $Gtfp$ may have spatial spillover effects because they are adjacent to each other, so adding spatial factors to the original basis will effectively reduce the regression deviation. There are three commonly used spatial econometric models: the spatial autocorrelation model (SAR), spatial error model (SEM) and spatial Durbin model (SDM). Therefore, the measurement models available for inspection are established as follows.

$$Gtfp_{it} = \alpha_0 + \beta_1 Er_{it} + \emptyset X_{it} + \varepsilon_{it} \quad (1)$$

Eq. (1) represents the basic regression model.

$$Gtfp_{it} = \alpha_0 + \rho_1 W_{ij} Gtfp_{it} + \beta_1 Er_{it} + \emptyset X_{it} + \varepsilon_{it} \quad (2)$$

$$Gtfp_{it} = \alpha_0 + \beta_1 Er_{it} + \emptyset X_{it} + \varepsilon_{it} \quad (3)$$

$$Gtfp_{it} = \alpha_0 + \rho_1 W_{ij} Gtfp_{it} + \beta_1 Er_{it} + \rho_2 W_{ij} Er_{it} + \emptyset X_{it} + \rho_3 W_{ij} Er_{it} + \varepsilon_{it} \quad (4)$$

Eqs. (1) (3) and (4) represent SAR, SEM and SDM, respectively.

$$Y_{it} = \alpha_0 + \beta_1 Er_{it} + \emptyset X_{it} + \varepsilon_{it} \quad (5)$$

Eq. (5) represents the mediating variable model constructed to further explore the intermediary effect influence mechanism of environmental regulation and high-quality economic development. Y_{it} represents the mediating variable (Ts , Inn , Fdi).

Finally, referring to the test procedure of Preacher and Hayes (2008), the mediating variable is used as the explained variable to verify the mediating effect based on Er on Ts , Inn and Fdi . A regression model is constructed which includes explanatory variables, intermediate variables and explained variables, as shown in Eq. (6):

$$Gtfp_{it} = \alpha_0 + \rho_1 W_{ij} Gtfp_{it} + \beta_1 Er_{it} + \rho_2 W_{ij} Er_{it} + \beta_2 Y_{it} + \rho_3 W_{ij} Y_{it} + \emptyset X_{it} + \rho_4 W_{ij} X_{it} + \varepsilon_{it} \quad (6)$$

4.3. Data source and characteristic analysis

The data selected in this paper are the research data of 30 provinces and cities in China (except Tibet) from 2004 to 2017, which are mainly from the China Statistical Yearbook, provincial statistical yearbook, Tai'an database, wind database and National

Bureau of Statistics. For some missing data, the linear interpolation method is used to supplement the complete data.

4.3.1. Explained variable

Referring to the research of Cai and Zhou (2017), this paper uses MAXDEA to calculate *Gtfp*. Suppose there are *m* inputs (*i* = 1, 2, ..., *m*) and *n* outputs (*i* = 1, 2, ..., *n*) in decision-making units, namely, provinces (*j* = 1, 2, ..., *s*). γ^* represents the optimal efficiency value, $0 \leq \gamma^* \leq 1$. w_i represents the weight of the input element *i*, $\sum_{i=1}^m w_i = 1 (w_i \geq 0)$. θ represents the radial efficiency value. s_i represents the relaxation variable corresponding to the input element *i*, ε_x represents the parameter integrating radial θ and nonradial relaxation variables, $\varepsilon_x \in [0, 1]$. *X*, *Y* and σ respectively represent the relative importance of input, output and reference decision-making unit, $X = (y_{ij}) \in R^{sn}$ and $X > 0, Y > 0$. Then, the EBM directional distance function is constructed as follows.

$$\gamma^* = \min \theta - \varepsilon_x \sum_{i=1}^m \frac{w_i s_i}{x_{i0}} \tag{7}$$

$$\text{s.t. } \theta x_0 - x\sigma - s = 0 \tag{8}$$

$$\sigma Y \geq y_0, \sigma > 0, s \geq 0 \tag{9}$$

Then, the GML index expression is constructed as shown in Eq. (10).

$$GML^{t,t+1}(x^t, y^t, b^t, x^{t+1}, b^{t+1}) = \frac{1 + D^G(x^t, y^t, b^t)}{1 + D^G(x^{t+1}, y^{t+1}, b^{t+1})} \tag{10}$$

In Eq. (10), b^t and b^{t+1} represent the unexpected output of the *t* and *t* + 1 periods, respectively. Then, the directional distance function Eq. (11) can be deduced:

$$D^G(x^t, y^t, b^t) = \max[\beta : (y + \beta y, b - \beta b) \in p^G(X)] \tag{11}$$

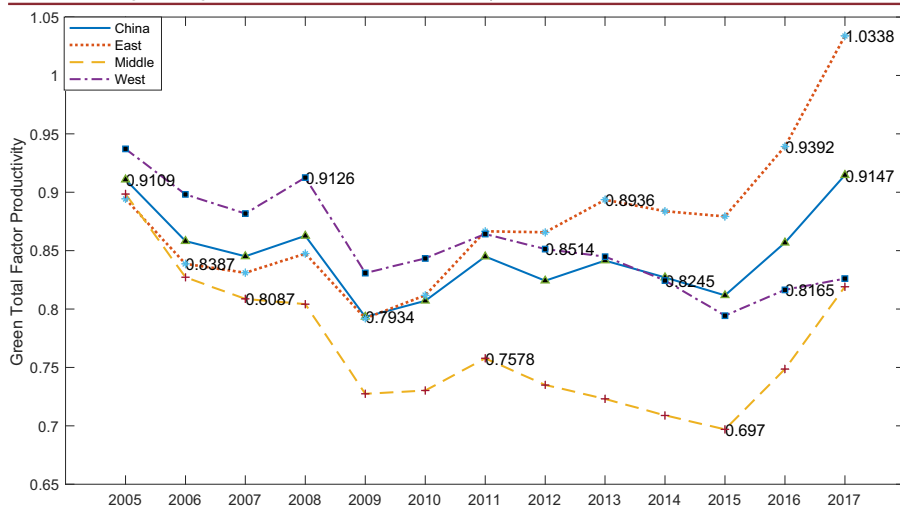
Since the GML index refers to the green total factor growth rate rather than itself, it is assumed that 2004 *Gtfp* is 1, 2005 *Gtfp* is 2004 multiplied by the GML index in 2005, and so on.

As mentioned above, *Gtfp* is divided into two parts: input and output. The indicators selected in this paper are shown in Table 2. Referring to Zhang et al. (2004),

Table 2. Green total factor production measurement index.

Input index (Province)	Output index (Province)
Working population: Employment at the end of the year (1000 persons)	Expected output: Real GDP (RMB100mn)
Energy consumption: Total energy consumption (10000 tons of standard coal)	Unexpected output 1: Industrial wastewater discharge (10000 tons)
Capital stock: Total capital stock (RMB100mn)	Unexpected output 2: Sulfur dioxide emission (10000 tons)

Source: completed by the authors.

Table 3. Regional green total factor productivity.

Source: completed by the authors.

using 2000 as the base period, the annual depreciation rate is 9.6%, and the perpetual inventory method is used to calculate the capital stock K of each province, as shown in Eq. (12).

$$K_{it} = (1 - \delta)K_{it-1} + \frac{I_{it}}{P_{it}} \quad (12)$$

The calculation results of regional green total factor productivity are shown in Table 3. Overall, China's green total factor productivity fluctuated greatly, but it increased significantly after 15 years. The eastern region is in a leading position with obvious advantages. The midlands are the lowest, which may be related to taking on many industries with high pollution and high energy consumption. The west is in the middle reaches, but the green total factor productivity is slowly rising due to the tightening of Er policies.

4.3.2. Core explanatory variable

Since this paper focuses on the investment in environmental pollution control, it is expressed by the ratio of the total investment in the treatment of pollutants such as wastewater, waste gas, solid pollutants, and noise in each province to the provincial GDP for reference Dong et al. (2011) and Yu and Sun (2017).

4.3.3. Mediating variable

With reference to Gan et al. (2011), Ts is expressed by the ratio of tertiary industry GDP to secondary industry GDP. The proportion of technology market turnover in the GDP of each province is taken as Inn . It is expressed by the ratio of utilized foreign direct investment to GDP in each province Fdi .

Table 4. characteristics of main variables.

	Sample size	Mean value	Standard deviation	Minimum value	Maximum value
<i>Gtff</i>	420	0.858	0.162	0.443	1.478
<i>Ec</i>	420	0.935	0.148	0.467	1.445
<i>Tc</i>	420	0.921	0.127	0.595	1.614
<i>Er</i>	420	1.328	0.659	0.103	4.24
<i>Ts</i>	420	1.194	3.611	-6.607	42.6
<i>Inn</i>	420	0.177	0.456	0.0002	4.487
<i>Fdi</i>	420	0.619	0.704	0.002	3.576
<i>Trade</i>	420	0.320	0.384	0.018	1.713
<i>Market</i>	420	0.212	0.095	0.079	0.627
<i>Urban</i>	420	52.403	14.199	26.28	89.6
<i>Invest</i>	420	0.669	0.238	0.237	1.480

Source: completed by the authors.

Table 5. Moran index of high-quality economic development from 2004 to 2017.

Year	<i>I</i>	<i>p</i> -value	Year	<i>I</i>	<i>p</i> -value
2004	-0.032	0.325	2011	0.054	0.061
2005	-0.056	0.153	2012	0.041	0.058
2006	-0.077	0.247	2013	0.052	0.051
2007	-0.064	0.108	2014	0.038	0.093
2008	0.068	0.052	2015	0.058	0.102
2009	0.035	0.179	2016	0.046	0.038
2010	0.055	0.069	2017	0.034	0.051

Source: completed by the authors.

4.3.4. Control variable

Urban is expressed as the proportion of the urban population to the total population. *Invest* is expressed as the ratio of total investment in fixed assets to GDP. *Trade* is expressed as the ratio of the total import and export of goods to GDP by the location of the business unit. *Market* is expressed by the proportion of government consumption expenditure to GDP. The characteristics of the main variables are shown in Table 4.

4.4. Spatial autocorrelation test

Spatial dependence is the premise of a spatial econometric model. In this paper, the Moran index is introduced to test *Gtff* for spatial autocorrelation. The results are shown in Table 5. The Moran index *I* basically passes the 10% significance test, indicating that there are obvious spatial agglomeration characteristics in the high-quality economic development of provinces and cities; that is, the spatial measurement method is applicable in this paper.

5. Empirical analyses

5.1. Spatial panel model identification and verification

First, the SAR, SDM and SEMs are identified and tested, and the results are shown in Table 6. LR tests significantly reject the original hypothesis. SDM cannot be simplified into SAR and SEM, and the log-*l* value of double fixed SDM is 521.93, which is the highest compared with SAR and SEM, indicating that SDM is optimal. The

Table 6. Calculation results of the spatial econometric model.

	SAR			SEM			SDM		
	Double fixation	Double fixation	Random effect	Individual fixation	Time fixation	Double fixation			
<i>Er</i>	-0.0218** (-2.49)	-0.018* (-2.04)	-0.015 (-1.55)	-0.016* (-1.72)	-0.021* (-1.74)	-0.044*** (-2.69)			
<i>Trade</i>	-0.242*** (-5.32)	-0.231*** (-5.16)	-0.181*** (-3.89)	-0.232*** (-4.94)	0.022 (0.57)	-0.238*** (-5.15)			
<i>Market</i>	0.045 (0.29)	0.066 (0.43)	0.089 (0.59)	-0.034 (-0.22)	0.204** (2.05)	-0.018 (-0.11)			
<i>Urban</i>	0.002 (0.91)	0.002 (1.07)	0.005*** (2.88)	0.003 (1.25)	0.003*** (2.58)	0.002 (0.7)			
<i>Invest</i>	-0.304*** (-7.41)	-0.302*** (-7.41)	-0.351*** (-9.01)	-0.308*** (-7.21)	-0.324*** (-6.53)	-0.293*** (-6.92)			
<i>Wer</i>			0.011 (0.27)	0.015 (0.37)	-0.417*** (-5.1)	-0.121* (-1.93)			
<i>Rho</i>	-1.134*** (-4.89)	-0.747*** (-3.84)	0.399*** (4.3)	0.425*** (4.75)	-1.203*** (-4.82)	-1.20*** (-4.89)			
<i>Log⁻¹</i>	520.250	515.192	413.045	484.358	278.311	521.943			
<i>Test</i>	LR chi2 = 13.5 Prob > chi2 = 0.019	LR chi2 = 3.39 Prob > chi2 = 0.064	Hausman Z = -22.25 420	LR chi2 = 75.17 Prob > chi2 = 0.000 420	LR chi2 = 487.26 Prob > chi2 = 0.000 420				

Notes. z value in parentheses, ***, **, * are significant at the level of 1%, 5% and 10% respectively.
Source: completed by the authors.

Table 7. Analysis of *Gtfp* and its index decomposition results.

	<i>Ts</i>	<i>Inn</i>	<i>Fdi</i>
<i>Er</i>	0.838*** (2.75)	0.075** (2.22)	-0.156*** (-3.53)
<i>Trade</i>	0.549 (0.59)	0.041 (0.40)	0.754*** (5.65)
<i>Market</i>	-2.611 (-1.05)	0.913*** (3.31)	-2.780*** (-7.82)
<i>Urban</i>	-0.009 (-0.41)	0.016*** (6.55)	0.015*** (4.75)
<i>Invest</i>	-1.519 (-1.32)	-0.539*** (-4.20)	1.021*** (6.14)
<i>Cons</i>	1.950* (1.87)	-0.618*** (-5.31)	-0.305 (-2.02)
F/rho	2.23*	38.81***	84.57***
Log - I year/orgin	Double fixation	Double fixation	Double fixation
N	420	420	420

Source: completed by the authors.

Hausman test of fixed effects and random effects shows that the value of -22.25 is negative, indicating that the fixed effect is better. In addition, in the LR test of the double fixation effect, individual fixation effect and time fixation effect, the original hypothesis is significantly rejected, so the double fixation effect is better. Therefore, this paper selects the double fixed space durbin model for empirical analysis.

5.2. Mediating variable regression analysis

To verify the significance of the impact of *Er* on mediating variables, regression analysis is carried out on Model (5) according to the intermediary effect, and the results are shown in Table 7. Obviously, the estimated coefficients of *Er* to *Ts* and *Inn* are significantly positive and to *Fdi* is significantly negative, which indicates that *Er* can accelerate *Ts* and promote *Inn* but inhibit *Fdi*. A possible reason for this is that the tightening of regulatory policies will force enterprises to develop green technology and cultivate green demand, realize the greening of industrial structure, and then promote *Ts* and *Inn*. At the same time, strict policies will raise the market access threshold and pollution discharge standards, form environmental barriers, block low-quality *Fdi*, increase the environmental governance costs of existing foreign-funded enterprises and occupy the R&D and management costs to inhibit *Fdi*.

5.3. Mediating effect regression analysis

5.3.1. Analysis of total regional mediating effect

As shown in Table 8, in the benchmark regression model, the total effect and direct effect estimation coefficients of the environmental estimation coefficients are significantly negative, indicating that *Er* has a significant inhibitory effect on *Gtfp* and local economic growth, and the spatial spillover effect is not obvious. This is consistent with the research conclusions of Lanoie et al. (2011) and Wang and Lu (2018); that is, *Er* will increase the cost of corporate environmental governance and reduce the profit space, thus crowding out green innovation and productive investment and

Table 8. Analysis of the influence mechanism of the mediating effect.

	Benchmark regression model			Mediating effect model		
	Direct effect Equation 1	Spatial spillover Equation 2	Total effect Equation 3	Direct effect Equation 4	Spatial spillover Equation 5	Total effect Equation 6
<i>Er</i>	-0.030** (-2.18)	-0.048 (-1.42)	-0.078** (-2.04)	-0.026*** (-3.15)	-0.046 (-1.16)	-0.072** (-2.16)
<i>Ts</i>				0.003* (1.84)	-0.050* (-5.10)	-0.048* (-4.96)
<i>Inn</i>				0.107*** (6.83)	0.155** (2.19)	0.262*** (3.43)
<i>Fdi</i>				0.053*** (4.28)	-0.027 (-0.56)	0.025 (0.53)
<i>Trade</i>	-0.240*** (-5.44)	-0.006 (-0.04)	-0.246 (-1.57)	-0.131*** (-3.07)	-0.143 (-1.04)	-0.274** (-1.98)
<i>Market</i>	0.017 (0.11)	-0.202 (-0.33)	-0.185 (-0.3)	0.324** (2.19)	-0.420 (-0.68)	-0.096 (-0.15)
<i>Urban</i>	0.002 (1.03)	-0.006 (-0.61)	-0.004 (-0.38)	0.007*** (3.10)	0.001 (0.13)	0.008 (0.79)
<i>Invest</i>	-0.299*** (-7.62)	-0.067 (0.45)	-0.248 (-1.5)	-0.261*** (-6.60)	0.193 (1.27)	-0.069 (-0.46)
<i>F/rho</i>	-1.203*** (-4.89)	-1.203*** (-4.89)	-1.203*** (-4.89)	-1.302*** (-5.41)	-1.302*** (-5.41)	-1.302*** (-5.41)
Log - l	521.943	521.943	521.943	-242.301	-242.301	-242.301
Year/origin	Double fixation	Double fixation	Double fixation	Double fixation	Double fixation	Double fixation
N	420	420	420	420	420	420

Source: completed by the authors.

inhibiting the growth of high-quality economic development. In the mediating effect model, the *Er* coefficient is effectively reduced, indicating that the negative effect on *Gtfp* is effectively alleviated after adding mediating variables. The direct effect estimation coefficients of *Ts*, *Inn* and *Fdi* are significantly positive. By optimizing resource allocation, industrial transfer, and other measures to promote production factors from nonclean industries with low productivity to clean industries with high productivity, the value chain can be effectively climbed (Umar et al., 2021). Through financial subsidies and other measures, enterprises are encouraged to carry out technology R&D and realize green innovation, which can effectively improve production efficiency. At the same time, reasonable preferential policies and strict *Er* can avoid the low-end *Fdi* of high pollution on the one hand and attract high-quality *Fdi* with advanced production technology and management means on the other hand to provide experience for China's sustainable development, occupy domestic enterprises with high pollution and realize healthy economic development. The spatial spillover and total effect of *Ts* are negative at the 10% level. A possible reason for this is that the radical tightening policy will force resource-based industries to transfer to surrounding areas with a backward economy or loose regulation policies, which has a diffusion effect. The spatial spillover and total effect of *Inn* are significantly positive at the levels of 5% and 1%, respectively, which is undoubtedly related to the spatial demonstration effect and diffusion effect caused by the improvement of technical capacity. The spatial spillover and total effect of *Fdi* are not significant. A possible reason for this is that it has almost no diffusion effect and cannot be copied.

Table 9. Analysis of the results of the subregional mediating effect mechanism.

	East			Midlands			West		
	Direct effect	Spatial spillover	Total effect	Direct effect	Spatial spillover	Total effect	Direct effect	Spatial spillover	Total effect
<i>Er</i>	-0.016 (-1.06)	0.061 (1.21)	0.044 (0.79)	-0.015 (-1.31)	-0.046 (-1.18)	-0.062 (-1.31)	-0.019* (-1.79)	-0.007 (-0.23)	-0.026 (-0.79)
<i>Ts</i>	-0.002 (-1.40)	0.002 (0.35)	0.0002 (0.03)	0.023*** (3.2)	0.057*** (2.55)	0.080*** (2.85)	-0.002 (-0.76)	-0.008 (-0.73)	-0.011 (-1.05)
<i>Inn</i>	0.309*** (9.87)	0.515*** (3.85)	0.823*** (5.35)	0.440*** (4.35)	0.495* (1.83)	0.935** (2.55)	-0.216*** (-3.68)	-0.876*** (-3.92)	-1.092*** (-4.2)
<i>Fdi</i>	0.036* (1.94)	0.006 (0.09)	0.043 (0.55)	0.113*** (3.27)	-0.373* (-4.09)	-0.259* (-2.88)	0.080 (1.57)	0.099 (0.79)	0.179 (1.19)
<i>Trade</i>	0.149*** (2.65)	-0.304* (-1.68)	-0.155 (-0.78)	0.357 (1.34)	1.690** (2.73)	2.048*** (2.73)	-0.210** (-1.98)	0.115 (0.44)	-0.095*** (-0.31)
<i>Market</i>	-1.093*** (-2.98)	-1.638 (-0.98)	-2.731 (-1.54)	-3.503*** (-3.90)	-8.763*** (-3.51)	-12.267*** (-3.78)	0.570*** (3.48)	0.632 (1.03)	1.202** (2.12)
<i>Urban</i>	0.022*** (5.11)	0.077*** (4.15)	0.099*** (4.74)	-0.013* (-1.80)	-0.017 (-0.83)	-0.030 (-1.18)	0.017** (2.42)	0.047** (2.48)	0.063*** (3.48)
<i>Invest</i>	-0.099* (-1.66)	0.332 (1.20)	0.233 (0.80)	-0.084 (-1.28)	-0.385 (-1.54)	-0.469 (-1.60)	-0.144*** (-2.77)	0.150 (0.76)	0.005 (0.03)
<i>rho</i>	-0.256 (-1.35)	-0.256 (-1.35)	-0.256 (-1.35)	-0.917*** (-3.71)	-0.917*** (-3.71)	-0.917*** (-3.71)	0.001*** (7.78)	0.001*** (7.78)	0.001*** (7.78)
Log - I	-81.55	-81.55	-81.55	56.69	56.69	56.69	95.85	95.85	95.85
Year/origin	154	154	154	84	84	84	182	182	182
N									

Source: completed by the authors.

5.3.2. Analysis of subregional mediating effect

In this section, 30 provinces and cities in China are divided into three regions: East, Midlands, and West for empirical analysis. The results are shown in Table 9.

In the east, Ts has no mediating effect, and the direct effect, spatial spillover, and total effect of Inn are significantly positive, indicating that Inn can effectively promote Er and then increase $Gtfp$ in this region, adjacent regions and total regions. Fdi only shows a positive direct effect at the 10% level, indicating that Fdi plays only an intermediary role in this region. A reason for this may be that fierce market competition in the eastern region urges enterprises to actively invest in technological innovation and improve management means. At the same time, the agglomeration of high-quality capital, labor and other factors can support the government's policies to improve emission standards and can also effectively screen out high-quality Fdi .

In Midlands, the direct effect, spatial spillover, and total effect of Ts and Inn are significantly positive, the direct effect of Fdi is significantly positive, and the spatial spillover and total effect are negative at the 10% level. A possible reason for this is that the midlands have strong external constraints on the environment and resources. As part of the strict regulation strategy, the local government will implement appropriate policy dividends as internal incentives to encourage enterprises to actively update green technology and upgrade production equipment to improve green efficiency. In addition, the economic development level of central China is similar, and there is no industrial transfer. Under Chinese-scale competition, the competitive regions adhering to the maximization of interests will imitate the optimized regulation strategies and industrial policies of the region, which will drive the strategic interaction of adjacent regions, thereby spreading these strategies throughout the whole region. There is both competition and cooperation among enterprises, and technology sharing and exchange are the norms. At the same time, the advantages created by perfect transportation infrastructure and strong industrial scale will attract many investors. However, to meet the needs of political promotion competition and economic development, the initiative of neighboring local governments may lead to low quality Fdi .

In the west, Ts and Fdi have no intermediary effect, and the estimation coefficients of the direct effect, spatial spillover and total effect of Inn are significantly negative, which is inconsistent with expectations. A possible reason for this is that the overall economic strength of the western region is weak, and the tightening of regulatory policies leads to increased environmental compliance costs and weak policy dividends. Due to the lag of regulatory policies and innovation effects, resource-based industries must make up for environmental governance investment by increasing economic output in the short term which increases the burden of pollution. The overall industrial infrastructure is not perfect, so it is difficult to attract high-quality Fdi .

5.3.3. Robustness check

As shown in Table 10, to ensure the validity of the conclusions, this paper tests the robustness of the empirical results from three aspects. First, the adjacency weight matrix is replaced for regression, and the adjacency weight matrix is replaced by the geographic distance weight matrix for empirical analysis. Second, we change the

Table 10. Robustness test.

	Replace matrix			Replace explained variable			Change measurement		
	Direct effect	Spatial spillover	Total effect	Direct effect	Spatial spillover	Total effect	Direct effect	Spatial spillover	Total effect
<i>Er</i>	-0.016* (-1.78)	-0.009 (-0.59)	-0.024 (-1.39)	-0.015* (-1.78)	-0.009 (-0.59)	-0.024 (-1.39)	-0.025 (-1.64)	0.018 (0.75)	-0.006 (-0.21)
<i>Ts</i>	-0.0006 (-0.54)	-0.001 (-0.27)	-0.001 (-0.44)	-0.0005 (-0.54)	0.0007 (-0.27)	-0.001 (-0.44)	-0.002 (-0.70)	-0.005 (-1.00)	-0.005 (-1.18)
<i>Inn</i>	0.095*** (5.75)	0.158*** (3.17)	0.566*** (5.85)	0.095*** (5.75)	0.158*** (3.17)	0.064 (-1.09)	0.200*** (7.04)	-0.145* (-1.73)	0.055 (-0.57)
<i>Fdi</i>	-1.973 (2.48)	-2.209** (-2.35)	-4.181** (-4.12)	-1.973** (-5.01)	-2.209** (-2.35)	-4.182** (-4.12)	-2.447*** (-3.56)	-3.387* (-2.09)	-5.834*** (-3.36)
<i>rho</i>	-0.054 (-0.79)	-0.054 (-0.79)	-0.054 (-0.79)	-0.054* (-0.79)	-0.230* (-1.71)	-0.230* (-1.71)	-0.082*** (-1.21)	-0.082*** (-1.21)	-0.082*** (-1.21)
Log - I	551,586 control	551,586 control	551,586 control	63.61 control	-63.61 control	-63.61 control	317,022 control	317,022 control	317,022 control
Year/origin	Double fixation 154	Double fixation 154	Double fixation 154	Double fixation 84	Double fixation 84	Double fixation 84	Double fixation 182	Double fixation 182	Double fixation 182

Source: completed by the authors.

Table 11. threshold effect test results.

Threshold variable	Threshold number	Threshold value	F	p	Critical value		
					10%	5%	1%
<i>Ts</i>	Single	0.495	17.85	0.157	20.670	24.411	33.740
	Double	1.194	10.76	0.463	22.442	25.740	33.617
	Triple	2.757	17.10	0.143	20.166	27.663	42.369
<i>Inn</i>	Single	0.503*	26.96	0.070	24.441	29.268	37.478
	Double	0.003	6.47	0.763	21.023	25.520	30.270
	Triple	0.937	6.51	0.690	19.205	21.866	42.703
<i>Fdi</i>	Single	1.362*	23.05	0.063	20.226	23.703	31.126
	Double	2.113	8.17	0.683	18.369	21.167	28.462
	Triple	2.180	6.86	0.670	15.207	18.544	25.776

Source: completed by the authors.

explained variables and use the per capita real GDP of provinces and cities instead of green total factor productivity as the variable to measure the *Gtfp* for regression analysis. Finally, the measurement method of the explained variables was changed. This paper calculates the green total factor productivity based on the EBM-GML model. Yu et al. (2019) changed the measurement method of green total factor productivity based on unchanged original data and used the SBM-ML model for calculation. *Ts*, *Inn* and *Fdi* still play a significant role in strengthening *Er* and *Gtfp*. The empirical results are more consistent with the original conclusions, but there are differences in the regression coefficients of explanatory variables. Therefore, the empirical results are basically stable.

5.3.4. Analysis of panel threshold effect

The above shows that *Er* has a significant negative impact on *Gtfp*. This impact will produce structural changes due to three mediating effect mechanisms: *Ts*, *Inn* and *Fdi*, which may have a nonlinear relationship. To further verify this relationship, referring to Yu and Sun (2017), this paper selects three mediating variables as threshold variables to analyze the threshold effect of *Er* on *Gtfp*. where π is the threshold and Q_{it} is the threshold variable, that is, *Ts*, *Inn* and *Fdi*. σ_{it} is a random interference term. The structure of the panel threshold model is shown in Eq. (13).

$$Gtfp = \alpha_0 + \alpha_1 Er_{it} * A1(Q_{it} \leq \pi) + \alpha_2 Er_{it} * A2(Q_{it} > \pi) + \alpha_3 x_{it} + \sigma_{it} \quad (13)$$

The results are shown in Table 11. This paper uses the bootstrap self-help sampling method to generate 300 samples to determine the threshold value and threshold number of threshold variables. Among them, the single threshold, double threshold, and triple threshold effects of *Ts* are not significant, and the single threshold effects of *Inn* are significant at the level of 10%, with thresholds of 0.503 and 1.362, respectively. The double threshold and triple threshold effects of both are not significant. There is no threshold effect in *Ts*, and there is a single threshold effect in *Inn* and *Fdi*.

5.3.5. Analysis of panel threshold effect

The threshold regression results are shown in Table 12. The results show that with the rise of *Inn* and *Fdi*, the relationship between and presents the characteristics of

Table 12. Threshold regression results.

Threshold variable	Threshold value	Coefficient	T	<i>p</i>	F
<i>Inn</i>	$Inn \leq 0.503$	-0.027***	-2.67	0.008	25.46***
	$Inn > 0.503$	0.053***	2.88	0.004	
<i>Fdi</i>	$Fdi \leq 1.362$	-0.031***	-3.05	0.002	26.61***
	$Fdi > 1.36$	0.026*	1.81	0.071	

Source: completed by the authors.

the ‘V’ threshold, which decreases first and then increases. When *Inn* is lower than 0.503, *Er* significantly inhibits the improvement of *Gtfp*, and *Er* follows the ‘cost effect’; that is, enterprises face problems such as lack of innovation incentives, lack of R&D stamina, and lack of funds. The tightening of *Er* has led to a rise in external environmental costs and a high-cost burden, forcing enterprises to improve product output and continue to accelerate the emission of pollutants, forming a vicious circle. When *Inn* is higher than 0.503, the implementation of *Er* significantly promotes *Gtfp*, which follows the ‘Porter Hypothesis’. With the improvement of the *Inn* level, the positive effect of *Er* on green development gradually appears. With the application of high and new technologies such as big data and artificial intelligence, resource allocation optimization and resource utilization improvement, the ‘innovation compensation effect’ improves the efficiency of the industrial chain and supply chain and finally improves green efficiency. When *Fdi* is lower than 1.362, *Er* significantly reduces *Gtfp*. At this time, the local government pays too much attention to the GDP first, focusing on the economy to improve performance, and takes on excesses levels of low-tech intensive industries transferred from developed countries and regions, resulting in the region becoming a ‘pollution refuge’ for developed countries and regions. When *Fdi* is higher than 1.362, *Er* has a significant positive effect on *Gtfp*. At this time, the tightening of the *Er* standard attracts rich capital and technology spillovers for local enterprises and promote the development of a green economy.

6. Conclusion and enlightenment

Based on the panel data of 30 provinces and cities in China from 2004 to 2017, this paper empirically studies the impact of *Er* on *Gtfp* in China and the intermediary effect mechanism through the spatial durbin model and threshold model. The results show that (1) *Gtfp* shows a fluctuating upward trend. The eastern region is higher than the national average. The midlands and west grew slowly before 2008 and showed a steady upward trend after 2008. (2) *Er* significantly inhibits *Gtfp*, but accelerating *Ts*, promoting *Inn* and improving *Fdi* will effectively ease the relationship between *Er* and local *Gtfp*. Among them, *Inn* is the primary driving force, with a significant spatial spillover effect. *Ts* has negative space overflow, and *Fdi* has no space overflow. (3) To further explore whether there is a nonlinear relationship between *Er* and *Gtfp*, the intermediary variable is used as the threshold variable to construct the threshold model. The analysis shows that *Ts* has no threshold effect, and *Inn* and *Fdi* have the characteristics of a U-shaped single threshold. When the levels of *Inn* and *Fdi* are low, *Er* is strengthened and economic development is hindered. With the increase in *Inn* and *Fdi* levels, *Er* can significantly mitigate the negative impact on *Gtfp*.

The conclusions of this paper provide the following useful enlightenment.

1. The formulation and implementation of scientific and differentiated environmental regulation policies. The government should set appropriate environmental regulation standards according to local conditions, maintain the existing environmental regulation intensity for the eastern region, and pay attention to the incentive effect of environmental regulation forms on green transformation. For the central and western regions with high intensities of environmental regulation, we should appropriately reduce the standard of environmental regulation. Excessive environmental regulation will increase not only the burden on enterprises but also the restrictive effect of the cost effect on the forced effect.
2. The formulation of environmental regulation policies should be guided by the green adjustment of industrial structure. A reasonable intensity of environmental regulation should further stimulate the adjustment of industrial structure, increase government subsidies for the R&D enterprises and innovation environment, encourage pursuit of green product structure by enterprises, improve production of technology and investment in advanced pollution control equipment, and resolutely abandon the traditional practice of ‘pollution first and treatment later’ to change the environmental pollution control mode from ‘end treatment’ to ‘source control’ and drive the upgrading of regional industrial structure.
3. Green technological progress is the driving force for improving high-quality economic development. Local governments should strengthen financial subsidies and preferential dividends of tax reduction and exemption for enterprises’ technological innovation strategies, encourage enterprises and R&D institutions to increase innovation investment and R&D, promote the joint participation of industry, universities and research between provinces and even urban areas in innovation activities, make use of the digital economy and internet cloud platform, accelerate green technology innovation, realize regional spillover, and improve the overall green economic development capacity.
4. The central government should control the pace of environmental policies and guide foreign investment to create healthy interactions. On the one hand, the central government should appropriately reduce local government discretion in the implementation of environmental regulations, actively guide the orderly competition of environmental regulations, and avoid the pollution paradise effect that may be caused by incomplete implementation. In addition, we should also encourage environmentally-friendly foreign-funded enterprises to settle locally, learn from and absorb the advanced green technology spillover experience of foreign-funded enterprises, and drive local enterprises to incubate and develop cleaner production enterprises to improve the coupling between foreign investment and the green transformation of China’s industrial structure.

Disclosure statement

No potential conflict of interest was reported by the authors.

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