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Testing the non-linear relationship between environmental policy and economic growth in China

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Introduction: In order to achieve the coordinated development of environmental protection and economic growth, China has implemented a series of environmental policies. However, the relationship between environmental policy and economic growth is ambiguous due to regional differences.

Methods: In this study, data of 30 provinces in China from 2010 to 2019 is collected to establish three panel threshold models with three different threshold variables and analyze the relationship between environment policy and economic growth.

Results: The results of this study are as follows: (1) when the R&D level is less than 9.890, environmental policy is detrimental to economic growth. When the R&D level is between 9.890 and 10.077, environmental policy has a slightly positive impact on economic growth. When the R&D level exceeds 10.077, environmental policy has a significant positive effect on economic growth. (2) When the level of economic development is less than 9.469, environmental policy is detrimental to economic growth. However, when the level of economic development exceeds 9.469, environmental policy has a positive effect on economic growth. (3) When the level of industrial dependence is less than 0.372, environmental policy promotes economic growth. When the level of industrial dependence exceeds 0.372, environmental policy is detrimental to economic growth.

Discussion: The novelty of this study is that there is a proved nonlinear relationship between environmental policy and economic growth, and it is concluded that the influence of environmental policy on economic growth is geographically different. We have made certain suggestions that will help achieve a win-win situation for both environmental protection and economic development.

KEYWORDS

environmental policy, economic growth, panel threshold model, threshold effects, non-linear relationship

1 Introduction

In recent years, solving the contradiction between environmental protection and economic development has become one of the most concerned issues of the Chinese government. While China has experienced rapid economic growth, its resource consumption and pollution emissions have also increased dramatically. According to data released by the National Bureau of Statistics of China, the total energy consumption in China in 2023 reached 5.72 billion tons of standard coal, marking a 5.7% year-on-year increase. The International Energy Agency (IEA) reported in the *2023 Global Carbon Emissions Report* that China's carbon dioxide emissions in 2023 reached 12.6 billion tons, accounting for 33% of the global total. China's rapid industrialization and urbanization have placed immense environmental pressure on the country (Shi et al., 2024). According to *The 2024 Global Environmental Performance Index* jointly published by Yale University, Columbia University and the World Economic Forum, China's environmental performance index ranked 118th among the 178 economies in the survey of 2024. The healthy development of a country or region relies on the coordination of population, economy, society, and the environment (Peng et al., 2024). At present, Chinese government has realized that economic growth cannot be at the expense of environmental damage. China is moving toward ecological civilization, and regards coordinating the relationship between economic growth and environmental protection as one of its goal in the future. In order to achieve this goal, China's economic growth model must be changed from the past model with relying on large-scale input factors, high-intensity consumption of resources and sacrificing the environment to a model featuring green, circular and low-carbon development (Cui et al., 2024).

Environmental policy refers to government intervention in environmental protection and appropriate use of environmental resources (Jiang et al., 2023). As a major means to achieve green development, environmental policy includes: environmentally-related mandatory rules and policies, as well as taxation, subsidies and other economic tools. On 1 January 2018, the Environmental Protection Tax Law of the People's Republic of China was officially implemented, marking the Chinese government's determination to protect the environment and achieve sustainable development, and also was a reflection of the growing environmental policy (Wang et al., 2024). The implementation of environmental policies has introduced new requirements for the existing economic development model. For example, regions that have been primarily resource-based can no longer exploit resources without restraint, and carbon emissions will be subject to strict control (Hepburn et al., 2021). However, strict environmental policies can lead to significant environmental improvements and stimulate new sources of economic growth (Wu et al., 2024a). This has made the relationship between environmental policy and economic growth unclear. Although many scholars have researched this issue, they have not reached a consistent conclusion regarding the relationship between the two (Huang et al., 2023). Furthermore, the relationship between environmental policy and economic growth is complex, influenced by various factors, yet existing studies have overlooked the differences between these factors (Huang et al., 2024). Therefore, this study further explores the complex relationship between environmental policy and economic growth by constructing a threshold regression model. It also examines the factors influencing this relationship from the perspective of regional differences. The value of this study lies in further clarifying the relationship between environmental policy and economic growth and identifying the reasons for regional differences in this relationship. This will help us better understand the coordination between the environment and the economy and provide support for policy recommendations that promote a balance between environmental protection and economic growth.

2 Literature review

The relationship between environmental policy and economic growth has long been a topic of interest among scholars worldwide. From the existing studies on the impact of environmental policy on economic growth, three representative hypotheses have emerged: the Pollution Haven Hypothesis (PHH), the Porter Hypothesis (PH), and the Environmental Kuznets Curve (EKC) (Dou and Han, 2019).

Firstly, multiple studies have shown that environmental policy is detrimental to economic development. Traditional urbanization, industrialization, and economic growth have largely relied on the extraction and consumption of natural resources, which inevitably leads to environmental degradation (Lv et al., 2024). Environmental policies that restrict the extraction of natural resources directly affect economic development (Ahmed et al., 2023). To mitigate the negative impact of environmental policies on the economy, many enterprises have begun to conduct production activities in countries and regions with lower environmental standards, leading to the formation of the Pollution Haven Hypothesis (PHH). The PHH states that for manufacturing companies, especially heavy pollution enterprises, there is a preference towards moving in countries or regions with lower environmental policy standards for their manufacturing operations (Levinson, 2023). This assumption indicates that environmental policy will lead to industrial transfer and industrial hollow, which will adversely affect local economic growth. At the same time, PHH is not just about moving "dirty" industries to areas with easy environmental policy, but about bringing out an increase in pollution emissions in the areas. If underdeveloped regions also implement strict environmental policies, it will reduce the use of non-renewable energy and the inflow of foreign direct investment, which can have a severe negative impact on the economic growth of countries that depend on resources such as fossil fuels (Murshed et al., 2021). Sadik-Zada and Ferrari (2020) present a variational model of environmental degradation. The model shows that strict environmental policy leads to a reduction in FDI, which can have a negative impact on poverty alliviation and employment opportunities in developing countries. Thus Scholars who are in favor of PHH believe that environmental policy has hindered economic development.

Secondly, some studies suggest that environmental policies are beneficial to economic development, with the "Porter Hypothesis" strongly supporting this viewpoint (Ambec and Barla, 2002). Unlike PHH, the Porter Hypothesis argues that environmental policies can promote economic growth through technological compensation effects. Specifically, appropriate environmental policies stimulate technological innovation, which not only reduces environmental pollution but also improves resource efficiency, product quality, and market competitiveness, thus fostering economic growth (Ahmad et al., 2023). Environmental pollution is a major factor affecting economic growth because emissions from pollutants such as wastewater and air pollutants increase production and management costs, suppressing economic growth (Chen et al., 2024). As climate change intensifies, the contradiction between increasing energy demand for economic growth and the non-renewable nature of natural resources becomes more prominent, making it urgent to find ways to promote sustainable economic growth (Chou et al., 2023). Many studies suggest that green technological innovation is a key solution to overcoming excessive dependence on traditional resources (Wang et al., 2025; Wang and Wang, 2024; Yang et al., 2023). Environmental policies impose new requirements on industrial development, and companies must adjust their production models to gain operational legitimacy (Xie et al., 2024). Therefore, flexible environmental policies can drive technological innovation. Technological innovation is crucial for improving production efficiency and promoting sustainable development in enterprises, achieving a win-win situation for both environmental protection and economic growth. At the same time, technological innovation, while transforming existing production models, can create new industries and employment opportunities by optimizing industrial structures, all of which contribute to the sustainability of economic development (Zou, 2024). Therefore, scholars supporting the Porter Hypothesis argue that environmental policies can achieve coordinated development between environmental protection and economic growth, with technological innovation being a key mechanism through which environmental policies impact economic growth (Manigandan et al., 2024).

Finally, some studies have found a more complex relationship between the environment and the economy. In 1991, American economists Gene M. Grossman and Alan B. Krueger, when analyzing the impact of the North American Free Trade Agreement (NAFTA) on the environment, discovered an inverted U-shaped relationship between environmental quality and *per capita* income. In their subsequent research, Grossman and Krueger (1995) further validated this hypothesis and named it the Environmental Kuznets Curve (EKC). EKC suggests that in the early stages of economic development, growth mainly relies on high-pollution industries, severely affecting environmental quality. However, as *per capita* income increases, people's awareness of environmental protection gradually strengthens, and environmental quality improves through industrial upgrading, the application of clean technologies, and other measures. EKC provides a fresh perspective for analyzing the relationship between the environment and the economy, and numerous studies have supported its viewpoint. Mohammed et al. (2024) used data from 27 EU countries between 1990 and 2019 to demonstrate the applicability of EKC. Ozkan et al. (2023) also confirmed EKC's applicability in China. However, some scholars have raised doubts about EKC. Research by Wang D. et al. (2023) shows that as income inequality deepens and income becomes more concentrated at the top, this leads to intensified consumption competition and longer working hours, which in turn increases energy consumption and pollution emissions. Therefore, the relationship between the environment and the economy has shifted from an inverted "U" shape to an "N" shape.

The analysis above reveals that the Pollution Haven Hypothesis (PHH), Porter Hypothesis (PH), and Environmental Kuznets Curve (EKC) provide deep insights into the relationship between the environment and the economy, offering important references for this study. However, they still have significant limitations. Firstly, the three hypotheses reach different conclusions, indicating that the relationship between environmental policy and economic growth remains unclear. Secondly, PHH and PH mainly rely on linear models to analyze the impact of environmental policy on economic growth, which have strict applicability conditions and insufficient consideration of the differences between various research subjects. While EKC describes the inverted U-shaped relationship between the environment and economic growth, it lacks a perspective on environmental policy. Additionally, when studying the relationship between environmental policy and economic growth, it is necessary to consider regional factors, as regional differences are also key factors affecting this relationship (Wang D. et al., 2023). To address these shortcomings, this study adopts a panel threshold model to analyze the non-linear relationship between environmental policy and economic growth from the perspective of regional differences and identifies the reasons behind this non-linear relationship.

3 Theoretical analysis of the threshold effect

Li et al. (2020) developed the China TIMES-30P model to project the key provincial socio-economic parameters and the provincial energy service demand. This model includes several socio-economic drivers such as social economy, energy supply, technology, industrial organization, policy, and population. The model provides an important insight for this study. Combined with the re-examination of PHH,PH and EKC in existing studies (Achuo and Ojong, 2024; Bagchi and Sahu, 2024), we argue that environmental policy may have a nonlinear influence on economic growth, which is considerably different in different regions. This may be due to the great differences in the level of R&D, economic development and industrial dependence of different regions. Therefore, this study establishes three panel threshold models and analyzes the threshold effects of environmental policy on economic growth, since panel threshold models can analyze the effect of changes in threshold variables on the relationship between the dependent and independent variables.

3.1 R&D level

The Porter Hypothesis (PH) explains the relationship between environmental policy and economic growth from the perspective of technical compensation effects (Wang et al., 2013b). Since the demand, the combination of factor inputs and the level of production technology in the market are constantly changing, enterprises have been always in a dynamic competitive environment (Su et al., 2024). Environmental policies will force or encourage enterprises to change their production methods through technological innovation, thereby achieving environmental improvements (Huang et al., 2021). At the same time, the technological compensation effect brought about by environmental policies helps enterprises enhance market competitiveness, leading to a win-win situation for both economic quality and ecological environment (Yin et al., 2024).

However, some regions are lagging behind in technology due to insufficient R&D investment. Under the pressure of environmental policy, it is not likely to promote technological reforms, and the technical compensation effect will not work. At this time, the environmental policy cannot improve the production efficiency of the enterprise. Instead, it will increase the production cost of the enterprise in terms of fines, taxes, etc., and reduce the business operations of the enterprise (Wu et al., 2024b). In contrast, in regions with higher R&D investment, there are more adequate technology funding, human capital, and infrastructure to support technological innovation. In general, the technical compensation effect of environmental policy on economic growth can only occur in regions with high R&D levels (Du et al., 2021). The technical compensation effect can not only offset the environmental cost imposed by environmental policy on business operations, but also improve the capability of enterprises in independent innovation and long-term development, which helps to promote regional economic growth. On the contrary, due to the backward technological innovation, environmental policy is not able to exert the technical compensation effect in regions with low R&D levels (Chen et al., 2023). The environmental costs generated by environmental policy are not compensated, and the productivity of enterprises is restricted by environmental policies, resulting in a decline in economic development. Therefore, this study proposes the following hypothesis:

Hypothesis 1: With low R&D level, environmental policy will lead a slowdown in economic growth; with high R&D level, environmental policy has a positive influence on economic growth.

3.2 Level of economic development

The relationship between environmental policy and economic growth is also affected by the level of regional economic development. The implementation of environmental policies will bring cost effects (Huang and Yi, 2023), which mainly refers to environmental cost and economic cost. Environmental cost means that the implementation of environmental policies will force enterprises to pay for the environmental resources used in their production process, so environmental policies increase the production costs of enterprises (Du et al., 2020). Economic cost means that the implementation of environmental policies will increase government spending on pollution control and prevention (Feng et al., 2021). From the perspective of environmental cost and economic cost, the cost effects of environmental policy will hurt economic growth.

Nonetheless, the cost effects of environmental policy may change depending on the level of regional economic development. Once people meet basic survival and development needs, they will increase the demand for quality of living environment. Therefore, people in regions with high levels of economic development can consciously protect the environment, control and treat waste water and waste gas generated in production activities, which can reduce the government's financial pressure on environmental management (Shah and Asghar, 2024). And for the above reason, the cost effect of environmental policy is lower in regions with high levels of economic development. and accordingly the cost effect of environmental policy would be greatly weakened. Conversely, in regions with low levels of economic development, people tend to exchange environmental resources for economic development than to provide financial support the governance environment (Jahanger et al., 2022). The implementation of environmental policies will undoubtedly bring drastic economic costs. Compared with regions with higher levels of economic development, the cost effect of environmental policy is higher in regions with low economic development levels. While at this time, the cost effect of environmental policy is greatly enhanced. Therefore, this study proposes the following hypothesis.

Hypothesis 2: With a low level of economic development, environmental policy will lead a slowdown in economic growth; with a high level of economic development, environmental policy has been a positive impetus to economic growth.

3.3 Level of industrial dependence

The level of industrial dependence refers to the contribution of regional industrial value-added to regional gross domestic product (GDP). The relationship between environmental policy and economic growth may be affected by the level of industrial dependence as well, because environmental policy may bring not only "technology compensation effect" and "cost effect", but also "restraint effect" (Wu et al., 2020). Enterprises make their decisions on the production and operation based on the consumers' demand and income, enterprise technology level and production process conditions. However, when the government implements policies on pollution prevention and environmental control, enterprises need to consider environmental factors in their original decisions on the production and operation (Zhang et al., 2023). When the decision-making of production and operation is restricted by environmental policies, enterprises can only arrange production and organize management under a smaller decision-making set, which will affect the efficiency of resource allocation and factor productivity of enterprises. Furthermore, the restraint effect of environmental policy will restrict the promotion of regional economic growth (Lee et al., 2023). Furthermore, the constraining effect of environmental policies can also increase administrative and supervision costs, while shrinking the scale of traditional industries, which will limit regional economic growth (Ren et al., 2023).

Thus, we propose that the degree of "restraint effect" is different in regions with different levels of industrial dependence. The "restraint effect" of environmental policy mainly affects enterprises by constraining their operation and production decisions. From a practical point of view, the restraint effect of environmental policy mainly produces profound consequences on industrial enterprises, but less on the service enterprises (Tang et al., 2020). Therefore, the regions with high levels of industrial dependence are significantly affected by the restraint effect. On this occasion, the restraint effect of environmental policies will be enhanced and lead a slowdown in economic growth (Paramati et al., 2022). On the other hand, regions with low industrial dependence are less affected by the restraint effect. At this time, the restraint effect of environmental policy is greatly weakened, and the influence of environmental policy on economic growth is positive. Therefore, this study proposes the following hypothesis:

Hypothesis 3: Environmental policy has a positive effect on economic growth in regions with low levels of industrial dependence, while it will lead a slowdown in economic growth in regions with high levels of industrial dependence.

4 Selecting the variables and building the models

Based on the theoretical analysis, it was found that regional innovation levels, economic development levels, and industrial dependence have different impacts on the relationship between environmental policy and economic growth. Therefore, this study uses data from 30 provinces, municipalities, and autonomous regions in China (excluding Hong Kong, Macau, Taiwan, and Tibet) from 2010 to 2019. It establishes three panel threshold models to examine the differences in the impact of environmental policies on economic growth under different factors. The definition of each variable is as follows:

Economic growth:This study follows the approach of Ma et al. (2024) by using the annual GDP growth in each province of China to represent the level of economic growth. (GDP, unit: 100 million of CNY). The data source is the National Bureau of Statistics of China.

Environmental policy: In existing studies of China's environmental policy issues, there is no single uniform measurement of EP. Scholars mainly adopt the following two methods to measure EP. The first method is to use pollution emission intensity to measure environmental policy (Hossain, 2024). It means to remove the dimension of different pollutant emissions through standardization, then calculate the weight of different pollutant emissions, and build a measurement index of pollution emission intensity of a certain region. The second method is to use the investment in environmental pollution control to reflect the intensity of EP in a direct way (Wu et al., 2024c). Compare with the second method, the first one mainly reflects the pollution emission intensity of a certain region, but does not directly reflect the level of EP. And the second method not only reflects the intensity of pollution control, but also indirectly reflects the level of pollution. The higher the amount of pollution control investment indicates that a region generates and discharges more waste, with more serious pollution problems and needs for more investment to improve the environment (Guo et al., 2023). Therefore, the investment in environmental pollution control can more directly measure the intensity of EP and reflect the level of regional EP. In this study, the amount of regional pollution control investment is used to express the EP. (EP, unit: 100 million of CNY). The data source is the National Bureau of Statistics of China.

R&D level: This study follows the approach of Li et al., (2023b) by using the number of invention patent grants to express regional R&D levels, because patents can straight reflect the results of research activities. (R&D, unit: patent). The data source is the National Bureau of Statistics of China.

Economic development level (ED): This study uses regional GDP to express the level of regional economic development. (ED, unit: 100 million of CNY). The data source is the National Bureau of Statistics of China.

Industrial dependence level: The level of industrial dependence express the dependence degree of regional GDP on industrial added value, namely, the contribution of industrial added value to GDP. Therefore, this study follows the approach of Yang and Khan (2022) by using the ratio of regional industrial added value to regional GDP to indicate the regional industrial dependence level. (Ind, unit:%). The data source is the National Bureau of Statistics of China.

In addition to the above major variables, to improve the accuracy of model estimation, this study draws on the study of Zhengning and Jinhua (2022) and sets control variables in the process of modeling, which are as follows:

Capital deposit: Capital deposit is one of the most important factors affecting economic growth. The investment in fixed assets is used to express the capital deposit, which is recorded as K. (K, unit: 100 million of CNY). The data source is the National Bureau of Statistics of China.

Labor force: Labor force is another important factor affecting economic growth. The employment of each region is used to indicate the labor input of the region, which is recorded as L. (L, unit: ten thousand people). The data source is the National Bureau of Statistics of China.

Per-capita carbon emissions:Controlling carbon emissions is currently an important means taken by China to achieve economic growth and environmental protection. According to the *Carbon Emission Guidelines* issued by the United Nations Intergovernmental Panel on Climate Change (IPCC), carbon emissions *per capita* are calculated as shown in Formula 1. (RCE, unit: tons)

$$RCE_i = \left(\sum_{i=1}^{8} A_i B_i\right) \Big/ Pep \tag{1}$$

RCE refers to carbon emissions *per capita*; i refers to energy type; A_i refers to energy consumption; B_i refers to carbon emission factor, which are separately 0.7559, 0.8550, 0.5857, 0.5538, 0.5714, 0.5921, 0.6185, and 0.5042; Pep refers to the number of people in the region at the end of the year.

In order to reduce heteroskedasticity in the data, this study follows Xie et al. (2023) approach and all data are taken in logarithmic form (except for data in units of percentages) and come from *the 2020 China Statistical Yearbook*. The statistical description of variables is shown in Table 1.

The panel threshold model proposed by Hansen (1999) was examined in this study. By virtue of the model, slice functions could be built based on changes in the threshold of variables, so as to analyze the relationship and degree of influence between variables (Xie and Zhang, 2021).

The basic equation of the model is as follows:

$$GDP_{it} = \mu_i + \beta_1' EP_{it} I(q_{it} \le \gamma) + \beta_2' EP_{it} I(q_{it} > \gamma) + e_{it} \tag{2}$$

According to the variables and measurements selected in this study, the definition of each code in this model is listed in Table 2.

In Formula 2, the indicator function will be assigned a value of 1 when the conditions in the parentheses are met; otherwise it will be assigned a value of 0. Formula 2 could be adjusted accordingly as follows Equation 3:

$$GDP_{it} = \begin{cases} \mu_i + \beta_0' z_{it} + \beta_1' EP_{it} + e_{it}, q_{it} \le \gamma \\ \mu_i + \beta_0' z_{it} + \beta_2' EP_{it} + e_{it}, q_{it} > \gamma \end{cases} \tag{3}$$

TABLE 1 Statistical description of variables.

Variables/(Units)	Obs	Average value	S.D.	Min	Max	Unit
GDP	300	9.548	0.892	6.926	11.404	100 million of CNY
EP	300	2.686	0.946	−1.032	4.953	100 million of CNY
R&D	300	9.525	1.518	5.429	12.715	patent
Ind	300	0.461	0.083	0.190	0.590	%
K	300	9.195	0.865	6.369	10.919	100 million of CNY
L	300	6.015	0.768	3.851	7.587	Ten thousand people
RCE	300	0.917	0.612	−0.862	3.108	Tons

Note: The minimum value of EP in the table is negative because the original data is less than 1 (in units of 100 million of CNY) after logarithmic processing.

TABLE 2 Code definition.

Code	Definition
i	Heavily polluting enterprises
t	Year
Y_{it}	Dependent variable
x_{it}	Independent variable
q_{it}	Threshold variable
γ	Threshold value to be estimated
e_{it}	Random disturbance item
$\beta_1^{'}, \beta_2^{'}$	Coefficient to be estimated
μ_i	Remove individual-specific means
I (.)	Indicator function

z_{it} is a set of control variables, including capital deposit and labor force. The panel threshold model is divided into two intervals, while the sum of the squared errors based on the Hansen calculations is as follows:

$$S_1(\gamma) = \hat{e}^*(\gamma)'\hat{e}^*(\gamma) = GDP^{*'}\left(1 - EP^*(\gamma)'(EP^*(\gamma)'EP^*(\gamma))^{-1}EP^*(\gamma)'\right)GDP^* \tag{4}$$

where $EP_{it}(\gamma) = \begin{pmatrix} EP_{it}I(q \leq \gamma) \\ EP_{it}I(q \geq \gamma) \end{pmatrix}$; $GDP_{it}^* = GDP_{it} - \bar{GDP}_{it}$; $e_{it}^* = e_{it} - \bar{e}_{it}$; $EP_{it}^* = EP_{it} - \bar{EP}_{it}$; $\hat{\beta}(\gamma) = (EP^*(\gamma)'EP^*(\gamma))^{-1}EP^*(\gamma)'GDP^*$; $\hat{e}^*(\gamma) = GDP^* - EP^*(\gamma)\hat{\beta}^*(\gamma)$.

Moreover, γ can be estimated by least squares and easily determined by minimization of the concentrated sum of the squared errors, which is shown in Formula 4. The least squares estimators are as follows Equation 5:

$$\hat{\gamma} = \arg\min_{\gamma} S_1(\gamma) \tag{5}$$

After $\hat{\gamma}$ is obtained, the residual variance is as follows Equation 6:

$$\hat{\sigma}^2 = \frac{1}{n(T-1)}\hat{e}^{*'}\hat{e}^* = \frac{1}{n(T-1)}S_1(\hat{\gamma}) \tag{6}$$

Given there is only one γ in the above example, the model is called single threshold model. (Panel threshold model with only one threshold value). Single threshold model can be expressed as follows:

$$GDP_{it} = \mu_i + \beta_0^{'}z_{it} + \beta_1^{'}EP_{it}I(q_{it} \leq \gamma_1) + \beta_2^{'}EP_{it}I(q_{it} > \gamma_1) + e_{it} \tag{7}$$

Thereafter, we can deduce the double threshold model (Panel threshold model with two threshold values). Double threshold model can be expressed as follows:

$$GDP_{it} = \mu_i + \beta_0^{'}z_{it} + \beta_1^{'}EP_{it}I(q_{it} \leq \gamma_1) + \beta_2^{'}EP_{it}I(\gamma_1 < q_{it} \leq \gamma_2) + \beta_3^{'}EP_{it}I(q_{it} > \gamma_2) + e_{it} \tag{8}$$

It can be seen from Equation 7 and Equation 8 that only one threshold value is selected in the single threshold model, and the model is divided into two segments; while there are two different threshold values in the double threshold model, and the model is divided into three segments.

5 Empirical results and discussion

In the double threshold model (Equation 8), the indicator function $I(.)$ has the following three cases: In the first case, neither γ_1 nor γ_2 exist, indicating that the threshold variable does not affect the relationship between environment policy and economic growth. In the second case, γ_1 exists but γ_2 does not exist, indicating that as the value of the threshold variable increases, the relationship between environment policy and economic growth changes once. In the third case, γ_1 and γ_2 both exist, indicating that as the value of the threshold variable increases, the relationship between environment policy and economic growth changes twice.

The F Value and P Value calculated by the threshold estimation are provided in Table 3. It can be seen that if we take the R&D level as the threshold variable, two thresholds will be calculated in the model, which are significant at the interval of 10% level and the 1% level respectively; while if we take the ED level or IND level as the threshold variable, one threshold will be calculated in the model, which is significant at the 1% level.

Based on the results in Table 3, we can determine the number of thresholds. As shown in Table 4.

As mentioned above, the panel model with two threshold values can be divided into three segments. The segmentation results are shown in Table 5.

TABLE 3 Threshold effect test.

Variables	Single threshold model						Double threshold model					
	F value	*p* value	BS	10%	5%	1%	F value	*p* Value	BS	10%	5%	1%
R&D	26.24	0.085	300	24.816	31.732	56.255	28.71	0.005	300	18.268	21.012	28.471
ED	163.21	0.007	300	26.978	32.031	53.225	10.36	0.397	300	25.012	31.631	45.796
IND	55.12	0.009	300	29.857	36.091	52.847	11.42	0.581	300	26.861	36.235	47.941

TABLE 4 Threshold value estimation.

Variables	The first threshold [lower upper]	The second threshold [lower upper]
R&D	9.890 [9.804 9.901]	10.077 [10.026 10.082]
ED	9.469 [9.464 9.643]	
Ind	0.372 [0.318 0.373]	

TABLE 5 Threshold model regression results.

GDP	OLS	Threshold effect model		
		R&D	ED	IND
EP	0.017 ***(0.004)	−0.031 ** (0.027) (R&D ≤ 9.890)	−0.021 ** (0.016) (ED ≤ 9.469)	0.048 *** (0.001) (Ind ≤0.372)
		0.087 *** (0.000) (9.890 < R&D ≤ 10.077)	0.023 ** (0.018) (ED > 9.469)	−0.020 * (0.075) (Ind >0.372)
		0.169 *** (0.002) (R&D > 10.185)		
K	0.511 *** (0.000)	0.399 *** (0.000)	0.471 *** (0.000)	0.516***(0.000)
L	0.547 *** (0.000)	0.491 *** (0.000)	0.436 *** (0.000)	0.535 *** (0.000)
RCE	0.481 *** (0.000)	0.507 *** (0.000)	0.514 *** (0.000)	0.483 *** (0.000)
Cons	1.422 *** (0.000)	2.621 *** (0.000)	2.651 *** (0.000)	1.980 *** (0.000)
obs	300	300	300	300
F test	36.62	32.07	26.33	33.92
Prob > F	0.000	0.000	0.000	0.000
R^2	0.9324	0.9347	0.9298	0.9352

Note: () is the standard error, "***", "**", and "*" represent the 1%, 5%, and 10% levels of significance respectively.

The calculation results of the threshold model show that EP have a threshold effect on economic growth due to the changes in the levels of the three threshold variables.

(1) When the R&D level is used as a threshold variable, the panel threshold model will have the following three results. The first result: when the R&D level is less than 9.890, the influence coefficient of environmental policy on economic growth is −0.031, which indicates that environmental policy is not conducive to economic growth. The second result: when the R&D level is between 9.890 and 10.077, the influence coefficient of environmental policy on economic growth is 0.087, which indicates that environmental policy has a slight contribution to economic growth at this time. The third result: when the R&D level is higher than 10.077, the environmental policy still has a positive influence on economic growth. Compared to the second result, the degree of influence is stronger, and the marginal influence coefficient is 0.169. The above results prove that with the increase of R&D level, the influence of environmental policy on economic growth changes from negative to positive. Specifically, the level of R&D affects the relationship between the enviromental policy and economic growth. In regions with low R&D levels, environmental policy has a negative influence on economic growth; in regions with high R&D levels, environmental policy has a positive

influence on economic growth. Therefore, Hypothesis 1 is confirmed.

Evidently, R&D level has a significant influence on the relationship between environmental policy and economic growth. In other words, the influence of environmental policy on economic growth is subject to regions with different levels of R&D (Yu et al., 2023). Environmental policies require enterprises to adopt new environmental protection equipment and green production technologies. In regions with low research and development (R&D) levels, enterprises often lack the technological capacity to effectively respond, leading to increased production costs, reduced competitiveness, and, consequently, a negative impact on economic growth (Wang D. et al., 2023). At the same time, regions with lower R&D levels tend to have a high dependence on traditional high-pollution industries. The implementation of environmental policies restricts these traditional industries, and low R&D levels prevent a rapid transition to green industries or the absorption of advanced technologies, leading to industrial hollowing, rising unemployment rates, and economic downturns (Zhang and Zheng, 2024). In contrast, in regions with higher R&D levels, enterprises have the capability to transform environmental constraints into technological opportunities. These enterprises are able to quickly absorb, spread, and innovate green technologies, enabling a rapid shift to high-value-added green industries (Shen and Zhang, 2023). The technological compensation effect of environmental policies can be fully realized in such regions.

(2) When the level of economic development is used as the threshold variable, the panel threshold model leads to the following two results. The first result: when the level of economic development is less than 9.469, the influence coefficient of environmental policy on economic growth is −0.021, indicating that environmental policy is detrimental to economic growth. The second result: when the level of economic development is higher than 9.469, the influence coefficient of environmental policy on economic growth is 0.023, indicating that environmental policy can promote economic growth. The above results prove that with the increase of economic development level, the influence of environmental policy on economic growth shifts from negative to positive. Specifically, in regions with low economic development levels, environmental policy has a negative influence on economic growth; in regions with high economic development levels, environmental policy has a positive influence on economic growth. Therefore, Hypothesis 2 is confirmed.

Evidently, economic development level has a significant influence on the relationship between environmental policy and economic growth. In other words, the influence of environmental policy on economic growth is subject to regions with different levels of economic development. Both enterprises and governments face significant costs in implementing environmental policies, which take up development funds. For regions with lower economic development levels, this imposes substantial cost pressure and adversely affects regional economic development (Huang et al., 2024). At the same time, regions with lower economic development levels tend to have inadequate infrastructure and incomplete market mechanisms, making it difficult to meet the new requirements of environmental policies (Ren et al., 2023). Furthermore, in these regions, enterprises often have lower environmental awareness, leading to high policy implementation costs and policy failure (Hu et al., 2023). On the contrary, in regions with high economic development level, people who meet basic survival and development needs will increase their requirements for living environment (Hariram et al., 2023). Therefore people in regions with high economic development levels tend to protect the environment spontaneously and the government's fiscal expenditure on EP will also decrease. At this time, the economic cost brought by environmental policy is low, and environmental policy has a positive influence on economic growth. Also, in regions with higher economic development levels, infrastructure is more advanced, and enterprises are better equipped to adjust their industrial structure to achieve green development (Lin and Xie, 2023).

(3) When industry dependence is used as the threshold variable, the panel threshold model will have the following two results. The first result: when the level of industry dependence is less than 0.372, the influence coefficient of environmental policy on economic growth is 0.048, indicating that environmental policy would promote economic growth under this condition. The second result: when the level of industry dependence is higher than 0.372, the influence coefficient of environmental policy on economic growth is −0.020, indicating that environmental policy would exert a negative effect on economic growth. The above results prove that with the increase of industrial dependence level, the influence of environmental policy on economic growth changes from positive to negative. Overall, the relationship between environmental policy and economic growth is influenced by industrial dependence levels. In regions with low industrial dependence levels, the environmental policy has a positive influence on economic growth. On the contrary, in regions with high industrial dependence, environmental policy would lead a slowdown in economic growth. Therefore, Hypothesis 3 is confirmed.

Evidently, industrial dependence level has a significant influence on the relationship between environmental policy and economic growth. In other words, the influence of environmental policy on economic growth is subject to regions with different levels of industrial dependence. Compared to the primary and secondary sectors, the tertiary sector consumes fewer resources and produces lower pollution emissions, meaning environmental policies have a smaller impact on it (Xiao et al., 2023). For example, compared with the service enterprises, environmental policy will have a greater restraint effect on industrial enterprises. Additionally, the tertiary sector is more flexible in the market and adaptable to policies, making it easier to adjust its industrial structure and reduce the transformation costs caused by environmental policies (Nilsson et al., 2021). Therefore, if regional GDP heavily depends on industrial added value, the restraint effect brought by environmental policy will be strong and environment policy has a negative influence on economic growth. On the contrary, in regions with low industrial dependence level, the economic development mainly depends on services, so the restraint effect of environmental policy is difficult to work and environment policy has a positive influence on economic growth.

6 Conclusions and recommendations

In this study a panel threshold model is established by using panel data at the provincial level in China to study the influence of EP on economic growth. The results show that there is a nonlinear effect of environmental policy on economic growth. Specifically, there is a threshold effect of environmental policy on economic growth, which is determined by the level of R&D, the level of economic development and industrial dependence. (1) In regions with low levels of R&D, environmental policy is detrimental to economic growth. In contrast, in areas with high levels of R&D the environmental policy will promote economic growth. (2) In regions with low levels of economic development, the environmental policy is detrimental to economic growth. But in areas with higher levels of economic development, the environmental policy can advance economic growth. (3) In regions with high levels of industrial dependence, the environment policy will slowdown economic growth. However, in regions with low levels of industrial dependence, the environment policy can promote economic growth.

In order to achieve a sustainable development, the Chinese government regards “green development” as its concept. It can be predicted that Chinese government will continue to intensify environmental policy. However, the research in this study shows there is a nonlinear relationship between environmental policy and economic growth. Under different circumstance, EP can either promote or slowdown economic growth. Achieving a synergistic development between environmental protection and economic development is an important goal for China in the future. Upon this account, we propose the following recommendations based on the research conclusions.

First, Chinese governments should implement EP in regions with high R&D levels, which can promote regional economic growth while controlling environmental pollution. However, the government’s implementation of EP in regions with low R&D levels will hinder regional economic growth. Hence, the levels of R&D should be given priority before the implementation of EP. This is because the technical compensation effect of environmental policy can only work in regions with high R&D levels. With the implementation of environmental policy, in regions with high levels of R&D, the technological advantages can be fully played to help enterprises there in the reform of production technology and the improvement of production efficiency and resource allocation efficiency. In doing so, regional economic growth will be improved with pollution problems solved at the same time, reflecting the positive influence of environmental policy on economic growth in regions with high levels of R&D. In regions with low R&D levels, the technology compensation effect is hard to be supported due to insufficient resources such as funds, talents and knowledge. At this time, the cost effect and the restraint effect brought by environmental policy cannot be offset, reflecting the negative influence of environmental policy on economic growth in regions with low levels of R&D. For regions with lower R&D levels, the government should adopt a gradual environmental policy. In the early stages, appropriate and more lenient environmental policies should be implemented, allowing enterprises sufficient time to enhance their green production capabilities. At the same time, the government should strengthen inter-regional technological exchanges to help enterprises improve their innovation capabilities. Enhancing the learning ability of enterprises is also crucial, as it helps improve their ability to absorb new technologies and processes. Furthermore, as information technology matures, the role of the digital economy in improving green innovation is becoming increasingly significant (Luo et al., 2023). Therefore, both the government and enterprises should fully capitalize on the major opportunities presented by the digital economy to enhance their green development capabilities.

Second, the government’s implementation of EP in regions with high economic development levels is more likely to achieve synergy between environmental protection and economic growth. However, the implementation of overly stringent EP in regions with low levels of economic development may be detrimental to regional environmental growth. The reason is that once people meet basic survival and development needs, they will call or a better quality of living environment. However, people in regions with high economic development levels can spontaneously protect the environment, control and treat waste water and waste gas generated in production activities, which can reduce the government’s expenditure for environmental governance. Thus, EP in regions with high economic development levels is help to avoid economic costs, reflecting the positive influence of environmental policy on economic growth. On the contrary, in regions with low levels of economic development, people are prone to exchange environmental resources for economic development than to provide financial support the governance environment, reflecting the negative influence of environmental policy on economic growth. In regions with lower economic development levels, to achieve a win-win situation for both environmental protection and economic growth, government departments should first establish a dynamic environmental standards system to reduce the negative impacts of environmental policies on economically weaker regions (Wang and Salman, 2023). Additionally, special funds should be set up to compensate enterprises for their environmental protection expenditures (Yuan et al., 2024). Enterprises that comply with environmental protection regulations and promote green development should be rewarded. Secondly, increased investment in environmental protection infrastructure is necessary to enhance regional environmental capacity (Peng et al., 2023). Moreover, government departments should place more emphasis on the cultivation and introduction of green talent, intensify the promotion of environmental protection knowledge, and encourage public participation in environmental protection initiatives.

Finally, in regions with low levels of industrial dependence, environmental policy can achieve a win-win situation for environmental protection and economic growth. However, in regions where industrial added value contributes a lot to regional GDP, the economic growth may ulitimately be swayed by the environmental policy. Compared with the service enterprises, industrial enterprises are more susceptible to environmental policy. In regions with high levels of industrial dependence, environmental policy have largely restricted the decisions on the production and management of local industrial enterprises. When the decision-making of production and operation of enterprises is restricted by environmental policy, enterprises can only arrange production and organize management under a smaller decision-making set. Under this circumstance, the resource allocation efficiency and factor productivity of enterprises would be affected, leading a slowdown in regional economic growth. However, only by focusing on environmental protection can we achieve a sustainable development. We should completely abandon the traditional model of economic development based on resource consumption. Especially in regions with high levels of industrial dependence, environmental standards should be exactly enforced. Based on the above conclusion, when it comes to assess local governments, environmental protection should be given a appropriate priority, while the proportion of assessment of economic growth should be properly reduced, so as to promote the implementation of environmental policies. To achieve these goals, the government should, on one hand, encourage industrial enterprises to invest in green innovation and adopt green production methods to reduce waste generation and emissions (Mehmood et al., 2024). For instance, digital transformation can significantly reduce the pollution emissions of enterprises (Li et al., 2023a). On the other hand, government industrial planning should focus on reducing dependence on traditional industries, adopting green energy and green technologies to fundamentally address resource consumption and pollution emissions (Usman et al., 2024).

The innovation of this study lies in constructing a threshold regression model to demonstrate the non-linear relationship between environmental policy and economic growth. This non-linear relationship is driven by differences in regional R&D levels, economic development levels, and industrial dependence. However, this study still has some limitations that need to be addressed in future research. On one hand, with the rapid development of emerging industries such as digitalization and artificial intelligence, the industrial structure will undergo significant changes. The impact of these emerging industries on the relationship between environmental policies and economic growth requires further exploration. On the other hand, this study focuses on the complex relationship between environmental policies and economic growth at the regional level. From a practical perspective, environmental policies directly affect the production and business activities of enterprises. The micro-level impact of environmental policies also deserves attention.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZW: Conceptualization, Writing–original draft. NW: Methodology, Writing–review and editing. RL: Data curation, Writing–review and editing.

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