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Research article

The impact of environmental regulations on the upgrading of the industrial structure: Evidence from China

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ABSTRACT

China's economy has transitioned into a phase of high-quality development, with enhancing its industrial structure becoming a critical objective. We gathered panel data from 30 major provinces in China from 2010 to 2020 and employed the fixed effects model to assess the actual influence of environmental regulations on industrial structure upgrading. Our empirical findings show that the impacts of various environmental regulations on industrial structure upgrading in China are significantly different. Mandatory environmental regulation demonstrates an inverted U-shaped nonlinear correlation with the upgrading level of the entire industrial structure. When the intensity of this regulation is low, it significantly accelerates industrial structure upgrading. As the intensity of this regulation rises, its effect on industrial structure upgrading is inhibitory. In contrast, induced environmental regulation exhibits a nonlinear U-shaped relationship with industrial structure upgrading and shows a nonlinear change trend of first decreasing and then rising. When the intensity of induced environmental regulation reaches a certain critical point and continues to increase, it will change from a negative influence on the upgrading of the industrial structure to a promoting effect. The further discussion of threshold regression and the robustness test also led to similar conclusions. The above research is conducive to the Chinese government's rational use of environmental regulation tools to promote industrial structure upgrading. It is also beneficial to developing countries, allowing them to learn from China's experience to improve the effectiveness of environmental regulation and boost their industrial development.

1. Introduction

In today's world, environmental pollution is becoming increasingly severe, with industrial and agricultural activities being the most prominent sources of environmental pollution [1–3]. Since the 1970s, many countries have mandated environmental laws and regulations to promote environmental protection [4], such as the *Clean Water Act* of 1972 in the USA and the *Control of Pollution Act 1974* in the UK. Recently, The 2018 United Nations Climate Change Conference proposed "promoting green and low-carbon development in industry", and the 2019 Climate Conference called for "creating a green manufacturing system to achieve industrial emission reduction". Relevant studies have shown that upgrading industrial structures is an important and effective way to control environmental pollution [5].

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Focusing on China, the country's rapid economic development since the reform and opening-up has caused severe ecological damage and environmental pollution [6,7]. Related research shows that environmental losses caused by pollution account for 3%–11% of China's GDP [8], which means that with the slowing of China's economic growth, severe environmental pollution will eventually become an obstacle to China's economic development. In 1989, the Chinese government promulgated the first version of the *Environmental Protection Law of the People's Republic of China*, which stipulates environmental protection, supervision, pollution prevention and legal liability. To promote the coordinated development of the economy and the environment, the Chinese government has established guidelines in line with the times and has continued to introduce environmental regulation policies at various top-level conferences [9]. From "equal emphasis on pollution prevention and ecological protection" in the 1990s to "adherence to ecological priorities" proposed in the 2012 Chinese government work report, China's environmental regulatory system has undergone many significant changes, and the *Water Pollution Prevention and Control Law*, *Air Pollution Prevention and Control Law*, *Solid Waste Environmental Pollution Prevention and Control Law*, *Total Pollutant Emission Control Plan*, *Cross-century Green Project Planning* and other regulations have been enacted. China's environmental regulation has experienced many changes, and the status of "ecology" has become increasingly prominent while "development" is stable [10], the timeline of the evolution of China's major environmental regulations is shown in Fig. 1. The cumulative effect of environmental regulation has been significant, and the previously damaged environment has been partially restored [11]. Numerous high-polluting and high-emission enterprises have been closed down and transformed. However, China's ecological environment has yet to undergo structural and fundamental changes, and environmental protection still faces many challenges [12,13]. To promote coordinated economic and environmental development [14,15], the Chinese government has continued to introduce environmental regulatory policies [16], such as the 2017 proposal to "promote economic development quality reform, efficiency reform, and dynamic reform, improving total-factor productivity, and focusing on the coordinated development of the industrial system of the real economy, technological innovation, modern finance, and human resources". *China's* 14th *Five-Year Plan* also clearly states its commitment to deepening efforts in environmental legislation [17], ecological space control, environmental economic policy and reform, environmental performance evaluation and accountability mechanisms, environmental governance systems, etc., to transform development modes and pay more attention to the role of environmental regulation and market mechanisms in ecological protection [18]. Moreover, to cope with climate change, more than 165 countries worldwide have signed the Paris Agreement [19]. China has committed to "striving to reach peak carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060" [20].

In this context, China's environmental regulatory system will be further improved, and its impact on industrial structure upgrading will be more profound [21]. Since the reform and opening up, China's industrial structures have been continuously optimized. At present, the proportion of primary industry firms shows a steady decline, but the decline is likely to slow down due to the implementation of the rural revitalization strategy and the rising price of agricultural products. Against the background of new technology and industrial transformation, innovation-driven development, and hard constraints of the "dual carbon" target, the high-end development trend of China's secondary industry has gradually emerged, and green development has reached a new level. Against the background of new-type urbanization and the upgrading of residents' consumption quality, China's tertiary industry has become a leading industry in economic development [22]. However, the policy effectiveness of some environmental rules has decreased, and the continuously rising carbon emissions price is urging industrial restructuring while also generating significant policy costs, leading to increased production costs for enterprises. When enterprises conduct innovative R&D to reduce costs, investment in R&D funds will squeeze out other activity costs, leading to new problems such as reduced production efficiency and product quality decline [23,24].

This paper aims to empirically analyze the impact of environmental regulations on China's industrial restructuring and propose corresponding policy recommendations by using panel data from 30 provinces in China from 2010 to 2020. The contribution and objectives of this paper lies in two aspects: First, using China's provincial panel data, this study provides new evidence to promote industrial structure upgrading and serves as a reference for Chinese government departments to develop environmental regulations scientifically. Second, the study distinguishes between mandatory and induced environmental regulations and investigates the impacts of these two types of regulations on industrial structure upgrading. This approach allows for comprehensive research and evaluation of the effectiveness of the two environmental regulations. The findings could also provide valuable insights for developing countries,

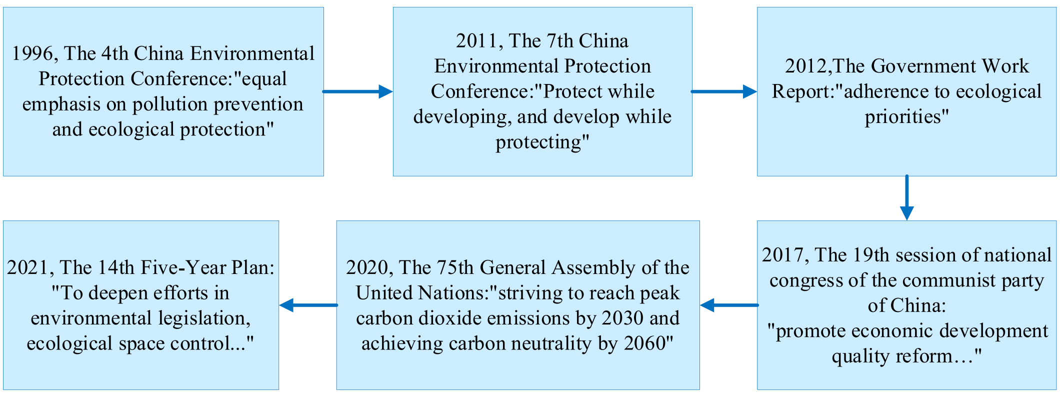

Fig. 1. Timeline of the evolution of major environmental regulations in China.

allowing them to formulate environmental regulation policies from different perspectives based on their actual conditions, promoting industrial structure upgrading to facilitate the sustainable development of their economies.

The remainder of this paper is presented as follows: Section 2 is the literature review, which analyzes the critical literature focusing on the article's keywords and performs a comprehensive review. Section 3 presents the data and methodology, explaining the measurement methods and data sources of the explanatory variables, explained variables, and control variables. The related empirical model equations are established. Section 4 presents the analysis of the empirical results and discussion. The descriptive statistics, the baseline regression and robustness test results are analyzed. Finally, Section 5 discusses the conclusions and offers suggestions for policies.

2. Literature review

Environmental regulation refers to measures taken to protect the environment from various forms of pollution. Currently, there are four main methods for measuring it: (1) The single indicator method, which is the most common approach, uses a single economic variable to quantify environmental regulation. For example, Antweiler et al. [25] used per capita income to measure the environmental regulation intensity. Lanoie [26] used the proportion of pollution expenditure to total enterprise costs to measure the environmental regulation intensity. (2) The composite indicator method uses various statistical indicators to measure a variable. For example, Chakraborty and Mukherjee [27] used an environmental performance index to measure the environmental regulation intensity. (3) The assignment method assigns values to environmental regulation according to some artificial rules to differentiate its degree. For example, Beers et al. [28] assigned 24 points to environmental regulation. (4) The classification method categorizes variables based on some characteristics to study the different effects of different types of variables. For example, Baumol and Oates [29] classified environmental regulation into administrative and market types. In the research on the relationship between environmental regulation and industrial structure upgrading, different types of environmental regulation may have different effects on industrial structure upgrading. Milliman and Prince [30] divided environmental regulation into five types: direct controls, emission subsidies, emission taxes, free marketable permits, and auctioned marketable permits. Using neoclassical economic theory (marginal analytical methods), they conclude that emission taxes and auctioned permits provided the highest firm incentives to promote technological change (these are market-oriented), while direct controls (these are administratively oriented) generally provided the lowest relative firm incentives to promote technological change [31]. Sun et al. [32] found that market-incentive environmental regulation has a more significant incentive effect on enterprise innovation than command-control environmental regulation. Based on the research of the above scholars and combined with the different intensities of China's environmental regulation policies, this paper classifies environmental regulation into mandatory and induced types using the classification method.

Scholars have different opinions on the impact of environmental regulation on upgrading industrial structures, which can be roughly classified into three categories.

The first category is the "pollution haven hypothesis", the prototype of which was first proposed by Copeland and Taylor when they studied the relationship between north and south and the environment [33]. According to this theory, the environmental regulation intensity levels in different countries or regions are different, which may lead to the relocation of high-polluting industries to countries or regions with weak regulatory intensity levels to avoid the cost of high-standard environmental constraints, which would then cause changes in the industrial structures of the initial and relocation places [34–36]. Taylor [37] divided the pollution refuge hypothesis into five categories: first, national characteristics directly affect the environmental regulation intensity levels; second, environmental regulation changes the production costs of enterprises; third, production costs affect the flow of international trade and foreign direct investment; fourth, these flows affect pollution, prices and incomes; and fifth, pollution, price and income will affect the environmental regulation intensity. At present, the academic circle has not reached a unified view on the pollution refuge hypothesis. Solarin S A et al. [36] supported the pollution refuge hypothesis by investigating air pollution in Ghana. Chaudhry et al. [38] empirically found that FDI is a pollution haven source in the region and found that there is a critical point for FDI to have a negative impact on the ecology, and foreign direct investment strategy maintained in a country with good institutional efficiency can improve the environment and promote economic development. Through the summary of the existing research results, we can improve our cognition of the pollution haven hypothesis and broaden the thinking when conducting the research of this paper.

The second category is the "compliance cost theory". Under the influence of classic economics, the costs of enterprises will be internalized due to the implementation of environmental regulations, thus increasing the production costs of enterprises, forcing enterprises to change their production decisions to maximize their profits, thus affecting their production decisions, entry or exit, and ultimately inhibiting the upgrading of the industrial structure [39]. Some of them, based on the cost structure and market structure characteristics of enterprises and departments, point out that enterprises' compliance with environmental regulations raises production costs [40], resulting in enterprises being in a disadvantageous positions in market competition, thus hindering the green innovation capabilities of industries. Other scholars, from a static point of view, believe that, under the assumption that the enterprise technology level, consumer demand and other factors remain unchanged, as long as environmental regulation is strengthened, enterprises will inevitably increase their investment in environmental protection [41], which will increase their production costs, thus hindering the production efficiency of enterprises and reducing their profit margins. Enterprises lack the internal power to transform, which is not conducive to the transformation and upgrading of the entire industry [42,43]. A similar conclusion was reached in the research by Kneller [44], who used panel data from 25 manufacturing industries in the UK in their analysis and found that stricter environmental regulations did not positively impact the total research and development investment. In summary, most of the above scholars agree with the "compliance cost theory"; that is, the implementation of environmental governance policies has increased the pollution control costs of enterprises, crowding out the R&D expenditures of enterprises [44], which in turn had a negative impact on the upgrading of the industrial structure.

The third category mainly supports the "Porter Hypothesis", and some of the scholars in this category believe that industrial development should be viewed from a dynamic perspective. Policy-makers can effectively stimulate enterprises to engage in technological innovation by implementing reasonable environmental regulations and compensating for early additional costs due to implementing environmental regulations through the innovation compensation effect [45]. Some scholars have also conducted research from the perspective of development. They believe that in the short term, enterprises may reduce their investment in innovation because of the additional costs brought by environmental regulations [45]. However, in the long term, because technological progress reduces the cost of environmental governance [46], environmental regulations can force enterprises to innovate, and the resulting innovation compensation effect [47], taken together, is likely to exceed the compliance cost. Other scholars believe that appropriate industrial policies can help guide the direction of industrial technological innovation and improve its efficiency [48,49]. Johnson [50] put forward the theory of the developmental state, believing that to achieve the goal of economic development, the state intervenes in the economy (market) by implementing industrial policies and giving guidance, restraint, and coordination to the private sector so that the allocation of resources can meet the country's long-term development needs. Therefore, according to the theory of industrial organization, it can be inferred that formulating appropriate environmental regulation policies is helpful in guiding industrial technological innovation. Some scholars have conducted further research on this basis. They believe that a higher environmental regulation intensity can enhance the effect of industrial structure upgrading [16]. They assume that if the environmental regulation intensity continues to increase, the enterprises in the region will face higher pollution control costs, which will force them to engage in comprehensive production technology innovations and increase their R&D investment levels to obtain innovation benefits to compensate for the high pollution control costs [51]. This will strengthen the trend of independent innovation by enterprises, and the wide application of new technologies can enhance the added value of various industries [52], which is conducive to developing the industrial structure to a higher level on the basis of rationalization [53].

Through an overview of the relevant literature, we can see that the impact of environmental regulations on upgrading industrial structures is complex. Although the existing research has achieved many results, it also has the following deficiencies: (1) Most research measured industrial structure upgrading from the technological innovation levels of enterprises without considering the weight change between industries. (2) Most studies only focused on one type of environmental regulation. This hinders the ability to explore how different types of environmental regulations affect industrial structure upgrading and to compare their differences. (3) Most of the literature has concluded that a linear relationship exists between environmental regulation and industrial structure upgrading without discussing the existence of a possible nonlinear relationship. To address these issues, this paper measures industrial structure upgrading by using the proportion of industrial added value method and divides environmental regulation into mandatory and induced types, uses the fixed effects model, and introduces the square term of the environmental regulation index to study the possible nonlinear relationship between environmental regulation and industrial structure upgrading in multiple dimensions.

3. Data and methodology

3.1. Data collection

This paper utilized panel data from 30 provinces in China from 2010 to 2020. The choice of 2010 as the starting year was based on the implementation of the Measures on Administrative Penalties for Environment by the Ministry of Environmental Protection on March 1, 2010, which expanded the scope and intensity of penalties for environmental violations [54]. As a result, this led to an increase in investment by relevant departments and enterprises in environmental pollution control, as well as improvements in the availability of relevant data. The data were sourced from several publications, including the *China Statistical Yearbook on Environment*, the *Statistical Yearbook of the Chinese Investment in Fixed Assets*, the *China Population & Employment Statistics Yearbook*, the National Bureau of Statistics of China and the provincial statistical offices. The yearbooks were uniformly obtained from CNKI and the data were analyzed using Stata 17 software. Considering the availability of data, this paper does not involve data from Tibet, Hong Kong, Macao, and Taiwan, and the total number of samples obtained following final processing is 330.

3.2. Selection of variables

3.2.1. Explained variables

In this study, the explained variable is industrial structure upgrading, which can be measured using several methods. This paper adopts the industrial added value proportion method proposed by Ye et al. [55] to measure industrial structure upgrading, which uses the ratio of the tertiary industry's added value to the secondary industry's added value. Data were obtained from China's National Bureau of Statistics. Because industrial structure upgrading is a transformation from a low-level form to a high-level form [56], tertiary industry is considered a high-level form of the industry. This method is preferred because it can reflect the evaluation index of whether the industry is developing toward servitization, which is a critical way to evaluate industrial structure upgrading.

3.2.2. Explanatory variables

The explanatory variable in this study is the environmental regulation intensity, which can be measured using various methods. In this study, we use an instrumental method, and the environmental regulation intensity is measured using environmental regulation tools [57]. This study classifies environmental regulations into mandatory and induced environmental regulations based on different levels of environmental regulation intensity in China.

Mandatory environmental regulations are the mandatory requirements imposed by government departments on localities or enterprises to alleviate environmental problems, such as the collection of additional fees and the social responsibilities that should be borne. In this paper, the pollutant discharge fees imposed by the government are selected as the indicators to measure the mandatory environmental regulation level, and the data come from the *China Statistical Yearbook on Environment*. The environmental protection tax from the *Tax Yearbook of China* is used to replace the data from 2018 to 2020 to ensure data relevance and availability [58]. The environmental protection tax has a higher legal effect and can promote environmental awareness among polluters.

The induced environmental regulation refers to the environmental regulation policy driven by social image value enhancement and profit maximization, which may induce enterprises to adjust their production behavior. To improve or even reverse the original social image and brand valuation to maximize profits, enterprises will adjust their original production behavior in a timely manner according to external regulations and the market competition environment [59,60]. For example, regarding active environmental protection investment and improvement of green innovation, this paper selects the amount of environmental pollution control investment by enterprises as an indicator to measure induced environmental regulation [61]. The data are from the *China Statistical Yearbook on Environment*, which includes investment in urban environmental infrastructure construction and industrial pollution control. The investment in environmental pollution control as a type of extra expenditure arising from the comprehensive consideration of the influence of regulation and the need for a competitive environment meets the conditions of induced environmental regulation.

3.2.3. Control variables

Based on the significant factors identified for the strategic upgrading of China's industrial structure and concerning literature such as Sochirca et al. [62], Wang et al. [63], Branstetter [64], Sechiyama [65] and Nathaniel et al. [66], we conclude that technological innovation, investment demand, foreign direct investment, the level of economic development, and human capital are essential control variables.

Technological innovation is a new way of increasing productivity created by modern enterprises through technological development, which can be effectively used to improve labor productivity and reduce the production cost of labor, thus promoting industrial structure upgrading. The index chosen in this paper is the number of patents granted by domestic enterprises [67], which was collected from China's National Bureau of Statistics.

Investment demand is the sum of the investment in fixed assets and the increase in inventories formed by society within a certain period. It can affect industrial structure upgrading differently by expanding the investment scale and changing the investment structure. This paper uses the fixed assets investment of each province, which was collected from the *Statistical Yearbook of the Chinese Investment in Fixed Assets*.

Foreign direct investment is the act of foreign enterprises directly investing capital, technology, etc., in accordance with the relevant policies announced by the government. Foreign enterprises have successively invested in constructing and establishing modern factories in China, which has promoted the further development of China's local machinery manufacturing technology and thus changed China's traditional industrial structure [68]. This paper chooses the amount of foreign capital each province utilizes as the foreign direct investment index, which is collected from provincial statistical offices.

The level of economic development is a regional economic phenomenon, and it changes at different stages and periods in various countries. The level of economic development will affect the quantity of labor employed, the quality of technology, and the market demand, thus changing industrial agglomeration and ultimately impacting the local industrial structure. Therefore, this paper uses per capita GDP to measure China's comprehensive economic development level, which is collected from China's National Bureau of Statistics.

Human capital can be reflected in terms of the workers themselves, and it also plays a vital role in upgrading the industrial structure. For example, the more high-quality talent there is, the higher the level of technological innovation, and the easier it is to form a cluster of high-tech industries, which effectively supports upgrading the industrial structure. This paper mainly uses the weighted average length of education to measure human capital [69]. It is calculated as follows: average years of schooling = (number of people who have not attended school *1+ number of primary school education *6+ number of junior high school education *9+ number of high school and secondary school education *12+ number of college and bachelor's degree or above *16)/total population over 6 years old. The relevant data are from the *China Population & Employment Statistics Yearbook*.

3.3. Empirical model

As the data in this paper are panel data with both cross-sectional dimensions and time dimensions, the fixed effects model can solve the problem of incorrect results caused by omitted variables. According to the Hausman test, the fixed effects model is more suitable. Therefore, this paper adopts the fixed effects model. The fixed effects model is a panel data analysis method, which means that the experimental results only aim to compare the differences between specific categories or categories of each self-variable and the interaction effects between specific categories or categories of other self-variable terms. This paper mainly controls the intragroup estimation method of individual fixed effects for estimation, and the deviation transformation eliminates the differences between groups of different individuals. Intragroup differences for each individual are preserved, so the estimated result of this method is also called an intragroup estimator [70]. It is set as equation (1):

$$lnISU_{it} = \alpha_0 + \alpha_1 lnER_{it} + \alpha_2 (lnER_{it})^2 + \alpha_3 lnTECH_{it} + \alpha_4 lnINV_{it} + \alpha_5 lnFDI_{it} + \alpha_6 lnPGDP_{it} + \alpha_7 lnEDU_{it} + \delta_i + \varepsilon_{it} \quad (1)$$

In this equation, "i" represents provinces, and "t" means the year. $lnISU_{it}$ represents industrial structure upgrading. $lnER_{it}$ represents environmental regulation, with lnER1 and lnER2 representing mandatory and induced environmental regulations, respectively. $lnTECH_{it}$ represents technological innovation, $lnINV_{it}$ represents investment demand, $lnFDI_{it}$ represents foreign direct investment, $lnPGDP_{it}$ represents the level of economic development, $lnEDU_{it}$ represents human capital, δ_i is the fixed effect and ε_{it} is the error term. This paper introduces a squared term of the environmental regulation index to investigate whether there is a nonlinear relationship between environmental regulation and industrial structure upgrading. Logarithmic transformations are applied to all the data in the analysis to avoid heteroscedasticity and multicollinearity issues.

4. Results and discussion

4.1. Descriptive statistics

Table 1 presents the descriptive findings of the main variables treated logarithmically. The mean value of industrial structure upgrading (lnISU) during the study period is 0.168, with a standard deviation of 0.387. The range of lnISU is significant, with a maximum value of 1.657 and a minimum value of −0.640, indicating differences in the industrial structures of the provinces. Some provinces have experienced much higher growth rates in the tertiary industry than in the secondary industry, implying a higher level of industrial structure upgrading. The slight standard deviation indicates that in most provinces, the growth rates of the secondary and tertiary industries are comparable, suggesting that the industrial structure needs further upgrading. The maximum and minimum values of mandatory environmental regulation (lnER1) and induced environmental regulation (lnER2) reveal differences among the provinces, emphasizing the need to explore the relationship between environmental regulation and industrial structure upgrading from another perspective. The statistical results of other control variables are consistent with those of previous studies [62–66]. However, the latest data on foreign direct investment (lnFDI) are missing in some provinces, so we use the linear interpolation method for supplementation.

4.2. Baseline results

4.2.1. Impact of mandatory environmental regulation on the upgrading of the industrial structure

Table 2 presents the baseline regression results of mandatory environmental regulation (lnER1) on industrial structure upgrading (lnISU). Columns (1) and (2) use lnER1 and its squared term, $(lnER1)^2$, as the main explanatory variables. The results indicate that the coefficient of lnER1 is 0.470, which is significant at the 1% level, suggesting a positive and significant impact of lnER1 on lnISU and demonstrating that mandatory environmental regulation accelerates industrial structure upgrading. Additionally, the coefficient of $(lnER1)^2$ is −0.025, indicating that further increasing the intensity of mandatory environmental regulation will still inhibit industrial structure upgrading. Based on these findings, it can be inferred that the relationship between mandatory environmental regulation and industrial structure upgrading exhibits a nonlinear inverted U-shaped trend overall. This implies that when the environmental regulation intensity is relatively low, it will have a positive effect on upgrading the industrial structure. When the environmental regulation intensity reaches a certain level, it will hinder industrial structure upgrading.

As a main means for local governments to implement mandatory environmental regulations, the imposition of pollutant discharge fees has a marked effect on pollution control in the short term, and the industrial structure has also been adjusted to a certain extent. In fact, this is also an approach commonly used by government departments in pursuit of short-term results. However, for enterprises, for the purpose of market competition and profit, it is impossible for them to eliminate the emission of pollution from the root cause, and in the long run, the cost caused by their "restraint" of pollutant discharge far exceeds the fee imposed by the government. Strict pollution charges have increased the burden on polluting enterprises [71]. At the same time, environmental protection taxes impose constraints on the polluting behaviors of enterprises, prompting them to increase investment in pollution control and environmental protection strategies and energy-saving and emission-reduction technology research [72]. This leads to cost increases, which may weaken the competitiveness of enterprises. Therefore, enterprises will not engage in industrial upgrading simply because of a slight increase in pollutant discharge fees. FurthermoreFurthermore, due to the lowering of the threshold for pollution charges in China in recent years, the government's collection of fees has continued to increase, resulting in a negative correlation between mandatory environmental regulation and industrial structure upgrading.

In terms of control variables, technological innovation (lnTECH) is positively correlated with the upgrading of the industrial structure. With the increase in the Chinese government's support and investment in technological innovation projects, the rapid

Table 1
Descriptive statistics.

Variable	N	mean	p50	sd	min	max
lnISU	330	0.168	0.143	0.387	−0.640	1.657
lnER1	330	10.706	10.750	0.921	7.955	12.791
lnER2	330	4.982	5.053	0.889	1.988	7.165
lnTECH	330	10.016	10.104	1.470	5.576	13.473
lnINV	330	9.472	9.485	0.826	6.925	10.990
lnFDI	330	3.546	4.026	1.711	−3.110	5.879
lnPGDP	330	1.532	1.502	0.465	0.253	2.798
lnEDU	330	2.213	2.207	0.094	1.964	2.547

Table 2
Baseline regression results - Impact of mandatory environmental regulation on industrial structure upgrading.

Variable	(1) FE1	(2) FE1_2
lnER1	−0.046***	0.470**
	(0.018)	(0.224)
$(lnER1)^2$		−0.025**
		(0.011)
lnTECH	0.065**	0.059**
	(0.030)	(0.030)
lnINV	−0.110***	−0.102***
	(0.033)	(0.033)
lnFDI	0.003	0.001
	(0.015)	(0.015)
lnPGDP	0.587***	0.585***
	(0.079)	(0.079)
lnEDU	0.396	0.366
	(0.250)	(0.248)
_cons	−0.723	−3.267**
	(0.677)	(1.288)
N	330	330
R^2	0.681	0.687

Note: ***, ** and ** designate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parentheses.

development of related emerging technology industries, emerging communication industries, environmental protection equipment and other high-tech industries is promoted, thus resulting in the overall improvement of labor productivity. This promoted the gradual transfer of the regional industrial center to the secondary and tertiary industries, which effectively promoted the overall optimization and upgrading of the domestic industrial structure [73]; Overall, investment demand (lnINV) inhibited the upgrading of the industrial structure. The possible reason is that the larger the scale of fixed asset investment, the smaller the scale of market liquidity, and some social resources flow into the fields related to the construction and investment of fixed assets, resulting in unbalanced development of the industrial structure or a decrease in the speed of industrial transformation [74], and thus have a negative impact on the upgrading of industrial structure. The regional economic development level (lnPGDP) will promote the upgrading of the industrial structure because the increase in per capita GDP directly affects the change in consumer demand, and the new demand change will stimulate the supply of new consumer goods. When in a buyer's market, demand can even directly determine the supply [75]; that is, the industrial structure will be adjusted and changed due to the change in consumer demand. In this study, the coefficients of foreign direct investment (lnFDI) and human capital (lnEDU) did not pass the significance level test, indicating that the two have no significant or a small impact on the upgrading of the industrial structure.

Table 3
Baseline regression results - Impact of induced environmental regulation on the upgrading of the industrial structure.

Variable	(1) FE2	(2) FE2_2
lnER2	−0.040*	−0.321***
	(0.022)	(0.100)
$(lnER2)^2$		0.028***
		(0.010)
lnTECH	0.053*	0.054*
	(0.030)	(0.030)
lnINV	−0.089**	−0.075**
	(0.035)	(0.035)
lnFDI	0.003	−0.003
	(0.015)	(0.015)
lnPGDP	0.610***	0.596***
	(0.080)	(0.079)
lnEDU	0.281	0.378
	(0.250)	(0.249)
_cons	−0.890	−0.520
	(0.675)	(0.679)
N	330	330
R^2	0.678	0.687

Note: ***, ** and ** designate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parentheses.

4.2.2. Impact of induced environmental regulation on the upgrading of the industrial structure

Table 3 shows the baseline regression results of induced environmental regulations (lnER2) on industrial structure upgrading (lnISU). The regression coefficient of lnER2 is significantly negative at the 10% significance level, indicating that induced environmental regulations will inhibit industrial structure upgrading in the short term. Furthermore, the coefficient of $(\ln ER2)^2$ is 0.028, which is significant at the 1% significance level, indicating a U-shaped relationship between induced environmental regulation and industrial structure upgrading.

As a major indicator of induced environmental regulation, investment in environmental pollution control will only increase the environmental production and enterprise management costs in the short term. Enterprises may increase social output for some time to save costs, thereby diluting enterprise costs [76]. This results in a significant short-term increase in the value added of the secondary industry, while the value added of the tertiary industry remains unchanged due to the smaller impact of environmental pollution control investment. This suppresses upgrading of the industrial structure when the investment in environmental pollution control is low. However, with the continuous increase in investment, infrastructure construction can be strengthened [77], and the production efficiency of the secondary and tertiary industries can be improved. On the other hand, it can stimulate and guide enterprises to engage in environmental protection innovation technology R&D, promoting the formation of a low-carbon industrial chain and increasing the overall economic level and providing conditions for upgrading the industrial structure and increasing low-carbon development [78]. Ultimately, induced environmental regulation can promote the upgrading of the industrial structure. This U-shaped relationship indicates a threshold effect of induced environmental regulation on upgrading the industrial structure.

The regression results with control variables show that the coefficients of technological innovation (lnTECH) and economic development level (lnPGDP) are significantly positive in the 10% and 1% significance tests, respectively, indicating that they promote upgrading of industrial structure. On the other hand, the coefficient of investment demand (lnINV) is significantly negative, suggesting that it somewhat inhibits the advancement of the industrial structure. The results of the other control variables are not significant and therefore are not further analyzed.

Tables 2 and 3 clearly show that the two types of environmental regulations affect industrial structure upgrading differently. Therefore, the government needs to study how to combine them and use them comprehensively to fully utilize their respective advantages. At the same time, it is necessary to formulate a scientific and efficient macroeconomic regulatory policy promptly in conjunction with the actual situation of the region. Otherwise, the expected results are often not achieved.

4.3. Threshold effect test

According to the baseline regression results, we can preliminarily know that the two types of environmental regulations have different nonlinear effects on the upgrading of the industrial structure, and their effects will show different characteristics when the environmental regulation intensity is in different intervals. To further test the nonlinear relationship between the variables, the panel threshold regression model proposed by Hansen is adopted to test the above nonlinear relationship [79]. As a nonlinear econometric model, threshold regression essentially finds the threshold variable among the variables reflecting causality, estimates the threshold value according to the sample data, and tests whether the parameters of the sample group divided according to the threshold value are significantly different [80]. For the econometric model in this paper, the panel threshold regression model is set as equation (2):

$$lnISU_{it} = \beta_0 + \beta_1 \ ln\ ER_{it} \bullet 1(ln\ ER_{it} \leq \gamma) + ln\ ER_{it} \bullet 1(ln\ ER_{it} > \gamma) + \lambda\ ln\ X_{it} + \mu_{it} \tag{2}$$

where, $1(\cdot)$ represents the characteristic function. When the expression in parentheses is false, the value is 0; otherwise, the value is 1. According to whether the threshold variable environmental regulation $\ln ER_{it}1$ or $\ln ER_{it}2$ is greater than the threshold value γ, the sample interval can be divided into two sections, and the slope values $\beta 1$ and $\beta 2$ are used to distinguish the two sections. X_{it} represents the control variable.

When industrial structure upgrading is the explained variable, the three cases of no threshold value, one threshold value and two threshold values of the two environmental regulations are estimated. By referring to the bootstrap method of Hansen [79], Stata 17 statistical software is applied. Through repeated sampling 300 times, the P value corresponding to the test statistic is obtained to determine whether there is threshold effect. The test results are shown in Table 4.

As from the above table shows, when lnER1 and lnER2 are threshold variables, the following conclusions can be drawn: the F statistic is only significant in the single threshold model, and the P values are both less than 0.1, so there is only one threshold value in

Table 4
Threshold effect test results.

Threshold variable	Number of thresholds	F value	P value	10%	5%	1%	Threshold value
lnER1	Single threshold	35.543	0.020	23.264	28.303	41.861	11.618
	Double threshold	5.211	0.810	21.549	29.415	46.816	
	Three thresholds	31.702	0.113	38.189	53.820	98.033	
lnER2	Single threshold	8.472	0.000	17.750	20.227	25.845	5.692
	Double threshold	3.901	0.301	15.415	17.905	25.539	
	Three thresholds	2.553	0.620	12.958	16.188	21.697	

Note: The P value is the probability value obtained by repeated sampling 300 times using the bootstrap method, and the significance level of the F statistic can pass the threshold effect test with this value.

the model, which is 11.618 for lnER1 and 5.692 for lnER2.

According to the threshold model principle, the threshold estimate value is the γ value corresponding to the likelihood ratio statistic LR approaching 0. Figs. 2 and 3 show the likelihood ratio function graphs of the two environmental regulation threshold estimate values under the 95% confidence interval. Among them, the lowest point of the LR statistic is the corresponding true threshold value, and the dashed line indicates the critical value of 7.35. Since the critical value of 7.35 is obviously greater than the threshold value, the above threshold value can be considered to be true and effective.

When the threshold value is obtained, the threshold regression results of mandatory and induced environmental regulations are obtained, as shown in Table 5.

As Table 5 shows, when the intensity of mandatory environmental regulation is lower than the threshold value, its influence coefficient on industrial structure upgrading is 0.031, which is significant at the significance level of 10%; when the intensity of mandatory environmental regulation is higher than the threshold value, the coefficient is −0.051, which is significant at the significance level of 1%.The lnER1 coefficient changes significantly in different stages, indicating that when mandatory environmental regulations are strengthened, the positive impact on the upgrading of the industrial structure is weakened, and when the threshold is crossed, the impact relationship becomes negative, showing an inverted U-shaped threshold feature. When the induced environmental regulation intensity is lower than the threshold value, its influence coefficient on industrial structure upgrading is −0.073, and when it is higher than the threshold value, the coefficient is 0.060, and both are significant at the 1% significance level. When the induced environmental regulation is enhanced to a threshold value, the impact on the upgrading of the industrial structure changes, and a U-shaped relationship is displayed in general. This is similar to the previous research results of the baseline regression, which further proves that the two environmental regulations have nonlinear effects on the upgrading of the industrial structure.

4.4. Robustness test

To test the validity and reliability of the empirical results, to determine whether the research method is suitable for the problem studied in this paper and whether extreme values in the sample will affect the empirical results, this paper conducted a robustness test from the following aspects.

First, this study employs the method of altering the sample size to conduct a robustness test by removing data from 2019 to 2020 to examine whether our conclusions remain robust. Due to China's increasing emphasis on environmental protection in recent years, there have been significant changes in environmental regulatory policies [81]. Starting in 2019, China issued intensive environmental protection policies, shifting environmental policy measures from administrative to comprehensive. The third-party pollution control initiative has been mobilized. Removing data from the past two years can help improve the representativeness of the sample data, making the conclusions more universally significant.

According to Table 6, the coefficient of the first-order term of mandatory environmental regulation (lnER1) is 0.493 and is significant at the 10% level. The coefficient of the second-order term is −0.027 and is significant at the 10% level, indicating an inverted U-shaped relationship between mandatory environmental regulation and industrial structure upgrading, which is consistent with the regression results in Table 2. Although the coefficients of the control variables are not exactly the same as those shown in Table 2, their significance levels are generally similar. The curve of the relationship between induced environmental regulation (lnER2) and industrial structure upgrading is U-shaped, which is consistent with the results in Table 3, indicating the reliability of the econometric results in this paper.

Second, considering the potential impact of omitted variables, we conducted a robustness test using the supplementary variable method. Han et al.'s [82] research indicated that the level of urbanization could contribute to industrial structural improvement, so we added a new control variable, the level of urbanization (lnUL), for the robustness test. With the advancement of urbanization, labor technology has developed, which has improved agricultural and industrial labor productivity, leading to the evolution of the industrial

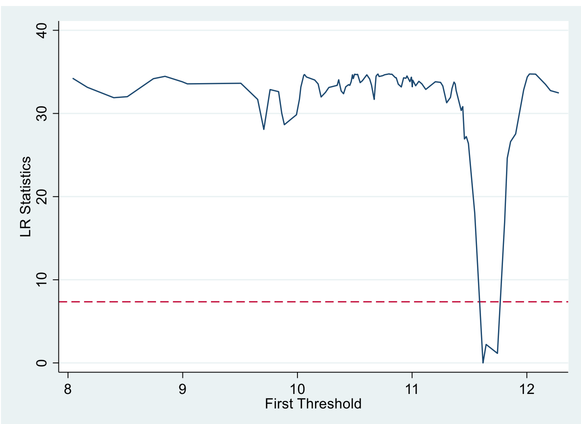

Fig. 2. Single threshold estimation results of mandatory environmental regulation.

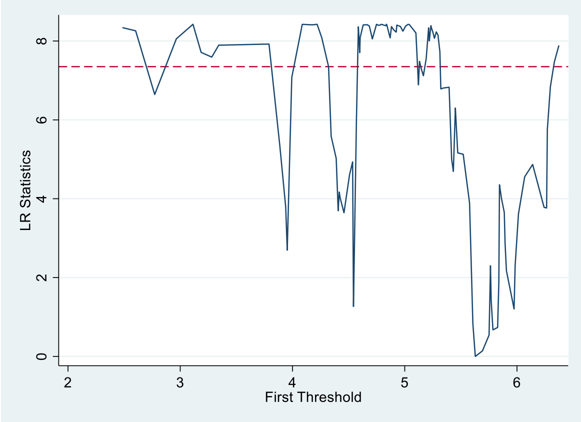

Fig. 3. Single threshold estimation results of induced environmental regulation.

Table 5
Threshold effect regression results of the single threshold model.

Variable	(1) lnISU	(2) lnISU
lnER1·1(lnER1≤11.618)	0.031*	
	(1.771)	
lnER1·1(lnER1>11.618)	−0.051***	
	(-2.950)	
lnER2·1(lnER2≤5.692)		−0.073***
		(-3.001)
lnER2·1(lnER2>5.692)		0.060***
		(2.683)
Control variable	YES	YES
_cons	−1.090*	−0.882
	(-1.653)	(-1.321)
N	330	330
R^2	0.346	0.359

Note: ***, ** and ** designate significance at the 1%, 5% and 10% levels, respectively. T values are in parentheses.

structure. Additionally, numerous people have migrated to cities, accelerating the improvement of the urban infrastructure and indirectly driving the development of related industries. Moreover, the growing population has expanded the scale of consumption, facilitating the rise of the tertiary industry and increasing its proportion, which profoundly affects the upgrading of the industrial structure [83].

According to Table 7, the coefficient of the first-order term of mandatory environmental regulation (lnER1) is 0.585, which is significant at the 5% level. The coefficient of its second-order term is −0.031, which is significant at the 1% level, indicating an inverted U-shaped relationship between mandatory environmental regulation and industrial structure upgrading, which is consistent with the results in Table 2. The coefficients, signs, and significance levels of the control variables are generally the same as those in Table 2. Induced environmental regulation (lnER2) has a U-shaped relationship with industrial structure upgrading, which is consistent with the results in Table 3. These results are comparable to the research findings of this paper, indicating the robustness of the econometric results.

5. Conclusions and policy recommendation

As the global environment continues to deteriorate, countries are emphasizing environmental protection and coordinated human-environmental development. The industry in the country plays a critical role in this effort, and promoting industrial structure upgrading is key to addressing the serious problem of global warming and maintaining a harmonious coexistence between humans and nature. With China now fully becoming a well-off society and people's requirements for a healthier ecological environment increasing, it is essential to coordinate the relationship between the environment and the economy.

This study examines the impact of environmental regulations on industrial structure upgrading, empirically analyzing the impact of two types of environmental regulations, mandatory and induced, on China's industrial structure upgrading.

This study found that different environmental regulations have significant differences in regard to their impact on the upgrading of industrial structures. Mandatory environmental regulation has a major impact on the upgrading of the industrial structure, generally

Table 6
Robustness test 1.

Variable	(1) FE1	(2) FE2	(3) FE1_2	(4) FE2_2
lnER1	−0.041*		0.493*	
	(0.021)		(0.283)	
lnER2		−0.071***		−0.277***
		(0.023)		(0.104)
$(lnER1)^2$			−0.027*	
			(0.014)	
$(lnER2)^2$				0.021**
				(0.010)
lnTECH	0.091**	0.083**	0.080**	0.080**
	(0.036)	(0.036)	(0.036)	(0.036)
lnINV	−0.126***	−0.110***	−0.102**	−0.088**
	(0.041)	(0.041)	(0.041)	(0.042)
lnFDI	0.031*	0.031*	0.036*	0.030
	(0.019)	(0.018)	(0.018)	(0.019)
lnPGDP	0.466***	0.454***	0.513***	0.505***
	(0.095)	(0.095)	(0.094)	(0.093)
lnEDU	1.366***	1.342***	1.242***	1.272***
	(0.486)	(0.484)	(0.473)	(0.470)
_cons	−2.966***	−5.593***	−2.983***	−2.649**
	(1.091)	(1.761)	(1.077)	(1.082)
N	270	270	270	270
R^2	0.624	0.630	0.633	0.640

Note: ***, ** and ** designate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parentheses.

Table 7
Robustness test 2.

Variable	(1) FE1	(2) FE2	(3) FE1_2	(4) FE2_2
lnER1	−0.042**		0.585***	
	(0.017)		(0.218)	
lnER2		−0.037*		−0.228**
		(0.021)		(0.101)
$(lnER1)^2$			−0.031***	
			(0.011)	
$(lnER2)^2$				0.019*
				(0.010)
lnTECH	0.064**	0.054*	0.058**	0.054*
	(0.029)	(0.029)	(0.029)	(0.029)
lnINV	−0.082**	−0.061*	−0.070**	−0.055
	(0.033)	(0.035)	(0.033)	(0.035)
lnFDI	−0.012	−0.011	−0.014	−0.014
	(0.015)	(0.016)	(0.015)	(0.016)
lnPGDP	0.570***	0.590***	0.566***	0.583***
	(0.077)	(0.078)	(0.076)	(0.077)
lnEDU	0.371	0.265	0.332	0.333
	(0.243)	(0.243)	(0.240)	(0.244)
lnUL	0.330***	0.339***	0.356***	0.299***
	(0.079)	(0.080)	(0.079)	(0.082)
_cons	−0.722	−0.867	−3.805***	−0.619
	(0.659)	(0.656)	(1.254)	(0.665)
N	330	330	330	330
R^2	0.699	0.696	0.707	0.700

Note: ***, ** and ** designate significance at the 1%, 5% and 10% levels, respectively. Standard errors are in parentheses.

exhibiting an inverted U-shaped relationship. When the intensity of this regulation is low, it has a significant positive impact on the upgrading of industrial structures. When the strength of regulation continues to increase, its promoting effect on the upgrading of the industrial structure is weakened, and its inhibiting effect is produced. In contrast, the relationship between induced environmental regulation and the upgrading of the industrial structure is U-shaped, showing a nonlinear trend of first declining and then rising. When the intensity of induced environmental regulation is low, it has a negative impact on the upgrading of industrial structures. However, when the intensity of regulation reaches a certain critical point and continues to increase, it promotes the upgrading of the industrial structure. Threshold regression is used to verify the results of the baseline regression, and similar conclusions are obtained, which further confirms the nonlinear relationship between the two environmental regulations and the upgrading of industrial structure.

Robustness tests were conducted by reducing the sample and adding explanatory variables, and the significance levels were generally the same, indicating that the econometric results were reliable.

The limitations of this paper are as follows: (1) Due to the complexity of the effect of environmental regulation on the upgrading of industrial structure, the action mechanism factors may not be limited to the three theories mentioned in this paper. (2) The research does not involve increasingly complex methods in the empirical aspect, and there are deficiencies in the depth of topic mining.

Given the vast territory and significant differences in economic development levels among different regions in China, the same environmental regulation tool can have greatly varying effectiveness. Therefore, the government must carefully consider economic development levels, ecological environment conditions, and people's environmental awareness levels in each region when formulating environmental regulation policies. Only in this way can the correct environmental regulation tools be selected and environmental regulation policies be formulated scientifically.

Based on the research conclusions, this study provides policy suggestions: (1) Because mandatory environmental regulations such as pollutant discharge fees show an inverted U-shaped nonlinear relationship with China's industrial structure upgrading, reducing environmental pollution by starting with pollutant discharge fees will not have a significant effect. (2) Because induced environmental regulation, such as investment in environmental pollution control, shows a U-shaped relationship with China's industrial structure upgrading, in regions with higher economic development levels, the government can increase the intensity of induced environmental regulation to increase corporate costs and restrict the development of some high energy-consuming and high-polluting enterprises, promoting their innovative development and transformation. However, in regions with lower economic development levels, where there are more small- and medium-sized enterprises and weaker awareness and ability to innovate and transform, the increase in induced environmental regulation and its intensity will raise production costs, reduce profits, and make it difficult to expand reproduction or even to survive in a competitive market. (3) It is suggested that developing countries learn from China's experience and improve the effectiveness of environmental regulation to help their industrial development. On the basis of strengthening the media publicity of environmental protection and expanding channels for the public to supervise the care of the environment, an environmental laws and regulations system should be constructed, including environmental objectives into government performance assessment, implementing the environmental evaluations of officials' tenure, energy conservation and emission reduction targets and environmental judicial review, and providing reliable guarantees for ecological environment construction with strict environmental regulations.

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Data availability statement

The data presented in this study are available upon request from the corresponding author, it can also be obtained from https://data.stats.gov.cn/, https://data.cnki.net/.

CRediT authorship contribution statement

Haicheng Zhu: Writing – review & editing, Writing – original draft, Supervision, Funding acquisition. **Hao Fang:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Feilong Hua:** Writing – review & editing, Formal analysis, Data curation. **Wei Shao:** Writing – review & editing, Supervision. **Penghui Cai:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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