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Research article

The effect exerted by environment regulation on industrial structure optimization: Evidence of 286 China's cities on the prefecture level

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ABSTRACT

Promoting industrial structure optimization and improvement on the basis of environment regulation based on "China's carbon peak and carbon neutralization" turns out to be a requirement that cannot be avoided for achieving China's economic growth with high quality. In this study, a dynamic game model for enterprises and governments in local areas with two phases, covering a polluting production sector and a clean production sector, is built for analyzing the influence mechanism of environment regulation of local governments on industrial structure optimization. Panel data of 286 cities on the prefecture level and above from 2003 to 2018 served as samples. The direct and dynamic impacts of environment regulation on industrial structure optimization are empirically tested, and the threshold model is adopted to test whether industrial structures and resource endowment will affect the effect of environment regulation on industrial structure optimization. Lastly, the effect exerted by environment regulation on industrial structure optimization is tested by region. The empirical results show that there is a nonlinear correlation of environment regulation and industrial structure optimization. Once the environment regulation intensity reaches a certain inflection point, it will hinder industrial structure optimization. When regional resource endowment and the secondary industry's ratio are used as threshold variables, environment regulation has a threshold effect on industrial structure optimization. The effect exerted by environment regulation on industrial structure optimization has regional heterogeneity.

1. Introduction

The economic growth in China ushers into a novel starting point with the transition from a phase of growth at large speeds to a phase of development with an excellent quality. For the promotion of economic growth with an excellent quality, the industrial structures should be regulated and optimized, and the road of "greening" development should be followed [1], such that a double-win result can be achieved between ecological and environment protection and economic growth [2]. China faces a chance and a difficulty in fulfilling the objective of carbon peak and carbon neutrality in the next 40 years [3,4]. To achieve this goal, the current energy structures and industrial structures will have to be revolutionized [5].

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As to whether environment regulation is capable of promoting industrial structure optimization, some distinctions remain in existing research. Several scholars suggested that environment regulation is capable of effectively driving industrial structure optimization and serve as a novel driving force in terms of industrial structures adjustment [6–8], which also verifies the "Porter hypothesis" to a certain extent. Some held the opposite view [9], arguing that environment regulation may hinder industrial structure optimization. Due to the existence of heterogeneous factors (e.g., industry differences [10,11], regional differences [12], resource endowment differences [13,14], and human capital level differences [15,16]), there is a nonlinear "U-shaped" correlation of environment regulation and regional industrial structure optimization [17]. In addition, different types of environment regulations may have different impacts on industrial structure optimization [18,19]. Both formal and informal environment regulations contribute to industrial structure optimization [20], and the effect exerted by formal environment regulations in terms of industrial structure optimization showed significant threshold characteristics and spatial heterogeneity [21,22]. Also, informal environment regulation boosts industrial structure optimization by promoting regional innovation, spatially diffuses information, and exhibits the features of double threshold influence [23]. By dividing industrial structure optimization into industrial structures rationalization and industrial structures supererogation, environment regulation is capable of promoting the industrial structures to be more rationalized while hindering industrial structures' supererogation [24]. Also, environment regulation had a U-shaped curve influence on the rationalization and supererogation of industrial structures [25].

To sum up, previous research has conducted sufficient theoretical and empirical analyses on the correlation of environment regulation and economic growth, environment regulation and industrial structure optimization, but most of them focus on the one-way impact of environment regulation on industrial structure optimization, while less consider the two-way impact between environment regulation and industrial structures, i.e., the reverse effect of industrial structures and resource endowment on local governments under the current official's performance appraisal system. In addition, the existing studies have questioned the measurement of the level of environment regulation and regional resource endowment. In view of this, this study constructs a two-phase dynamic game model of local governments and enterprises that includes both clean and polluting production sectors to explore how local government environment regulation affects industrial structure optimization, and two indicators of command-control environment regulation and environment regulation composite index are built respectively for exploring the instrumental heterogeneity of the role played by environment regulation on industrial structure optimization. This study selects panel data of 286 cities at prefecture level and above during 2003–2018 as samples to empirically examine the direct and dynamic effects of environment regulation on industrial structure optimization, and tests whether industrial structures and resource endowment affect the role played by environment regulation on industrial structure optimization through a threshold model, and finally the effects of environment regulation on industrial structure optimization by regions are examined.

2. Theoretical model

In this study, the small model of open economy in macroeconomics is employed to simulate the operation of urban economy in reality. Capital, a mobile production factor, can be allocated among different economies and sectors in the small model of open economy. It is assumed that a region is a perfectly competitive market, and there are two industrial sectors, comprising the polluting production sector (equivalent to the secondary industry in reality) and the clean production sector (equivalent to the primary and tertiary industries in reality). The production of the polluting sector requires the input of two production factors, i.e., capital (K_d) and labor (L_d), and the production function is: $Y_d = AK_d^{\alpha}L_d^{1-\alpha}, 0 < \alpha < 1$. Moreover, polluting production sectors generate output as well as pollution. The production function of pollution is assumed as $P = \rho K_d$, in which $\rho > 0$ is constant, representing the pollution generated by the respective unit of capital invested in the production of the polluting sector. It is assumed that the cleaner production sector requires only one factor of production, labor (L_d) (in reality, the primary and tertiary industries are both capital-light industries), and the unit output of each labor force is constant, i.e., the labor productivity is fixed, such that the production function of the cleaner sector is: $Y_c = aL_c, a > 0$. In addition, the production of the clean sector will not bring pollution, such that the government will not levy emission tax and other fees on it. Since the total amount of labor in the region is fixed, for simplicity, the total amount of labor can be normalized to 1, i.e., $L_d + L_c = 1$. Furthermore, the price of the products in the polluting sector is normalized to 1, and the price of the products in the clean sector is q.

The government should develop environmental policies and regulate polluting enterprises to control pollution emissions. The main means for local governments to control pollution emissions of enterprises is currently to force enterprises to install emission reduction equipment and invest in emission reduction. For instance, all new power plants were required in the "Eleventh Five-Year" period to install desulfurization equipment to control sulfur dioxide emissions. It is assumed that the government requires polluters to invest in emission reduction, i.e., τ units of emission reduction equipment should be invested for the respective unit of pollution emission, or it can also be understood that the government levies τ units of emission tax rate on enterprises. B is adopted to represent the emission reduction investment of enterprises, then $B = \tau\rho K_d$. The emission reduction of pollutants by an enterprise is a function of its investment in emission reduction equipment: $\varphi(B) = \varphi(\tau\rho K_d)$. To be specific, $\varphi' > 0, \varphi'' < 0$.

A two-phase dynamic game is conducted between local governments and enterprises. In the first phase, local governments decide the environmental policy variable, i.e., the emission reduction investment rate τ per unit of pollution emission. In the second phase, after the government's environmental policy is given, the enterprise makes production decisions based on profit maximization. In a perfectly competitive market, given the wage rate w, the price of capital R, and the emission reduction investment rate τ per unit of pollutant, the polluting firm chooses the optimal production factors (labor and capital) to maximize its profit. Denote π_d as the profit of the polluting firm. In this case, the profit function of the polluting firm is below:

$$\pi_d = (1 - t_d)AK_d^{\alpha}L_d^{1-\alpha} - wL_d - (R + \tau\rho)K_d \tag{1}$$

To be specific, t_d is the production tax levied on polluting sectors, equaling value-added tax in reality, and it is exogenously given for local governments. k_d is defined as the per labor capital of the pollution sector, $k_d = K_d/L_d$. The first-order condition of the profit maximization problem of pollution enterprises is written below:

$$(1 - t_d)A\alpha k_d^{\alpha-1} = R + \tau\rho \tag{2}$$

$$(1 - t_d)A(1 - \alpha)k_d^{\alpha} = w \tag{3}$$

Eq. (2) requires that the marginal output of capital equals the marginal cost of capital: the interest rate plus investment in abatement equipment. Eq. (3) indicates that the wage paid by enterprises to workers is equal to the marginal productivity of workers. The optimal per labor capital level of polluting enterprises can be solved by Eq. (2):

$$k_d(\tau) = [(1 - t_d)A\alpha]^{\frac{1}{1-\alpha}}(R + \tau\rho)^{\frac{1}{\alpha-1}} \tag{4}$$

where per labor capital $k_d(\tau)$ is the capital level that enterprises need to invest, which is a function of the emission reduction investment rate τ set by the government.

Next, the production behavior of firms in the clean sector is considered. Under competitive market conditions, based on the wage rate w and the price of capital R, a firm in the cleaning sector selects inputs of capital and labor to maximize profits. Denote π_c as the profit of the cleaning firm. The profit function of a firm in the cleaning sector is expressed below:

$$\pi_c = q(1 - t_c)aL_c - wL_c \tag{5}$$

To be specific, t_c denotes the production tax levied on the cleaning sector, consistent with the reality of value-added tax. In terms of local governments, it is exogenously given. The first-order conditions of the profit maximization problem of enterprises in the cleaning sector are expressed as:

$$q(1 - t_c)a = w \tag{6}$$

Given the government's environmental policy τ, the labor market clears and the wages of firms in the clean and polluting sectors are equal under competitive market conditions. The market equilibrium comprises Eqs. (3) and (6) and the equations below:

$$(1 - t_d)A(1 - \alpha)k_d^{\alpha} = q(1 - t_c)a = w \tag{7}$$

$$L_d = \beta, L_c = 1 - \beta, 0 < \beta < 1 \tag{8}$$

where w denotes the market equilibrium wage; β represents the amount of employment absorbed by the polluting sector. Since labor is capable of moving freely between the two sectors, the marginal returns to labor in the two sectors should be equal and equivalent to the market wage price, as indicated by Eq. (7). Under the setting of constant returns to scale in the production function, since β represents the allocation of labor force between the two sectors, per labor capital of the polluting sector k_d and labor productivity of the clean sector a are fixed when several variables are given (e.g., interest rate, tax rate, emission reduction investment rate, and product price of the clean sector). It is therefore suggested that the output of polluting sector and clean sector is ultimately determined by the level of labor input, such that the value β can be adopted to represent the industrial structures of an economy.

Eq. (7) suggests that the per labor capital of the polluting sector k_d can be adopted to represent the per labor output of the clean sector:

$$y_c = qa = (1 - t_d)A(1 - \alpha)k_d^{\alpha} / (1 - t_c) \tag{9}$$

Lastly, the question of optimal environmental policy for the government is considered. Assuming that the government's goal is to maximize its performance, the performance of local governments primarily comprises three aspects (i.e., regional GDP, fiscal revenue, and environmental governance) under the current assessment system. In the process of environmental decision making, the government should select the optimal τ to maximize its performance. Denote π_g as the profit of the government. The objective function of the government is expressed as:

$$\pi_g = t_c qY_c + t_d Y_d + \gamma(qY_c + Y_d) - \theta e \tag{10}$$

To be specific, the first two terms of the objective function are fiscal revenue. Y_c and Y_d denote the actual output of the clean sector and the pollution sector, respectively, i.e., both functions of τ. The third term refers to the requirement of local governments for GDP due to the pressure of performance assessment. The consideration of environment by the local government serves as the fourth item, indicating the significance that the local government attaches to the environment, or representing the severity of the environmental accountability of the higher government. $e = \rho K_d - \varphi(\tau\rho K_d)$ represents the final emission of pollution. The objective function of the government is a weighted average of GDP, fiscal revenue, and pollutant emission. Based on the derivative regarding τ, the first-order condition for maximizing the performance of the government is expressed as:

$$-\theta\rho\beta k_d^{'}(\tau) + \theta\rho\beta\varphi^{'}(B)[\tau k_d^{'}(\tau) + k_d]$$

$$= -(\gamma + t_c)(1-\beta)y_c^{'}(\tau) - (\gamma + t_d)A\alpha\beta k_d^{\alpha-1}k_d^{'}(\tau) \tag{11}$$

where $k_d^{'}(\tau) = \frac{\rho k_d}{(\alpha-1)(R+\tau\rho)} < 0$, suggesting that the per labor capital input of polluting sectors will decline with the rise of environmental policy variables τ.

The right side of Eq. (11) is the intensity of the government's environmental policy, i.e., the marginal cost brought by the rise of emission reduction investment rate of polluting enterprises τ to local governments, which is the reduction of output and fiscal and tax revenue of polluting enterprises and clean enterprises. The first item on the right is the reduction in output and fiscal revenue of the cleaner production sector caused by environmental policy intensity. Although environmental policy does not exert any direct effects on cleaner production department, the per labor output in the cleaning sector is a function of per labor capital in the polluting sector, as indicated by Eq. (9). When the promotion of environment regulation policy triggers the decline of investment in the polluting sector, the wage rate of the whole market and the market price of products in the cleaning sector will decline. As a result, the output in the cleaner production sector will decline, and then its fiscal and tax revenue will be reduced. The second term on the right refers to the reduction in GDP and fiscal and tax revenue brought by environmental policy intensity to the polluting production sector. The left side of Eq. (11) is the rise of marginal revenue of the government when the intensity of environmental policy τ increases, primarily the performance revenue brought by the reduction of pollutant emission to the local government. It can be seen in Eq. (11) that when the government formulates environment regulation policies, it is actually a trade-off between the loss of economic performance caused by reducing pollution emissions and the rise of environmental performance, and the optimal environmental policy of the government is to equalize the two in marginal benefits.

Next, the effect exerted by government environmental policies on industrial structures β is investigated through comparative statics. It is assumed that the problem covers an interior point solution, with the use of Eqs. (4) and (8), and applying the implicit function theorem on Eq. (11), it yields:

$$\left\{\frac{(t_c+\gamma)(1-\alpha)(1-t_d)\theta[\rho+\varphi^{'}(B)R]}{Z} + \theta\varphi^{'}(B)\tau\rho\beta k_d[(1-\alpha)R-\alpha\tau\rho]\right\}\frac{\partial\beta}{\partial\tau} = -\frac{|D|}{(1-t_c)(1-t_d)(1-\eta)} \tag{12}$$

To be specific, $Z = (t_c + \gamma)(1-\beta)(1-\alpha)(1-t_d) + (t_d+\gamma)\beta(1-t_c) + \alpha\theta\varphi^{'}(B)\beta(1-t_c)(1-t_d) > 0$. The first item in the braces on the left side of Eq. (12) represents the direct impact of the change in the ratio β of the secondary industry on fiscal revenue, GDP, and environmental pollution, with a positive sign. The second term represents the effect exerted by the change in the share β of the secondary industry on emission reduction, and its sign is dependent on $(1-\alpha)R-\alpha\tau\rho$. Notably, when the value β is significantly small and tends to zero, the second term in braces approaches zero. If the sign in braces is positive, $\partial\beta/\partial\tau$ becomes negative. When the value β is large and the second term in the braces is negative, the sign in the braces can be either positive or negative. Subsequently, $\partial\beta/\partial\tau$ can be either positive or negative.

As revealed by the above-mentioned investigation, the effect exerted by environment regulation policies on industrial structures is uncertain and not linear. Under a low ratio of the secondary industry in a region, the ratio of added value of the secondary industry in GDP will decrease with the rise of environment regulation intensity, i.e., the environment regulation of the local government promotes the transformation of the industrial structures from the secondary industry with heavy pollution to the primary industry and the tertiary industry with less pollution. Under a high ratio of the secondary industry, the ratio of added value of the secondary industry in GDP shows a positive correlation with the environment regulation intensity, i.e., the enhancement of environment regulation will facilitate the rise of the secondary industry's ratio in the regional industrial structures. This is the result of the trade-off of economic growth objectives and environmental objectives set by local government officials maximizing their political performance. To be specific, under a low secondary industry's ratio in GDP, the contribution of secondary industry to local fiscal and tax revenue and GDP is not large, and local governments have a willingness in implementing rigorous environment regulation policies to protect the local environment. In this case, the implementation effect of environment regulation policies is quite good, which can facilitate the transformation of local polluting industries into clean industries. With the rising ratio of the secondary industry, the contribution of the secondary industry to local fiscal and tax revenue and GDP gradually increases. When the secondary industry takes up a relatively high ratio, the economic cost of implementing strict environmental policies by local governments gradually increases. The environment regulation policy of local government at this time is not sure for the role played by the industrial structures. Whether environment regulation policies can facilitate the transformation from polluting industries to clean industries is dependent on which is greater, the loss of economic performance or the rise of environmental performance with the reduction of the secondary industry's ratio.

3. Econometric model, variables, and data

3.1. Model setting

Some scholars [26,27] summarized the connotation of industrial structure optimization as industrial structure optimization and the improvement of the intra-industry structure. Based on previous research methods [28,29], this study divides industrial structure optimization into the improvement of the intra-industry structure and industrial structure optimization, and further believes that the improvement of the intra-industry structure is primarily indicated in the greening of industrial structures, i.e., the green transformation of industry. For the exploration of the effect exerted by environment regulation on industrial structure optimization. Denote IND_{it} as industrial structure optimization index of city i in year t. This study sets the benchmark model below:

$$IND_{it} = \alpha_0 + \alpha_1 ER_{it} + \alpha_2 CV_{it} + u_i + \varepsilon_{it} \tag{13}$$

$$IND_{it} = \beta_0 + \beta_1 ER_{it}^2 + \beta_2 ER_{it} + \beta_3 CV_{it} + u_i + \varepsilon_{it} \tag{14}$$

where IND_{it} represents industrial structure optimization index of city i in year t, which is examined by the weighted ratio of three industries in GDP; ER_{it} denotes the environment regulation intensity in year t of city i. To more comprehensively assess the effect exerted by environment regulation on industrial structure optimization and overcome the endogeneity of traditional environment regulation metrics, this study constructs a command-control environment regulation index and a comprehensive environment regulation index to measure environment regulations. CV_{it} denotes other control variables affecting industrial structure optimization, such as regional economic growth level, fixed asset investment level, human capital level, etc.; u_i is the individual fixed effect that does not change over time, and ε_{it} represents the random disturbance term. Theoretical research indicates a possible nonlinear correlation of environment regulation and industrial structure optimization. Accordingly, this study introduces the quadratic term of environment regulation into the empirical model to test it.

3.2. Description of variable selection

3.2.1. Dependent variable

Industrial structure optimization index (IND), according to the Petty-Clark theorem, the ratio of non-agricultural output value in the economy increases, which is a sign of industrial structure optimization in the region [30]. This study draws on the measurement method of industrial structure optimization [31,32] to construct industrial structure optimization index. Denote *IND* as industrial structure optimization index. The specific equation is written below:

$$IND = L_1 \times 1 + L_2 \times 2 + L_3 \times 3 \tag{15}$$

where L_i represents the ratio of the added value of industry i in the regional GDP, expressed as a percentage. The value of IND is between 100 and 300. The closer the index value is to 100, the lower the industrial structures level of the region is; otherwise, the higher the industrial structures level of the region is.

3.2.2. Independent variables

Command-control environment regulation (ER_1). Previous research has primarily employed the number of environment regulations enacted, the amount of investment in environmental pollution control, the ratio of investment in environmental pollution control to GDP, and comprehensive environment regulation indicators based on environmental pollutant emissions for measuring the government's environment regulation capacity, whereas the above-mentioned environment regulation indicators have a strong endogeneity with economic growth, which can lead to large errors in the empirical results. The publication of the government work report at the beginning of the year, not affected by the economic fluctuations of the year, and the selection of the provincial level government work report will be conducive to alleviating the endogeneity problem arising from reverse causality. Besides, since municipalities on the prefecture level are inevitably constrained from the provincial level in implementing environment regulation policies, the administrative pressure on environmental policy from the provincial level will be increased with the rise of the share of the added local industrial value in the province's added industrial value. The government's work report is more concerned with future plans and targets, which have not yet been implemented. Thus, the indicator of command-control environment regulation in this study is not adopted to examine the effectiveness of the implementation of environment regulation policies, but rather to indicate the extent to which the government highlights environmental protection and the determination of environmental management, or to measure the intensity of the local government's environmental policy formulation.

Based on existing research [13,25], this study builds environment regulation variables based on provincial government work reports, which can be divided into the three steps below. First, Python is adopted to perform Chinese word segmentation on the government work reports of 31 provinces from 2003 to 2018, and the ratio of environment-related words in the total number of words (environment-related words frequency) is counted.[1] Next, the added industrial value of the prefecture-level city is divided by the added industrial value of the province to obtain the ratio of the added industrial value of the prefecture-level city in the whole province. If the added industrial value of some cities and years is missing, it is approximately substituted with the added value of the secondary industry. The third step refers to the calculation of the index by multiplying the ratio of added industrial value of the respective city on the prefecture level in the whole province with the frequency of environment-related words in the corresponding provincial government work report.

Comprehensive index of environment regulation (ER_2). To evaluate the effect exerted by environment regulation on industrial structure optimization more comprehensively, and to verify the robustness of the test results, the comprehensive index of environment regulation was built and re-tested. This study adopts the comprehensive index method to measure the level of environment regulation [33,34]. The calculation includes three single indicators, i.e., the removal rate of industrial smoke (dust), the removal rate of industrial SO_2 and the comprehensive utilization rate of general industrial solid waste. The calculation steps are elucidated in the following. First,

[1] Environment-related words in the government work report include: environment, environmental protection, protection of the environment, environmental protection, environmental regulation, environmental sanitation, environmental quality, pollution, environmental friendliness, environmental monitoring, environmental pollution and other 88 words.

each indicator is standardized; Secondly, the entropy method is adopted to determine the weight of the index, and the comprehensive index of environment regulation is calculated in accordance with the weight and standardized value. Since the comprehensive index of environment regulation reveals the comprehensive implementation effect including various environment regulation tools, the higher the score of the comprehensive index, the stronger the implementation effect of environment regulation in the region.

3.2.3. Control variables

Economic growth level (PGDP). The improvement of a region's industrial structures should naturally be linked to the level of local economic growth, rather than separated from the current phase of development. This study uses the per capita GDP of cities on the prefecture level to measure the level of local economic growth, and uses the per capita GDP index of cities on the prefecture level to deflate the per capita GDP with 2003 as the base period.

Industry scale (SCA). In this study, the ratio of the total social fixed asset investment in the GDP of each city is adopted to represent the level of fixed asset investment, and the industrial scale of each city is characterized.

Degree of financial development (CRE), which is crucial to industrial structure optimization, is examined by the per capita loans from financial institutions at the end of the year, i.e., the total loans from financial institutions at the end of the year divided by the population at the end of the year.

Degree of opening up (OPEN). In this study, the ratio of actual utilized foreign investment in GDP in the current year was examined, and the actual utilized foreign investment was adjusted into RMB through the exchange rate, which was obtained from the website of the National Bureau of Statistics in each year.

Intensity of government role (GOV), which reveals the institutional factors affecting the improvement of China's industrial structures. In this study, the ratio of the financial expenditure of each city government to the total output value of the city in the current year is adopted to measure the participation degree of the local government in the local economic activities.

Population density (PEO). In general, the higher the population density, the more significant the negative externality impact of pollution in the production of enterprises on residents' lives will be, and the higher the environmental protection awareness of people will be, thus contributing to the improvement of local industrial structures. In this study, population density was examined by the number of people per square kilometer.

Education level (EDU) primarily affects industrial structure optimization by affecting people's awareness of environmental protection and residents' participation in environmental protection social activities. People's resistance to high-polluting enterprises and the degree of intervention in illegal emissions will be stronger when the population in a region has a higher education level. In contrast, pollution enterprises in areas with low education level are more likely to be accepted, which has a lasting effect on the local industrial structures. The ratio of college students in the total urban population is adopted in this study to examine the education level.

Technological innovation (TECH). In this study, the technological innovation capability of a region is examined by dividing the number of invention patents granted each year by the total population at the end of the year, i.e., the number of invention patents granted per 10,000 people. The patent authorization data originate from China Research Data Service Platform (CNRDS) Innovation Patent Research (CIRD).

3.3. Data source and processing

This study used 2003–2018 panel data of over 286 cities on the prefecture level and above primarily originates from China city statist*ical yearbook*, *China's regional economic statistical yearbook* and *China statistical yearbook*, the National Bureau of Statistics official website, and statistical yearbook of provinces and cities on the prefecture level and statistical bulletin of national economic and social development of cities on the prefecture level. In accordance with the missing data in the sample period, the relevant data of individual cities were eliminated in the provinces below: Chaohu City in Anhui Province; Xigaze City, Changdo City, Nyingchi City, Naqu City in Tibet Autonomous Region; Bijie City, Tongren City in Guizhou Province; Sansha city, Danzhou City in Hainan Province; Turpan City, Hami City in Xinjiang Autonomous Region; Haidong City in Qinghai Province.

The panel data of 286 cities on the prefecture level and above also included the samples of Beijing, Shanghai, Tianjin, and Chongqing. However, since the above-mentioned four municipalities are equivalent to provinces at the administrative level, the

Table 1
Description data.

Variable	Variable meaning	Mean	Standard deviation	Minimum	Maximum	Sample
IND	Industrial structure optimization	223.93	14.55	182.23	282.20	4576
ER_1	Command-control environment regulation	0.50	0.58	5.85e-03	5.97	4576
ER_2	Comprehensive index of environment regulation	57.04	21.64	7.28	99.88	4576
PGDP	GDP per capita	13633.60	10512.13	50.94	184127.60	4576
SCA	Industrial scale	0.75	0.65	0.09	10.98	4576
CRE	Degree of financial development	53092.87	93140.81	695.67	1627621	4576
OPEN	Degree of opening up	0.02	0.03	2.40e-06	0.77	4576
GOV	Intensity of government role	0.19	0.22	0.03	6.04	4576
EDU	Education level	154.67	212.62	0.59	3502.18	4576
TECH	Technological innovation capability	0.77	2.75	0	48.13	4576
PEO	Population density	424.79	328.97	4.70	2661.54	4576

samples of the four municipalities are excluded in the robustness test. Besides, during the measurement of the intensity of command-control environment regulation in municipalities, since municipalities are subjected to the jurisdiction of the central government and subject to constraints and pressures from the central government level, the frequency of environment-related words in the municipal government work report and the ratio of added industrial value of the respective municipality in the total of the four major municipalities are multiplied to examine the intensity of command-control environment regulation of municipalities. In addition, when measuring the comprehensive index of environment regulation, since the removal amount of industrial sulfur dioxide has been only published from 2003 to 2010, the production amount of industrial sulfur dioxide has been published after 2011.

The description data of the above variables are listed in Table 1 below:

4. Empirical results and analysis

4.1. Direct impact of environment regulation on industrial structure optimization

Before the formal panel regression, STATA software was adopted to draw a scatter plot based on the data of this study to observe the direction of the core independent variable environment regulation on industrial structure optimization of the dependent variable. Fig. 1 shows the scatter plots of command-control environment regulation with industrial structure optimization. Fig. 2 shows the scatter plots of comprehensive index of environment regulation with industrial structure optimization.

As can be seen in Figs. 1 and 2, there is basically a positive correlation between environment regulation and industrial structure optimization in China. To be specific, compared with the role played by comprehensive environment regulation on industrial structure optimization, command-control environment regulation has a more obvious promoting effect on industrial structure optimization. This study will specifically discuss the effect exerted by environment regulation on industrial structure optimization through empirical analysis.

Table 2 shows the regression results of command environment regulation and comprehensive environment regulation on industrial structures respectively. In this study, the fixed effects model is selected for testing.

According to the panel data regression estimate results of Table 2, model (1) and model (2) are fixed effect models of command-control environment regulation and comprehensive index of environment regulation respectively on the effect exerted by industrial structure optimization, and model (3) and model (4) are fixed effects models after adding the square term of command-control environment regulation and the comprehensive index of environment regulation, respectively.

From the regression results of model (1) and model (2) in Table 2 and it can be seen that both command-control environment regulation and comprehensive index of environment regulation have significant promoting effects on industrial structure optimization, and both are significant at the significance level of 1%. As shown in the scatter plot of the effect exerted by environment regulation on industrial structure optimization, the promotion effect of command-control environment regulation on industrial structure optimization is greater than that of the comprehensive index of environment regulation. The influence coefficient of command-control environment regulation on industrial structure optimization is 1.211, while the influence coefficient of the comprehensive index of environment regulation on industrial structure optimization is 0.016. It can be seen that command-control environment regulation has a stronger promoting effect on industrial structure optimization. As the comprehensive index of environment regulation integrates various environment regulation means such as command-control, market incentive and public participation, it reveals the comprehensive effect of environment regulation, which also means that command-control environment regulation is more effective than other means of environment regulation. It also indicates that the government's command-control environment regulation is more effective than other environment regulation methods in promoting the structural improvement of industries in China.

It can be seen from the regression results of model (3) in Table 2 that the correlation coefficient of the quadratic term of command-

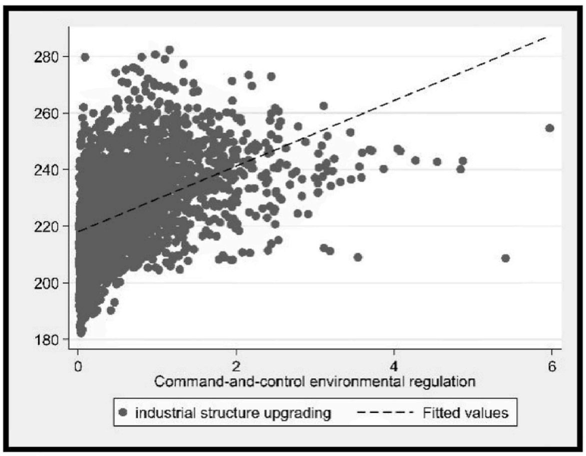

Fig. 1. Correlation of command-control environment regulation and industrial structure optimization.

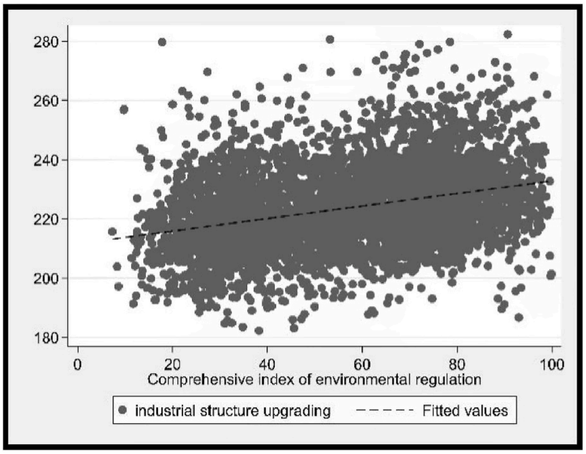

Fig. 2. Correlation of comprehensive index of environment regulation and industrial structure optimization.

Table 2
Direct effects of environment regulation on industrial structure optimization.

	(1)	(2)	(3)	(4)
	IND	IND	IND	IND
ER_1	1.211***		5.188***	
	(3.98)		(8.52)	
ER_2		0.016**		0.005
		(2.16)		(0.14)
ER_12			−1.315***	
			(-7.53)	
ER_22				0.000
				(0.34)
PGDP	0.000***	0.000***	0.000***	0.000***
	(9.09)	(10.56)	(7.67)	(10.56)
SCA	−0.195	−0.144	−0.324	−0.145
	(-0.58)	(-0.43)	(-0.98)	(-0.43)
CRE	0.000***	0.000***	0.000***	0.000***
	(5.86)	(6.16)	(6.32)	(6.16)
OPEN	24.082***	24.245***	22.974***	24.294***
	(4.73)	(4.75)	(4.53)	(4.76)
GOV	−2.376***	−2.717***	−1.743*	−2.716***
	(-2.64)	(-3.03)	(-1.94)	(-3.03)
EDU	0.023***	0.024***	0.023***	0.024***
	(31.32)	(32.66)	(30.68)	(32.66)
TECH	−0.373***	−0.391***	−0.429***	−0.392***
	(-3.78)	(-3.96)	(-4.36)	(-3.97)
PEO	0.005***	0.005***	0.005***	0.005***
	(8.81)	(8.93)	(8.00)	(8.93)
_cons	240.414***	239.073***	240.342***	239.340***
	(106.13)	(105.22)	(106.75)	(99.45)
Provincial FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
N	4576	4576	4576	4576
R^2	0.69	0.69	0.69	0.69

Note: ***, **, * indicate the statistical significance of 1%, 5% and 10% respectively, and t-statistic values are in parentheses, as below.

control environment regulation is significantly negative at the level of 1%, and the correlation coefficient before the primary term is significantly positive at the level of 1%. Thus, it can be concluded that there is an inverted U-shaped curve correlation of command-control environment regulation level and industrial structure optimization, which is roughly consistent with the distribution of the scatter plot in Fig. 1. In addition, the inflection point of the inverted U-shaped curve between command-control environment regulation level and industrial structure optimization is 1.973. At present, the intensity of command-control environment regulation in most cities is less than 1.973, i.e., it is distributed on the left side of the inflection point. Accordingly, the current command-control environment regulations in most of China are still able to facilitate industrial structure optimization and have not yet reached a phase where they hinder it.

According to the regression results of model (4) in Table 2, both the quadratic and primary correlation coefficients of the comprehensive index of environment regulation are not significant. This indicates that there is only a linear correlation of the comprehensive index of environment regulation and industrial structure optimization, or that the implementation of environment regulation can facilitate industrial structure optimization as long as the comprehensive index of environment regulation is greater than 0.

Since the adjustment of industrial structures always takes a certain time, the effect exerted by environment regulation on industrial structure optimization will have a certain time delay effect, i.e., the current environment regulation policy can not immediately cause the adjustment of industrial structures, but will play a role in the next period of industrial structures adjustment. Thus, this study adds a first-order lag term to the benchmark regression model to explore the lag effect of environment regulation on industrial structure optimization.

Table 3 shows the regression results of command-type environment regulation and comprehensive index of environment regulation with first-order lag term on industrial structure optimization. In this study, the fixed effect model is selected for testing.

According to the panel data regression results in Table 3, model (1) is the regression results of the first-order lag term of command-control environment regulation on industrial structure optimization, and model (2) is the regression results of command-control environment regulation on industrial structure optimization by adding the current term on the basis of the first-order lag term. Model (3) is the regression result of the first-order lag term of the comprehensive index of environment regulations on industrial structure optimization, and model (4) is the regression result of the comprehensive index of environment regulations with the current term added on the basis of the first-order lag term on industrial structure optimization.

The regression results of model (1) in Table 3 show that the correlation coefficient between the first-order lagged term of command-control environment regulation and industrial structure optimization is significantly positive at 1%, and the correlation coefficient is greater than the regression coefficient of the current term of command-control environment regulation on industrial structure optimization in Table 2. This indicates that industrial restructuring takes time, and the effect of government command-control environment regulation on industrial structure optimization has a time lag effect, i.e., the current period's environment regulation policy may not have a greater effect until the next period.

The results of model (2) in Table 3 show that the first-order lagged terms of command-control environment regulation are positively correlated with industrial structure optimization, while the correlation coefficients of the current-period terms are not significant. This indicates that the promotion effect of command-control environment regulation on industrial structure optimization is not immediate, and the promotion effect of command-control environment regulation on industrial structure optimization in the current period is actually superimposed on the effect of command-control environment regulation in the previous period.

According to the regression results of model (3) in Table 3, the regression coefficient of the first-order lag term of the

Table 3
Dynamic effects of environment regulation on industrial structure optimization.

	(1)	(2)	(3)	(4)
	IND	IND	IND	IND
L.ER_1	1.390***	1.009**		
	(4.38)	(2.26)		
ER_1		0.525		
		(1.22)		
L.ER_2			0.017**	0.013
			(2.23)	(1.40)
ER_2				0.007
				(0.77)
PGDP	0.000***	0.000***	0.000***	0.000***
	(7.95)	(7.74)	(9.60)	(9.56)
SCA	−0.255	−0.262	−0.177	−0.185
	(-0.77)	(-0.79)	(-0.53)	(-0.56)
CRE	0.000***	0.000***	0.000***	0.000***
	(5.88)	(5.84)	(6.25)	(6.25)
OPEN	33.075***	32.916***	33.003***	33.061***
	(5.99)	(5.96)	(5.97)	(5.98)
GOV	−2.397***	−2.365***	−2.839***	−2.829***
	(-2.68)	(-2.64)	(-3.19)	(-3.18)
EDU	0.023***	0.023***	0.023***	0.023***
	(30.64)	(30.39)	(31.84)	(31.81)
TECH	−0.351***	−0.348***	−0.378***	−0.376***
	(-3.58)	(-3.56)	(-3.85)	(-3.84)
PEO	0.005***	0.005***	0.005***	0.005***
	(8.20)	(8.14)	(8.31)	(8.25)
_cons	239.464***	239.647***	237.944***	237.836***
	(104.00)	(103.86)	(102.99)	(102.74)
Provincial FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
N	4290	4290	4290	4290
R^2	0.70	0.70	0.70	0.70

comprehensive index of environment regulation on industrial structure optimization is significantly positive at the level of 5%. Compared with Table 2, the first-order lag term of the comprehensive index of environment regulation is larger than the regression coefficient of the current term on industrial structure optimization, consistent with the comparison result of command-control environment regulation. It also indicates that the effect of environment regulation implementation on industrial structure optimization has a certain lag.

The effects of various control variables in model (1)–(4) in Table 2 on industrial structure optimization can be summarized below:

Firstly, there is a significant positive correlation between opening up to the outside world (OPEN) and industrial structure optimization, and the correlation coefficients are all significant at 1%. As the openness indicator measures the share of foreign direct investment in local GDP, it actually reveals the degree of local openness to the outside world. Local governments may have focused more on high-tech industries when introducing foreign investment, which has to some extent contributed to industrial structure optimization.

Secondly, the correlation coefficients between government role intensity (GOV) and industrial structure optimization are both significantly negative at 1%. This suggests that local government intervention has the potential to hinder the of industrial structure optimization of a region.

Thirdly, educational attainment (EDU) has a moderate contribution to industrial structure optimization, and the correlation coefficients are all significantly positive at 1%, but the coefficients are relatively small.

Fourthly, the correlation coefficient between technological innovation (TECH) and industrial structure optimization is negative and significant in both command-control environment regulation regression equations. While it is inconsistent with common sense, it may also be that technological innovation is examined by the number of invention patents per 10,000 people, and the secondary industry, especially manufacturing, is the most likely to generate invention patents, while the tertiary industry is relatively difficult to patent. Accordingly, the higher the ratio of tertiary industries in a region, the fewer invention patents there may be, which leads to a negative correlation between technological innovation indicators and industrial structure optimization indicators.

Fifth, there is a significant positive correlation between population density (PEO) and industrial structure optimization, and the correlation coefficients are all significant at 1%, but the coefficients are relatively small. This is because the higher the population density of a region, the more abundant the local labor resources are, and the more favorable to the development of industries. Moreover, a densely populated area will have relatively higher environmental requirements, which will force industrial structure optimization from the heavily polluted secondary industry to the less polluted tertiary industry.

4.2. *Threshold effect test of the effect exerted by environment regulation on industrial structure optimization*

Most resource-based cities are resource-dependent, i.e., taking mining and processing mineral resources as the leading industry in the region. However, the above-mentioned resource-based industries are typical industries with heavy pollution and high energy consumption. Under the call of the state to facilitate energy conservation and emission reduction, as well as the destruction of the regional ecological environment and the excessive exploitation of natural resources, many resource-based cities are facing severe transformation problems. The resource endowment of a region usually determines the industrial structures of the region, and it also has a direct impact on the regional environment regulation policy, and through the environment regulation policy, it has an indirect impact on the industrial structures. Compared to the average city, the economic growth of resource-based cities is dominated by the secondary sector, with the exploitation of natural resources accounting for a larger ratio of the economy. The ratio of secondary industries is usually higher in resource-based cities than in non-resource-based cities. Moreover, since the pollution emission intensity of the primary and tertiary industries is generally lower than that of the secondary industries, especially industry, this has led to a series of problems (e.g., a single industrial structures, resource dependency and ecological environment) in resource-based cities gradually exposed with the growth of the economy. Since the environmental problems faced are more serious than those of ordinary cities, this will affect the formulation of environment regulation policies to a certain extent. Considering the environment as a special factor of production, enterprises will seek the optimal production path by regulating the factor input structure under different levels of environment regulation. Environment regulation affects the industrial structures under the adjustment of enterprises' production behavior brought about by the rise of factor prices for polluting production due to the promotion of environment regulation. The above-mentioned effect may be non-linear depending on the cumulative extent of environment regulation itself.

The above linear analysis can only indicate the refinement of the current mechanism of action of the environment regulation role system in China, whereas it cannot examine the non-linear impact of environment regulation on industrial structure optimization in different types of cities in depth, nor can it determine the phase of the effect exerted by environment regulation policies on industrial structures in China. Thus, this study will analyse the non-linear impact of environment regulation on industrial structure optimization in China from the perspective of cities on the prefecture level, using resource endowment and industrial structures as threshold variables respectively, and using a threshold regression model to make reference to the rationality of the existing environment regulation intensity policies in China and the changes in the environment regulation intensity policies in the future. Based on the threshold regression method [35], the panel threshold model is built below:

4.2.1. *Single threshold model*

$$IND_{it} = \alpha_i + \beta_1 ER_{it}(Q_{it} \leq \gamma_1) + \beta_2 ER_{it}(Q_{it} > \gamma_1) + \delta CV_{it} + \varepsilon_{it} \tag{16}$$

4.2.2. Double threshold model

$$IND_{it} = \alpha_i + \beta_1 ER_{it}(Q_{it} \leq \gamma_1) + \beta_2 ER_{it}(\gamma_1 < Q_{it} \leq \gamma_2) + \beta_3 ER_{it}(Q_{it} > \gamma_2) + \delta CV_{it} + \varepsilon_{it} \tag{17}$$

where the explained variable IND_{it} represents industrial structure optimization index of city i in year t; The core explanatory variable ER_{it} denotes the environment regulation intensity of city i in year t; Q_{it} is the threshold variable, γ_1 and γ_2 is the threshold value; CV_{it} denotes other control variables affecting industrial structure optimization, such as regional economic growth level, fixed asset investment level, human capital level, etc.; ε_{it} denotes random disturbance term.

With regard to the measurement of resource abundance, there are generally two categories: First, select energy output, energy reserves, per capita resources and other indicators to measure. Second, extractive industry employees' ratio in the total population [36, 37], extractive industry employees' ratio in the total number of employees [38], the ratio of resource industry output value in GDP [39], and so forth. In this study, the ratio of the number of employees in the extractive industry to the number of employees in the secondary industry is adopted for measurement. The ratio of the number of extractive industry employees in the local population or the total number of employees refers to a measure of local resource dependence. If the industrial structures of a region are upgraded and no longer dependent on the secondary industry, the extractive industry, and other heavy industries, the number of people employed in extractive industries as a percentage of the total number of people employed or the total population is certainly not very high even under the abundant natural resources of the region. Extractive industry employees' ratio in the secondary industry reveals the internal structure of the secondary industry, if a region has abundant natural resources, the local secondary industry is naturally dominated by heavy industries (e.g., extractive industry), and the number of people employed in the extractive industry takes up a relatively large ratio of the number of people employed in the secondary industry.

Besides resource endowment, local industrial structures also serves as a major factor for local governments to consider when formulating environment regulation policies. Accordingly, the ratio of added value of the secondary industry to regional GDP is taken as the threshold variable. First, the number of thresholds should be determined. Table 4 lists the self-sampling test results of the panel threshold variables estimated with resource endowment (RES) and secondary industry's ratio (STRU), respectively.

As can be seen from Table 4, when resource endowment is taken as the threshold variable, the threshold effect of command-control environment regulation on industrial structure optimization is not significant, while the comprehensive index of environment regulation has a single threshold effect on industrial structure optimization, which passes the single threshold test and is significant at the 10% level. It indicates that the effect exerted by environment regulation on industrial structure optimization is nonlinear, i.e., the effect of environment regulation on industrial structure optimization is different in regions with different resource endowments.

The regression results of the single-threshold model with resource endowment as the threshold variable are listed in Table 5 below. Model (1) represents the regression equation of command-control environment regulation on industrial structure optimization, and model (2) is the regression equation of the comprehensive index of environment regulation on industrial structure optimization.

Since the regression of command-control environment regulation on industrial structure optimization does not pass the threshold effect test, the regression results of model (1) are only for reference. According to the regression results of model (2) in Table 5, the correlation coefficients between the comprehensive index of environment regulation and industrial structure optimization are significantly positive at the level of 1%, indicating that there is a significant positive correlation between them. When the resource endowment index is less than or equal to 6.6239%, the regression coefficient of the comprehensive index of environment regulation on industrial structure optimization is 0.098. When the resource endowment index is greater than 6.6239%, the regression coefficient of the comprehensive index of environment regulation on industrial structure optimization decreases to 0.062. This indicates that when the resource endowment of a region is relatively rich, the effect of environment regulation on industrial structure optimization decreases, revealing that the abundant natural resources will make the local area too dependent on the resource industry, thus triggering resource dependence.

The regression results of the dual-threshold model with industrial structures as the threshold variable are listed in Table 6 below. Model (1) represents the regression equation of command-control environment regulation on industrial structure optimization, and model (2) is the regression equation of comprehensive index of environment regulation on industrial structure optimization. Since the regressions of the command-based environment regulation and the comprehensive index of environment regulation on industrial

Table 4
Significance test results of panel threshold variables.

Threshold variable	Independent variables	Number of threshold	F value	P value	10%	5%	Threshold value
RES	ER_1	Single threshold	12.34	0.6367	28.9092	33.7059	68.6069
		Double threshold	12.82	0.4300	30.1783	38.1244	7.1733
		Three threshold	9.68	0.6400	26.9606	32.0353	41.2715
	ER_2	Single threshold	49.65	0.0667	43.9275	51.4999	6.6239
		Double threshold	18.41	0.4800	33.5426	38.0213	0.1857
		Three threshold	12.99	0.8033	45.7603	53.2770	68.6069
STRU	ER_1	Single threshold	183.66	0.0000	56.2009	63.1841	55.0400
		Double threshold	91.84	0.0000	40.8798	46.4040	47.5400
		Three threshold	52.93	0.9767	151.5828	166.2529	33.8066
	ER_2	Single threshold	359.31	0.0000	87.7256	96.5675	54.7600
		Double threshold	190.72	0.0000	52.2834	64.0483	48.0700
		Three threshold	76.55	0.9800	171.3122	182.7560	65.8600

Table 5
Estimation results of the single threshold model with resource endowment as the threshold variable.

	(1)	(2)
	IND	IND
ER_1 (RES≤68.6069)	1.117***	
	(3.85)	
ER_1 (RES >68.6069)	9.021***	
	(3.86)	
ER_2 (RES≤6.6239)		0.098***
		(17.84)
ER_2 (RES >6.6239)		0.062***
		(10.10)
Control Variables	YES	YES
_cons	215.064***	212.527***
	(296.48)	(294.66)
N	4576	4576
R^2	0.311	0.355

Table 6
Estimation results of the dual-threshold model with the secondary industry's ratio as the threshold variable.

	(1)	(2)
	IND	IND
ER_1(STRU≤33.8066)	4.536***	
	(12.38)	
ER_1 (33.8066<STRU≤47.5400)	1.312***	
	(3.99)	
ER_1(STRU >47.5400)	−3.353***	
	(-8.01)	
ER_2(STRU≤48.0700)		0.132***
		(24.33)
ER_2 (48.0700<STRU≤54.7600)		0.073***
		(13.80)
ER_2(STRU >54.7600)		−0.008
		(-1.17)
Control Variables	YES	YES
_cons	214.540***	211.991***
	(303.80)	(309.73)
N	4576	4576
R^2	0.349	0.419

structure optimization passed the double-threshold test when the industrial structures was taken as the threshold variable, the dual-threshold model was used for estimation.

As can be seen from the regression results of model (1) in Table 6, the regression coefficients of command-control environment regulation on industrial structure optimization are all significant at 1% level. When the secondary industry's ratio is less than or equal to 33.8066, the correlation coefficient between command-control environment regulation and industrial structure optimization is 4.536. When the secondary industry's ratio is between 33.8066 and 47.54, the correlation coefficient decreases to 1.312. When the secondary industry's ratio is greater than 47.54, the correlation coefficient between them is −3.353. It indicates that when the secondary industry's ratio in the industrial structures of a region is higher, the effect of command-control environment regulation on industrial structure optimization is smaller, or even negative. In other words, command-control environment regulation may even hinder industrial structure optimization in a region.

According to the regression results of model (2) in Table 6, when the secondary industry's ratio is less than or equal to 54.76%, the correlation coefficients between the comprehensive index of environment regulation and industrial structure optimization are both significant at the level of 1%. When the secondary industry's ratio is greater than 54.76%, the correlation coefficient between the comprehensive index of environment regulation and industrial structure optimization is negative, but the coefficient is not significant. Results are roughly the same as the regression result of model (1), which also indicates that the effect of environment regulation on industrial structure optimization in a region will decrease with the rise of the secondary industry's ratio. When the secondary industry's ratio exceeds a certain threshold, environment regulation may have a negative effect on industrial structure optimization.

4.3. Regional characteristics of the effect exerted by environment regulation on industrial structure optimization

Due to the imbalance of regional development in the east, the middle and the west, does the implementation of environment regulation in different regions have different effects on industrial structure optimization? Thus, this study will carry out empirical tests based on parts of eastern, Western and Western regions.

Table 7 shows the regional test results of command-control environment regulation on industrial structure optimization. Model (1) is the regression equation of command-control environment regulation in the eastern region on industrial structure optimization, and model (2) is the regression equation of command-control environment regulation in the eastern region on industrial structure optimization after adding the quadratic term. Model (3) is the regression equation of command-control environment regulation in the central region on industrial structure optimization, and model (4) is the regression equation of command-control environment regulation in the central region on industrial structure optimization after adding the quadratic term. Model (5) was the regression equation of command-control environment regulation on industrial structure optimization in the western region, and model (6) was the regression equation of command-control environment regulation on industrial structure optimization in the western region after adding the quadratic term.

The regression results of model (1), model (3) and model (5) in Table 7 show that the correlation coefficients of command-control environment regulation and industrial structure optimization in the eastern and western regions are both positive at the 1% significance level, while the regression coefficient in the central region is negative at the 1% significance level. This shows that the command-control environment regulation in the central region hinders industrial structure optimization, while the command-control environment regulation in the eastern and western regions has a facilitating effect on industrial structure optimization, and the facilitating effect is greater in the western region. This may be due to the implementation of the strategy of the rise of the central region in recent years, which has relaxed the environment regulation intensity in pursuit of high economic growth, thus taking over the industrial transfer from the eastern region.

According to the regression results of model (2), model (4) and model (6) in Table 7, the regression coefficients before the quadratic term of command-controlled environment regulation are all negative, and the regression coefficients before the primary term are all positive and significant at the significance level of 1% in all regions. It indicates that there is an inverted U-shaped curve between command-control environment regulation and industrial structure optimization in the eastern, central and western regions. In other words, when command-control environment regulation exceeds a certain strength, it will hinder industrial structure optimization. The inflection point of command-control environment regulation over industrial structure optimization is 1.633 in the eastern region, 0.863 in the central region and 2.381 in the western region. Accordingly, the position of the inflection point in the central region is significantly lower than that in the eastern and western regions, which means that the implementation of environment regulation policies of the same intensity may facilitate industrial structure optimization in the eastern and western regions, while it may hinder it in the central region. The possible reason for the above result is that the current industrial structures in the central region continue to be dominated by heavy industry, thus exhibiting more sensitivity to environment regulation policies.

Table 8 shows the regional test results of the comprehensive index of environment regulation on industrial structure optimization. Model (1) is the regression equation of the comprehensive index of environment regulation in the eastern region on industrial structure optimization, and model (2) is the regression equation of the comprehensive index of environment regulation in the eastern region on industrial structure optimization after adding the quadratic term. Model (3) is the regression equation of the comprehensive index of environment regulation in central region on industrial structure optimization, and model (4) is the regression equation of the comprehensive index of environment regulation in central region on industrial structure optimization after adding the quadratic term. Model (5) is the regression equation of the comprehensive index of environment regulation in western region on industrial structure optimization, and model (6) is the regression equation of the comprehensive index of environment regulation in western region on industrial structure optimization after adding the quadratic term.

4.4. Robustness test

This study not only tests the effect of command-control environment regulation on industrial structure optimization, but also tests the effect of comprehensive environment regulation on industrial structure optimization, and verifies the robustness of the results. On

Table 7
Regional test results of command-control environment regulation.

	Eastern region		Central region		Western region	
	(1)	(2)	(3)	(4)	(5)	(6)
	IND	IND	IND	IND	IND	IND
ER_1	1.624**	8.007***	−1.563***	1.986*	2.175***	6.619***
	(3.61)	(7.00)	(-2.64)	(1.73)	(3.62)	(6.26)
ER_1^2		−2.452***		−1.150***		−1.319***
		(-6,06)		(-3.62)		(-5.09)
_cons	239.2***	238.984***	222.893***	221.759***	203.911***	203.734***
	(118.20)	(119.38)	(200.93)	(192.98)	(165.56)	(167.07)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Provincial FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
N	1616	1616	1744	1744	1216	1216
R^2	0.76	0.77	0.61	0.61	0.67	0.67

Table 8
Regional test results of the comprehensive index of environment regulation.

	Eastern region		Central region		Western region	
	(1)	(2)	(3)	(4)	(5)	(6)
	IND	IND	IND	IND	IND	IND
ER_2	0.016	−0.003	0.007	0.065	0.018	0.081
	(1.55)	(-0.07)	(0.58)	(1.15)	(1.40)	(1.31)
ER_2^2		0.000		−0.001		−0.001
		(0.40)		(-1.05)		(-1.03)
_cons	238.102***	238.599***	222.378***	221.110***	203.280***	202.032***
	(115.79)	(99.45)	(190.40)	(131.61)	(153.80)	(112.87)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Provincial FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
N	1616	1616	1744	1744	1216	1216
R^2	0.76	0.76	0.61	0.61	0.66	0.66

From the regression results of each model in Table 8, the regression coefficients of the comprehensive index of environment regulation on industrial structure optimization are not significant in either the eastern, central or western regions.

this basis, the robustness test will be further conducted in this study. The idea of robustness test is to screen the samples, including eliminating municipalities and carrying out tail reduction and truncation treatment.

4.4.1. Treatment of eliminating municipalities

Since municipalities are at the same administrative level as provinces and higher than other cities on the prefecture level, they are also subject to more intervention and constraints from the central government, such that they need to be separated from other cities on the prefecture level in the study.

Table 9 shows the regression results of command-control environment regulation and comprehensive index of environment regulation on industrial structure optimization after excluding municipalities. To be specific, the model (1) and model (2) are regression equations of the effect exerted by command-control environment regulation with primary term and command-control environment regulation with secondary term on industrial structure optimization, respectively. The model (3) and model (4) are regression equations of the comprehensive index of environment regulation with primary term and the comprehensive index of environment regulation with secondary term on industrial structure optimization.

From Table 9 model (1) and (3), the regression results show that after excluding municipalities, the regression coefficients of command-control environment regulation and the comprehensive index of environment regulation on industrial structure optimization are significantly positive at the level of 1%, and the regression coefficient before command-control environment regulation is larger than that before the comprehensive index of environment regulation. This is the same as the regression results in Table 2, indicating that the regression results of the benchmark model are robust.

As indicated by the regression results of model (2) and model (4) in Table 9, the coefficient of correlation between the primary term of command-control environment regulation and industrial structure optimization is significantly positive at 1% after excluding municipalities, and the coefficient before the quadratic term of command-control environment regulation is significantly negative. After the inclusion of the quadratic term, the correlation coefficient between the primary term of the comprehensive index of environment regulation and industrial structure optimization becomes insignificant, basically consistent with the regression results in

Table 9
Regression results excluding municipalities.

	(1)	(2)	(3)	(4)
	IND	IND	IND	IND
ER_1	1.287***	5.298***		
	(4.15)	(8.63)		
ER_1^2		−1.332***		
		(-7.55)		
ER_2			0.016**	0.003
			(2.19)	(0.10)
ER_2^2				0.000
				(0.39)
_cons	211.274***	210.834***	210.770***	211.063***
	(247.16)	(247.61)	(237.20)	(181.31)
Control Variables	Yes	Yes	Yes	Yes
Provincial FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
N	4512	4512	4512	4512
R^2	0.66	0.67	0.66	0.66

Table 2, confirming the robustness of the regression results of the baseline model again.

4.4.2. Winsorization and truncation treatment

To deal with the influence of extreme values and outliers on the regression results, the study conducted winsorization and truncation at 1% and 99% percentiles. Table 10 and Table 11 present the regression results.

The regression results in Tables 10 and 11 show that the regression coefficients of command-control environment regulation and the comprehensive index of environment regulation on industrial structure optimization are still significantly positive after the winsorization and truncation treatment. After the inclusion of the quadratic term, the correlation coefficients between the quadratic term of command-control environment regulation and industrial structure optimization are significantly negative at 1%, consistent with the previous results, indicating an inverted U-curve correlation of command-control environment regulation and industrial structure optimization.

Compared to the regression results of the baseline model in Table 2, the regression coefficients of command-control environment regulation on industrial structure optimization are larger after truncation treatment, which demonstrates the robustness of the baseline model regression results and suggests that outliers do not have a significant impact on the regression results.

5. Conclusions and policy implications

5.1. Conclusions

First of all, both command-control environment regulation and comprehensive index of environment regulation notably contribute to industrial structure optimization. Moreover, command-control environment regulation takes on greater significance to industrial structure optimization than the comprehensive index of environment regulation, indicating that command-control environment regulation is the most effective means of environment regulation at present. Besides, the effect exerted by environment regulation on industrial structure optimization has a time-lag effect, and the environment regulation in the last period can facilitate industrial structure optimization more than the environment regulation in the current period.

Second, a non-linear correlation of environment regulation and industrial structure optimization is identified, with a clear inverted U-shaped curve between command-control environment regulation and industrial structure optimization. It indicates that once the environment regulation intensity reaches a certain inflection point, it will prevent industrial structure optimization, which is still not reached in most Chinese cities.

Thirdly, environment regulation has a threshold effect on industrial structure optimization. The empirical results show that when the resource endowment and the secondary industry's ratio in a certain region exceed a certain threshold, the positive effect of environment regulation on industrial structure optimization will decline, or even become negative. This also verifies the hypothesis proposed in the theoretical model, i.e., local governments will make a trade-off between economic growth and environmental protection for the purpose of maximizing political performance, such that the regional resource endowment and industrial structures will affect the implementation effect of environment regulation.

Fourthly, the effect exerted by environment regulation on industrial structure optimization is heterogeneous across regions. Due to the differences in development degree and industrial structures in different regions, the effect of environment regulation on industrial structure optimization in different regions is also different. In this study, we conducted a sub-regional test of the eastern, central and western regions, and found that in terms of command-control environment regulation, the central region had the most obvious effect, followed by the eastern region, and the western region had no obvious effect. In terms of the comprehensive index of environment regulation, the eastern region has the most obvious role, followed by the central region, and the western region has the least.

5.2. Policy implications

(1) Reduce the time lag of environment regulation policies.

To targeted reduce environment regulation policy lag, the following three aspects can be conducted in the beginning. First, local governments and environmental protection departments should improve their strategic decision-making capacity in coordinating regional economic growth and environmental protection, and be able to predict the situation of regional resources, environment and economic growth in advance. We should not drain resources and environment for the sake of economic growth; Second, local governments and environmental protection departments should improve administrative efficiency, enhance implementation capacity, formulate policies and put them into action in a timely manner in light of regional economic and environmental development changes. Third, protect the public's right to know about the contents of environment regulation policies and the information of the offending units, improve the transparency of information through diversified channels such as the Internet and media, and ensure the implementation of environment regulation policies through public supervision and participation.

(2) Facilitate regional coordination of environment regulation.

Local natural resources and ecological conditions should be considered during the formulation of regional environment regulation policies. To be specific, advanced demonstration zones can be set in some areas exhibiting high ecological efficiency to fully exploit their positive spatial spillover effects. The environmental protection concept, environmental protection technology and environmental

Table 10
Regression results after winsorization treatment.

	(1)	(2)	(3)	(4)
	IND	IND	IND	IND
ER_1	1.187***	3.301***		
	(3.61)	(6.72)		
ER_1^2		−0.737***		
		(-5.79)		
ER_2			0.016**	−0.019
			(2.23)	(-0.59)
ER_2^2				0.000
				(1.10)
_cons	228.697***	228.585***	227.379***	228.256***
	(102.15)	(102.46)	(101.41)	(95.95)
Control Variables	Yes	Yes	Yes	Yes
Provincial FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
N	4576	4576	4576	4576
R^2	0.69	0.69	0.69	0.69

Table 11
Regression results after truncation treatment.

	(1)	(2)	(3)	(4)
	IND	IND	IND	IND
ER_1	1.404***	3268***		
	(4.19)	(6.41)		
ER_1^2		−0.672***		
		(-4.84)		
ER_2			0.015**	−0.019
			(2.09)	(-0.57)
ER_2^2				0.000
				(1.04)
_cons	228.837***	228.799***	227.495***	228.340***
	(101.63)	(101.87)	(100.73)	(95.19)
Control Variables	Yes	Yes	Yes	Yes
Provincial FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
N	4443	4443	4443	4443
R^2	0.69	0.70	0.69	0.69

management experience of the advanced demonstration area will be spread to the surrounding areas, while encouraging the cross-regional flow of clean production capital and professional environmental protection talents. Notably, the regions with relatively low ecological efficiency should be considered, and key factors (e.g., talents, funds and technologies) should be radiated to the surrounding areas with high ecological efficiency cities as the core, with an aim of increasing regional ecological efficiency locally and generally. Regions with low eco-efficiency should take the initiative to undertake the transfer of clean industries, enhance their ability to identify industrial projects, take clean industries and circular economy industries as the first choice, eliminate several high-pollution industrial projects, and fully exploit their late-mover advantages by learning and drawing on the environmental governance experience of high eco-efficiency regions.

Under the effect of China's unbalanced regional development, the industrial structures layout among regions is not the same, and there are huge differences in resource endowments and development degrees across regions. Accordingly, when formulating environment regulation standards, measures should adapt to local conditions, classified policies should be adopted, the actual situation and development phase of the local should be fully considered, and the use of a one-size-fits-all policy should be avoided. When ecological construction is being promoted, the government is required to actively provide public goods and services for ecological construction. In general, overly one-size-fits-all policies are detrimental to the sustainable development of the region.

Author contribution statement

Wei Dai, Linhao Zheng: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Wei Dai, Mengyao Cheng: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

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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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