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RESEARCH ARTICLE

Dwindling regional environmental pollution through industrial structure adjustment and higher education development

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Abstract
This paper uses Chinese provincial data from 2006 to 2021 as a sample period to study the relationship between higher education development, industrial structure adjustment, and environmental pollution. Conclusions were as follows: (1) the industry structure adjustment can reduce environmental pollution in Chinese regions except eastern, and the increase in the proportion of the tertiary industry will increase pollution emissions in the eastern region. (2) Although there is a negative correlation between higher education and environmental pollution in China, it is not significant. From different regions, the coefficients in the eastern are positive which means aggravated environmental pollution, and the coefficients in the central region are not significant, but higher education in the western region improves environmental pollution. (3) Urbanization has a significant moderating effect on the national and regional environmental pollution, but in the central and western regions, it is smaller than the eastern region; although environmental regulation has a certain inhibitory effect on environmental pollution, the coefficient in the eastern region is significantly positive, and there is a situation of "more pollution, more control." Further, the increase of foreign direct investment will aggravate environmental pollution; although the elasticity coefficient in the eastern region is negative, there is a trend of improving environmental pollution, but it is not significant. The study holds promising implications for the development of policies related to education, industry, and the environment. Through the research on the relationship between the three, exploring and improving the regional environmental pollution level from the perspective of higher education and industrial structure have important practical significance for the regional green development.

Keywords Higher education · Industrial structure · Environmental pollution · China

Introduction

In recent years, with the rapid economic development, environmental problems have become the main problem faced by sustainable economic development. Statistics show that from 2004 to 2020, industrial SO2 emissions increased at a rate of about 1.95% per year, and smoke (powder) dust emissions increased at a rate of about 4.74% per year (Zhang 2022; Wang et al. 2021a, b). Pollutant emissions have been much higher than the environmental capacity. The emissions of pollutants such as SO2, NO2, and PM 2.5 rank among the top in the world, and haze pollution is serious, among which Beijing has PM 2.5 in 2015. The annual average value of 5 concentrations reaches 80.6 μg/m3 (Wang 2016), while the maximum annual average value that the World Health Organization considers no harm to health is only 10 μg/m3(Lu et al. 2019). At the same time, Chinese economic growth rate has slowed down. It is generally believed that environmental problems and economic growth are two sides of the same coin (Omri and Bélad 2021; Wang et al. 2021a, b). It seems that economic growth must be sacrificed in order to solve environmental problems, while promoting economic growth seems to be inevitable. Sacrifice the environment (Khan et al. 2021; Borhan et al. 2021). Facing with such a "dilemma," China has proposed supply-side reform and green development requirements, eliminating outdated production capacity, and strives to solve the two major problems of environmental pollution and economic slowdown. Obviously, industrial

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structure adjustment cannot only provide new impetus for economic growth, but also provide a way out for the control of environmental pollution (Ozturk et al. 2016). Therefore, industrial structure adjustment has become an inevitable way to solve the "two major problems" at the same time. In fact, in the early stage of an economy's development, with economy growth, environmental problem pollution become more and more serious, but when economy grows to a certain level, environmental pollution problem will gradually weaken. This is the so-called environmental EKC theory (Pata and Caglar 2021). When environmental pollution problems occur, the welfare level of residents will decline, and the government will strengthen environmental regulations, so that enterprises with serious pollution will withdraw from the local area and develop high-tech industries which improve the environment (Polemis 2017). Studying the interrelationship between them is conducive to solving environmental pollution problem in China and promoting Chinese economic development.

Based on the construction of ecological civilization, pollution prevention and control are regarded as one of the three tough battles to win the overall construction of a moderately prosperous society. The focus is on winning the battle to defend the blue sky and promoting green development, the growth of material resource consumption is unsustainable. It is necessary to implement low-carbon transformation and take the road of sustainable development form a new low-carbon economic development. The three main driving forces are all derived from human capital (Azam 2019). Labor quality improvement needs to rely on the development of higher education, while scientific and technological progress and management innovation require higher-level and more reasonable human capital and talents. The strategy of strengthening the country is the first strategy of strengthening talents and human resources, which is enough to clarify the important role of human capital. Faced with a new round of technological and industrial revolution in the world today, human capital is the most important strategic resource and means (Dedeolu et al. 2021). "Talent is the foundation of innovation, and innovation-driven is essentially talent-driven." As the main body of innovation, when human capital is damaged due to environmental pollution, the level of innovation will inevitably be affected. The accumulation of talents depends on higher education development; it provides high-quality innovative talents for national development. Therefore, studying the relationship between higher education, industrial structure, and environmental pollution has a certain implications. Based on this, this paper takes the 2006–2021 of Chinese provincial panel data as the research sample, adopts the fixed effect model to study the impact of higher education and industrial structure on environmental pollution, and proposes to improve the level of regional environmental pollution from the perspective of higher education and industrial structure. It has an important practical significance on green development.

The possible marginal contributions of this paper are as follows: (1) incorporate higher education, industrial structure and environmental pollution into the regression model at the same time. Existing research mainly focuses on the relationship between industrial structure and environmental pollution. There are few literatures considering higher education and environmental pollution. The improvement and supplementation of the research are also the main contribution of this research that is different from previous scholars. (2) Most of the existing researches are analyzed from the perspective of industry and province. In order to make the research more comprehensive and accurate, this paper introduces 30 regions across the country and divides the 30 regions into the east, middle, and western regions. Conduct research from an overall and subregional perspective. Therefore, the research sample selection and data sources in this paper are relatively novel. (3) Put forward targeted measures to improve environmental pollution, and provide theoretical reference for regional green development.

The research structure of this paper is as shown in Fig. 1.

Literature review

Higher education impact on environmental pollution

Few literatures are about the relationship of higher education and environmental pollution. The domestic and foreign literature mainly focuses on human capital and environmental pollution. For example, most studies show that they have a clear positive correlation. Hartman and Kwon (2002) discussed the relationship between them by constructing an endogenous growth model covering environmental pollution and human capital, and their conclusion showed that human capital can reduce environmental pollution. Kurtz and Brooks (2011) used a cross-country data sample abd found that higher accumulation of human capital help guide natural resource development toward supporting emerging technologies and higher-quality economic sectors. Liu (2014) introduced the factors of human capital accumulation into

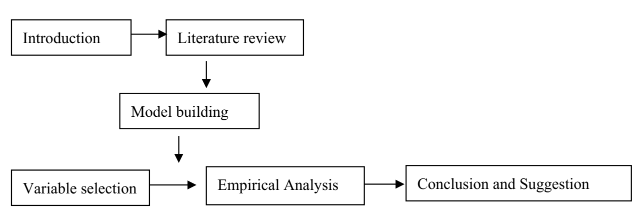

Fig. 1 Technology roadmap

the Stokey–Aghion model and found that under the pollution control path of "source control," the accumulation of human capital can contribute to the "win–win" goal. Yuan and Ban (2017) found that the improvement of education level has brought about the enhancement of environmental protection awareness. Chen et al. (2021) found that the average years of education of the labor force increased and the industries gradually shifted to high-tech industries, which was conducive to the improvement of environmental quality. Fan and Li (2022) believe that the improvement of human capital and technical level will help reduce environmental pollution. Fu (2008) research shown that human capital determines the host country's absorptive capacity and technology diffusion capacity, reducing environmental pollution. Hou and Chen (2018) discussed the impact of population change on the environment using Chinese provincial panel data and found that the faster the growth rate of human capital, the greater the improvement in environmental pollution. Zhang (2017) found that rural human capital can reduce pollution emissions. Wu and Tian (2012) analyzed the EKC curve of provincial environmental pollution and found that high-level human capital can reduce the environmental pollution. However, Lan et al. (2012a, b) found "pollution shelter" with low human capital levels. Because the environmental standards in such regions are generally lower, this leads to more foreign direct investment at the expense of the environment. Domestic scholar Yang (2022) also shows that the higher the stock of human capital, the more water pollution can be promoted to a certain extent. In addition, the literature also has shown nonlinear relationship between them (Sapkota and Bastola 2017; Shobande and Asongu 2021; Nazeer and Tabassum 2016).

The impact of industrial structure on environmental pollution

The relationship of them is an important environmental economics topic. Scholars have studied the environmental pollution effects of industrial structure adjustment from different perspectives. First, industrial structure impacts on environmental pollution. For example, using methods such as environmental input–output analysis method and effect decomposition analysis method, the industrial structure change and its impact on environmental pollution are analyzed from an empirical perspective (Soukiazis et al. 2019). Ding (2022) believes that the upgrading of industrial structure can promote the transformation of industrial development from factor-driven to innovation-driven, from extensive, high-consumption, and epitaxy to intensive, green, and low-carbon transformation. Grossman and Krueger (1995) found an inverted "U" shape of them, but Brajer et al. (2011) research has shown that the inverted "U" shape relationship does not exist between them. Oosterhaven and Broersma (2007) and Lan et al. (2012a, b) explored the relationship between them. Jalil and Feridurn (2011) believed that financial industry proportion increased to a certain extent, the production of pollutants can be inhibited, thereby reducing the risk of environmental pollution. Only through technological innovation can the emission of pollutants be reduced. Cherniwchan (2012) adopted different research methods and used the neoclassical growth model to explore industrialization impact on pollutant emissions and found that in the process of industrialization, as the input share of the industrial sector increases, the pollutant emissions also increase. Most scholars measure the impact on environmental quality through environmental Kuznets curve (EKC) theory (Islam 2021; Aung et al. 2017). Gupta and Barman (2009) studied the trend relationship between industrial waste emissions and economic growth in the process of industrialization and analyzed whether economic growth and industrial waste emissions were in an inverted "U" shape. Although the frontier theory of EKC in foreign or domestic countries is innovative, there has been no breakthrough in the theory and research methods.

From the above literature, it can be seen that they provide many references for this paper, but it can be seen that there is still room for further expansion: (1) research on the relationship between the three is fewer, and most researchers separate the relationship between the three to conduct research, mainly focusing on industrial structure and environmental pollution, as well as the research on the relationship between higher education and environmental pollution. There is little research on the relationship between the three. Therefore, the research in this paper is a supplement and improvement to the existing research. (2) Most of the research in the article is mainly concentrated on the national level or a specific region, and there are few reflecting the differences between regions. This paper will make a comparative analysis of three regions of China. (3) Few consider higher education impact, most scholars only use it as a control variable, and their understanding of its role is not fully understood and even ignore the interpretation of higher education. Its impact on environmental pollution has not received enough attention and attention. In particular, higher education has multiple and complex impacts on economic growth, alleviating resource and environmental constraints and driving low-carbon transformation. The research in this paper can further enrich the understanding of the role of higher education and further extension of the existing research field.

Methodology

The panel data model can comprehensively utilize the sample data in various aspects and at the same time reflect the changing trends and laws of the sample variables from the two dimensions of time and space. It has an irreplaceable role in quantitative economic analysis and has high application value, greatly enriching the panel data model usability.

Panel data model

Unity test of panel data

Panel data models require panel variables to be stationary; otherwise, spurious regressions may occur. Therefore, it needs to test unit root on the panel variables before building the model. Panel variable unit tests can be divided into two categories:

(1) *Unit root test in the case of homogeneous roots*

In the case of homogeneous roots, the unit root test assumes that each section sequence has the same unit root process, and the test methods mainly include LLC test, Breitung test, and Hadri test. The LLC test takes the form of the ADF test. The null hypothesis has the same unit root, and the alternative hypothesis has no unit root. Breitung test is similar to LLC test, and the test hypothesis is the same, but the proxy variables in the test formula are different. The Hadri test is similar to the KPSS test, and the null hypothesis is that each section sequence does not contain a unit root.

(2) *Unit root test in the case of heterogeneous roots*

The unit root test in the case of heterogeneous roots includes three test methods: IPS, Fisher-ADF and Fisher-PP. The construction of the heterogenous root test statistic combines the unit root test results of each section data and finally gives a comprehensive conclusion on whether the individual section has a unit root; it shows panel data model as follows:

$$y_{it} = \varphi_i y_{it-1} + x_{it}^{'}\beta_{it} + \mu_{it} \quad i = 1, 2, \cdots N; t = 1, 2, \cdots, T \tag{1}$$

where x_{it} represents exogenous variable; β_{it} is the regression coefficient of the explanatory variable; N is the number of samples; T is the time length; μ_{it} is the random disturbance term; and φ_i represents y_{it-1} coefficient, if $|\varphi_i| < 1$, the original sequence is stationary, if $|\varphi_i| = 1$ means non-stationary.

Cointegration test of panel data

Cointegration test methods for panel data can be divided into two categories. One is the panel cointegration test based on the Engle and Granger two-step test. The specific methods mainly include Pedroni test (Pedroni 1999) and Kao test (Kao 1999). The DF and ADF tests propose a method for testing panel cointegration. The null hypothesis of this method is that there is no cointegration relationship, and the residuals of static panel regression are used to construct statistics; the other is based on the Johansen cointegration test. Fort the panel cointegration test, this paper mainly uses the Pedroni test and the Kao test for the variables.

Panel data regression model selection

Fixed influence variable intercept model The fixed effect variable intercept model assumes that the individual difference effects of cross-section members can be represented by different constant terms. The regression equation for constructing the fixed effect model is Eq. (2), where y_i represents the T × 1-dimensional explained variable and x_i represents T × k-dimensional explanatory variables, β represents the k × 1-dimensional coefficient vector, the intercept term α_i between the i section member equations is constant and allows cross-section variation, and μ_i represents the random error term, which represents the difference between the different section members ignored in the model estimation. The effects of differences and time-varying factors are shown as follows:

$$y_i = \alpha_i + x_i\beta + \mu_i, \; i = 1, 2, \cdots N \tag{2}$$

Random influence variable intercept model The random effect variable intercept model divides α_i into two parts: the constant term α and the random variable term v_i. The basic formula of the model is shown by Eq. (3), $x_{it} = \left(x_{1,it}, x_{2,it}, \cdots, x_{k,it}\right)^{'}$, where α represents the constant term part of the intercept term, which represents the consistent change trend of each panel data, v_i represents the stochastic effect of the cross-section, and μ_{it} represents the stochastic effect of the variation of the period factor:

$$y_i = \alpha + x_{it}^{'}\beta + v_i + \mu_{it}, i = 1, 2, \cdots, N; t = 1, 2, \cdots, T \tag{3}$$

Hausman test is a hypothesis testing method selected to determine the model form when modeling panel data. The hypothesis testing method proposed by Hausman and Taylor (1981) first constructs a random influence model; the null hypothesis is set as the random influence model. In the model, there is no correlation between individual influences and explanatory variables. If the null hypothesis holds, it is a random influence model; otherwise, it is a fixed influence model.

In summary, the research methodology of this paper is shown in Fig. 2.

Variable selection

Environmental pollution (EP)

For the environmental pollution index, this paper selects the "three wastes" with the highest degree of industrial

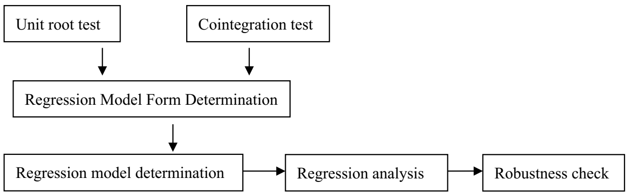

Fig. 2 Research method framework

pollution, that is, industrial waste gas emissions (unit: 10,000 tm) and industrial waste gas emissions are mainly sulfur dioxide emissions. Since urban sulfur dioxide emissions are very small, their emissions are included in the industrial emissions. Sulfur dioxide emissions, industrial wastewater emissions (unit: 10,000 t), and industrial solid waste emissions (unit: 10,000 t) were obtained through the entropy weighting method (Ssali et al. 2019). The main steps are as follows:

(1) Perform dimensionless processing on the data, the processing method is the efficacy coefficient method, and the formula is as follows:

$$p'_{ij} = \frac{p_{ij} - min_j}{max_j - min_j} \times 70 + 30 \quad (4)$$

In formula (4), p_{ij} ($i = 1, 2, \cdots, n, j = 1, 2, 3$) represents the emission value of the jth pollutant in the ith year; $min_j = min\ (p_{ij})$ represents the jth pollutant. The minimum value of the emission, maxj = max (p_{ij}), is the maximum value of the jth pollutant emission; p'_{ij} represents the pollutant emission data after dimensionless processing.

(2) Use the entropy method to determine the weight of the jth pollutant. Let e_j represents the entropy of the jth pollutant. According to the entropy calculation formula, e_j can be expressed as follows:

$$e_j = -\frac{1}{ln^3}\sum_{i=1}^{n} f_{ij} ln^{(f_{ij})} \quad (5)$$

In formula (5), $e_j > 0, f_{ij} = p'_{ij} / \sum_{i=1}^{n} p'_{ij}$ represents the characteristic proportion of the jth pollutant in the ith year; $\sum_{i=1}^{n} p'_{ij}$ represents the sum of the observation data of all years of pollutants of the jth category.

(3) Let w_j represent the entropy weight of the jth pollutant; according to the calculation formula of the entropy weight, w_j can be expressed as follows:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{3}\left(1 - e_j\right)} \quad (6)$$

(4) Let pi represent the pollution index of the ith year; the formula can be expressed as follows:

$$p_i = \sum_{j=1}^{3} \overline{p}_{ij\bullet} w_j \quad (7)$$

After calculation, the weight of w_1 (discharge of industrial waste gas) is 0.3452, the weight of w_2 (discharge of industrial wastewater) is 0.3563, and the weight of w_3 (discharge of industrial solid waste) is 0.2985.

Higher education (EDU)

Higher education refers to the use of human capital as a direct input factor in the production process, which acts on carbon emissions with the help of internal effects, external effects, and substitution effects. The internal effect means that the improvement of human capital investment will enhance the learning, technology, and adaptability of workers, thereby improving their own work efficiency and increasing their own returns. The external effect means that human capital enables workers to improve efficiency and also promotes the further renewal of these input factors, thereby improving production efficiency. The substitution effect means that with human knowledge system improvement, human capital can replace material capital to a certain extent, thereby dispelling concerns about energy shortages caused by rapid economic development and ultimately achieving sustainable development (Li et al. 2021).

Based on a comprehensive analysis of the research results, the multi-dimensional influencing factors of higher education are comprehensively analyzed from a systematic perspective, and 10 impact indicators are selected based on the scientific nature and availability of indicator data, as shown in Table 1.

Through the comparative analysis of research method, the entropy method could better avoid subjective factor influence and fully consider the influence of the mutual influence between the indicators on the overall weight. The weight method calculates the weight coefficient of the evaluation index. The specific steps are as mentioned above, and the above data are all from the "China Statistical Yearbook Data," "Statistical Bulletin of National Education Development," and other official data.

Industrial structure (IS)

The industrial structure is related to environmental pollution. Industrial structure adjustment makes the resources flow among the industries, resulting in the problem of resource utilization. In industrial structure upgrading, technological progress, and the continuous improvement of the quality of the labor force, the industrial structure will be conducive to

Table 1 Indicator system and weight of higher education and regional economic development

Evaluation system	Evaluation indicators	Index weight	Directivity
Higher education level system	Number of colleges and universities (number)	0.1213	Positive
	Number of graduates (person)	0.0924	Positive
	Enrollment (10,000 people)	0.1004	Positive
	Number of students in school (10,000 people)	0.1009	Positive
	Number of teaching staff (person)	0.1021	Positive
	Number of full-time teachers (10,000 people)	0.1023	Positive
	Number of college students per 100,000 population	0.1123	Positive
	Budgetary education funds (100 million yuan)	0.0992	Positive
	Graduated graduates (person)	0.0934	Positive
	Teacher–student ratio (%)	0.0757	Positive

environmental pollution improvement. However, if resource utilization is neglected in this process, it will bring about environmental pollution (Ayamba et al. 2019). The impact of a region's industrial structure and development model on the environment is crucial. The proportion of the tertiary industry in GDP is used to represent the industrial structure (IS).

Control variables

Urbanization rate (UR) Urbanization and environmental pollution not only restrict each other but also promote each other. First of all, urbanization continues to accelerate, the rural surplus labor gather in cities, and industrial industries, service industries, and financial industries continue to gather in cities, increasing the income of resident's level. However, as people's lives become more and more prosperous, after people are satisfied with their material life, they turn to pursue healthy living conditions. Therefore, the ecological environment has changed from a luxury to a necessity. Meanwhile, with urbanization improvement, citizens' awareness of environmental protection has become stronger and stronger, and the government and related social organizations have also paid more attention to the environmental problems, thus formulating environmental protection measures (Rahman and Alam 2021). In this sense, the development of urbanization has promoted the improvement of the ecological environment. This paper mainly reflects the level of population urbanization and uses the proportion of urban population in the total population.

Environmental regulation (EI) The government's environmental regulation means that the government directly or indirectly conducts certain guidance, constraints, or penalties on the production of pollutants by the enterprises through administrative means, thereby forcing the enterprises to reduce pollutants and improve the environment. The main means are environmental protection legislation, promulgation of environmental protection laws and regulations, collection of sewage charges, introduction of guiding policies, and so on. In related research, Porter and Van der Linde (1995) believed that the technological advantages obtained by enterprises will enable enterprises to obtain certain competitive advantages in the market, and the resulting benefits can offset or even exceed environmental protection compliance. And due to technological innovation, enterprises can use resources more effectively, control pollution, and ultimately improve environmental pollution. Porter and Van der Linde's (1995) study also believes that the collection of sewage charges will bring cost pressure to enterprises, but it may not necessarily encourage enterprises to improve technology and reduce sewage discharge but may enable enterprises to expand production scale and further increase pollution emissions. There are many ways to measure environmental regulation, and there is no unified method yet. Sewage charges, industrial pollution control investment, and comprehensive index are the methods that scholars use more often. This paper chooses the ratio of the amount of pollutant discharge fees released to the warehouse to the local GDP to measure the intensity of environmental regulation.

Foreign direct investment (FDI) The impact mechanism of FDI on environmental pollution was proposed by Grossman and Krueger (1995). After that, many scholars have used the influence mechanism in the research results of Grossman and Krueger to establish analytical frameworks and empirical models. By analyzing and summarizing the research results of scholars, it can be found that most scholars believe that FDI may have an aggravating impact on environmental pollution through scale effects and structural effects while improving environmental pollution through technological effects. Meanwhile, FDI will further deteriorate the environmental pollution of the host country and vice versa will improve the environmental pollution of the host country. Among them, the scale effect of FDI shows that with the continuous entry of foreign businessmen, the production activities continue to increase, which leads to a further increase in the amount of pollutants and then deteriorates the environment; the structural effect of FDI shows that with the continuous entry of foreign businessmen in high-polluting industries, it increases the proportion of local high-polluting industries, resulting in increased pollutant discharge and increased environmental pollution; the technical effect of FDI is that with the production and business activities of foreign investors, the host country's enterprises, governments, institutions, society, and other subjects continue to interact, through technology spillover, environmental protection demonstration, and appropriate competition; foreign businessmen have promoted the improvement of technology of the host country's enterprises, improved the overall environmental protection technology level of the host country, reduced pollution, and improved the environment. The ratio of FDI flow to local GDP is used to measure FDI. The higher the ratio of FDI flow to GDP, the greater the utilization of FDI in the region. The FDI data comes from the "actual utilized foreign direct investment" in the "Wind" database.

Table 2 Descriptive statistics of variables

Variable	Number of samples	Mean	Standard deviation	Minimum	Maximum
lnEP	480	79.2231	43.5542	2.5562	187.7818
lnIS	480	0.7843	0.0453	0.5843	1.0321
lnEDU	480	52.0312	5.3145	44.3341	72.5682
lnUR	480	0.8505	0.8683	0.0229	3.9895
lnEI	480	0.1122	0.8743	0.2144	0.4352
lnFDI	480	0.2322	0.2145	0.0655	0.3322

Model construction

According to the above analysis, the model is constructed as follows:

$$\text{lnEP} = \alpha_i + \beta_1 lnEDU + \beta_2 lnIS + \beta_3 lnUR + \beta_4 lnEI + \beta_5 lnFDI + \mu_i \tag{8}$$

Among them, lnEP, lnEDU, lnIS, lnUR, lnEI, and lnFDI represent environmental pollution, industrial structure, higher education, urbanization rate, environmental regulation, and foreign direct investment, respectively. The descriptive statistic of variable is as follows in Table 2.

Results

Unit root test

In general, if a time series becomes stationary after *d* differences, the original series is said to be a *d*-order integrated of *d* series. If a series cannot make the series stationary no matter how many times the difference is, then the series is a non-single integral series. The unit root test includes LLC, IPS, Fisher-ADF, and Fisher-PP test. The unit root test is performed on the variables. In Table 3, all variables are after first-order difference. It means that the variables are rejected. The null hypothesis is the first-order stationary and can be tested for cointegration. At the same time, Chang (2002) proposed to use nonlinear instrumental variable estimation to eliminate the correlation between cross-section elements and realize the normality of test statistics, so this paper uses the S_N test method to test the correlation between cross-sections elements; S_N test results show that the cross-sectional data are stationary. Results are in Table 3.

Table 3 Single integer test

Variable	LLC test	IPS test	Fisher-ADF test	Fisher-PP test	S_N test
lnEP	−9.0976***	−6.3348***	132.5543***	146.0321***	0.5784*** (c,0,2)
lnIS	−17.4322***	−11.0443***	254.0432***	276.5619***	0.0455*** (c,0,2)
lnEDU	−6.3432***	−1.9085***	71.4432***	165.3383***	0.3434*** (c,0,2)
lnUR	−135.6784***	−44.4532***	234.6652***	257.0346***	0.2672*** (c,0,2)
lnEI	−14.6684***	−11.5542***	178.8842***	213.3479***	0.1498*** (c,0,2)
lnFDI	−11.2341***	−9.0642***	177.5211***	215.7732***	0.0965*** (c,0,2)

*** represents a significance level of 1%, in the setting of the test formula, the parameter c represents the intercept, t represents the trend with time, and the value of the third parameter represents the lag order.

Table 4 Cointegration test results

Testing method	Test hypothesis	Statistics	Statistical value	*P* value
KaoTest	Ho: there is no cointegration relationship (ρ = 1)	ADF	− 0.6733***	0.0021
PedroniTest	Ho: ρi = 1 H1: (ρi = ρ) < 1	Panel v-statistic	− 1.5903	0.1340
		Panel rho-statistic	2.3402	0.2209
		Panel PP-statistic	− 0.8893***	0.0010
		Panel ADF-statistic	− 1.2932***	0.0000
	Ho: ρi = 1 H1: ρi < 1	Group rho-statistic	3.9926	0.5462
		Group PP-statistic	− 5.3291***	0.0012
		Group ADF-statistic	− 4.1283**	0.0672

*** and ** represent a significance level of 1% and 5%

Table 5 Random effect test of cross-sectional data

Test summary	Chi-Sq. statistic	Chi-Sq. d.f	Prob
Cross-section random	44.8832	3	0.0000

Cointegration test

The method used in this paper is the cointegration test method proposed by Engle and Granger in 1978, which are Pedroni test and Kao test. The lag order is determined by the SIC criterion. The results as follows Table 4, in the Kao test, the ADF-Statistic is significant at the 5% significance level, and in the Pedroni test, the Panel PP-Statistic is significant at the 5% significance level. Panel ADF-Statistic, Group PP-Statistic, and Group ADF-Statistic are all at 1, which means long-term cointegration relationship between the explanatory variable environmental pollution and other explanatory variables.

Determine the model form

In this paper, *F* statistic test is used to determine which model. The *F* statistic is defined as

$$F = \frac{\left(S_r - S_u\right)/[(NT-k-1)-(NT-N-k)]}{S_u/(NT-N-k)} = \frac{\left(S_r - S_u\right)/(N-1)}{S_u/(NT-N-k)} \quad (9)$$

where *Sr* is the residual sum of squares of the constrained model and *Su* is the residual sum of squares of the unconstrained model. The results are shown in Table 5. Because $P = 0.0000$, so the individual fixed effect model should be chosen.

Regression results

Through the analysis of the model, the following is an analysis of each variable impact on environmental pollution according to the regression results of the individual fixed effect model. The results are as follows shown in Table 6.

Industrial structure

In Table 6, from a national perspective, the coefficient of the industrial structure is negative, and it is passed the significant test and means that the proportion of the tertiary industry increase will reduce environmental pollution, which is also consistent with previous theoretical explanation. The

Table 6 Panel data regression results

Variable	Nationwide	East	Central	West
lnEP	− 1.2124*** (6.18)	0.1345*** (5.41)	− 0.5123*** (4.11)	− 0.9943*** (-5.28)
lnEDU	− 0.0675 (0.78)	− 0.2729*** (2.92)	− 0.1533 (-0.65)	0.1034**** (5.67)
lnUR	− 0.1032*** (5.34)	− 0.1433*** (6.12)	− 0.0718** (-2.22)	− 0.0454** (-1.99)
lnEI	− 0.1342 (0.39)	0.0124* (1.87)	− 0.0655 (-0.15)	− 0.1154 (-0.21)
lnFDI	0.1112*** (5.54)	− 0.1123 (0.72)	0.1522*** (5.47)	0.1945*** (4.92)
R^2	0.9564	0.9976	0.9453	0.9672
Adjusted-R^2	0.9455	0.9864	0.9348	0.9567
F statistic	124.3762	872.6674	435.56	964.5443
Prob (*F* statistic)	0.0000	0.0000	0.0000	0.0000

***,**, and * represent a significance level of 1%, 5%, and 10%

tertiary industry is a service-oriented industry with low resource consumption and low environmental pollution. Therefore, tertiary industry can reduce pollution. This is consistent with the views of most scholars. For example, Han and Yu (2015) found that in the long run the increase in the proportion of the secondary industry and GDP will accelerate environmental degradation, while the tertiary industry is conducive to improving environmental pollution, but the existing research rarely studies the impact of industrial structure on different regions of China. This paper expands the relevant research fields and is also the innovation point of this paper.

Industrial structure in the eastern region has a positive relationship with environmental pollution. Tertiary industry coefficient is positive and passed the significantly test. This shows that tertiary industry proportion in the eastern is related to environmental pollution emissions. There is a positive correlation between them, and the increase in the proportion of the tertiary industry will increase pollution emissions. The possible explanations are as follows: although the pollution level of the tertiary industry is relatively low compared with the secondary industry, with the continuous increase of the proportion of the tertiary industry, the emission of pollutants has also gradually expanded, except for the traditional catering industry. With the advancement of urbanization and the increasing proportion of pollution, such as oil fume pollution and medical waste pollution, the exhaust emissions from the transportation industry driven by the rapid development of tourism in the tertiary industry are also rising, and the postal service in modern society is on the Internet. Shopping also contributes to the emissions of transport energy pollutants. This makes the tertiary industry less polluting than the secondary industry, but the expansion of the proportion of the tertiary industry will still increase the degree of pollution. Therefore, the above reasons are possible explanations for the increase in the proportion of the tertiary industry in the eastern region but aggravated environmental pollution.

The industrial structure coefficient of the central and western regions is negative, and it is established at a significant level of 1%, that is to say, the tertiary industry proportion increase will reduce the pollution emissions in the central and western regions, which is just the opposite of the situation in the eastern region, which is different from that of the whole country. The situation is the same. The possible reasons are, on the one hand, the tertiary industry is less polluting than the secondary industry, so there is no doubt that an increase in the proportion of the tertiary industry and a decrease in the proportion of the secondary industry will reduce pollution. The expansion of the scale of the tertiary industry will increase the amount of pollution emissions. Because the development level of the central and western regions is far behind that of the eastern coastal cities, the pollution discharge is greatly affected by the increase in the proportion of the tertiary industry and the decrease, so the overall performance is that with the increase of the tertiary industry, the pollution has decreased. This explains why the change trend of the industrial structure coefficient in the central and western regions is different from that in the eastern region but is the same as that of the whole country.

Higher education

From a national perspective, the coefficient of higher education is negative but not significant, indicating that high education in the labor force has not really brought about an improvement in environmental pollution. The proportion of high education in the labor force in China has been gradually increasing. The proportion of technology development is still small, and it is still in the stage of imitating and innovating foreign technologies, and the original technology development and innovation capabilities are still relatively weak, which limits the role of higher education in improving carbon emission efficiency. This is different from the conclusions drawn by some scholars. For example, Chen et al. (2021) and Fan and Li (2022) believe that higher education will help reduce environmental pollution. The reason for the difference may be that the selection of indicators for higher education is different. The proportion of higher education is used to measure higher education, and most scholars use the amount of human capital to reflect, so different results have emerged, which is also the difference between this paper and previous scholars' research.

From the perspective of different regions, there are significant differences in the impact of higher education in each region. The coefficients of the eastern and central regions are positive, but the central region is not significant, and the western region has a significantly negative impact, which is completely different from the national impact. The development of higher education in the eastern region can effectively reduce the level of environmental pollution in the eastern region. The higher education in the central region has no obvious effect on the environmental pollution in the central region. It is closely related to the economic environment on which higher education plays its role. The economic structure of the eastern region is high, and there is a strong demand for highly educated talents, while the industrial structure level of the central and western regions has a lower demand for highly educated talents, especially in the western region. The proportion of higher education has increased, but there is no matching industrial demand, resulting in waste of human capital resources, thus increasing environmental pollution.

Control variables

Urbanization From a national perspective, urbanization has a significant mitigation effect on environmental pollution. It may be that urbanization promotes regional economic development and makes high-quality resources relatively concentrated, which is conducive to the reduction of environmental pollution levels. Different scholars have come to different conclusions in the research on the relationship between the two. For example, York and Rosa (2003) used a decomposable double logarithmic model to study the impact of urbanization level on the ecological environment. The study found an inverted U-shaped relationship between urbanization and environmental pollution. Kharel (2010) analyzed the use of land resources in the process of urbanization. The results show that the process of urbanization has caused serious damage to land resources, and there is a big gap with the results of this paper. The possible reasons are that the situation is different in different countries. The environmental benefits brought about by China's urbanization in recent years are greater than the environmental costs, so it shows a positive relationship. However, this paper also concludes that different regions have different characteristics, which is consistent with the views of some scholars Ding 2014; Yang et al. 2014). From the perspective of each region, due to the dense concentration of large, medium, and small cities in the eastern region, the high degree of aggregation, the relatively developed social division of labor, and the overall level of urbanization, its advantages in politics, economy, culture, and technology have a greater role in promoting the ecological environment, while in the central and western regions, due to the relatively backward economic development, mainly medium and small cities, and fewer large cities, the distribution of cities is relatively scattered in the process of urbanization development and the agglomeration and radiation effects. Compared with the eastern region, it is weaker, coupled with less investment in environmental protection and backward technology level, and thus has a smaller role in promoting the ecological environment.

Environmental regulation The result shows that the coefficient is negative in the whole country, and it has not passed the significance test, which shows that under the independent action of Chinese environmental regulation, although it has a certain inhibitory effect on environmental pollution, the effect is not significant. From the perspective of various regions, the coefficients of the estimated results of environmental regulation in the central and western regions are all negative numbers, and none of them has passed the significance test. In the inhibition effect, the effect is not significant, and related studies have also confirmed that the environmental regulation of the Chinese government has no significant effect on improving environmental pollution, such as Lu and Zhu (2016). The coefficient of environmental regulation in the east is significantly positive, indicating that the environmental regulation in the eastern region will further aggravate the environmental pollution in the eastern region under its independent action. Referring to the research of Ji et al. (2015), environmental regulation is significant precisely because the local government's regulation is seriously lacking in forward-looking and effective, and there is a situation of "the more pollution, the more control."

Foreign direct investment The coefficient of foreign direct investment is positive and established at a significant level of 1%, which means that the increase of foreign direct investment will aggravate environmental pollution. The reason may be that foreign investment has expanded Chinese economic scale and output level, which has led to an increase in pollutant emissions, especially when companies in developed countries face high pollution costs and strict environmental controls, the often pollution-intensive industries are transferred to developing countries with relatively loose environmental controls. In relatively developed cities such as eastern of China, environmental controls are relatively strict. Although FDI in the east has a positive impact on the environment, it does not passed the significance test; the western region has become a key area for FDI, and the investment may be mainly concentrated in pollution-intensive industries. Therefore, the increase in foreign investment leads to more serious pollution, so the impact of FDI on environmental pollution in the central and western regions is significantly positive.

Robustness test based on GMM model

Generalized method of moments (GMM) sets the parameters according to the theoretical relationship and replaces the theoretical relationship with the approximate value calculated according to the sample. The basic idea is to select the minimum distance estimate. Because of OLS estimation and maximum likelihood estimation, both have good statistical properties under certain assumptions. The GMM estimation method is a robust estimation method, which does not have too many restrictions on the random disturbance term and allows the random disturbance term to have heteroscedasticity and serial autocorrelation, so the obtained estimator is also more reliable.

To further verify the robustness of the effect of the explanatory variables on the explained variables, this paper uses the two-step system generalized moment estimation method to test the model results. When operating with EViews, the second-order lag of the explained variable and the first-order lag of the explanatory variable are selected as instrumental variables. The specific estimation results are as shown in Table 7.

Table 7 Robustness test results

Variable	Nationwide	East	Central	West
LnEP(-1)	0.3341*** (6.54)	0.4531*** (4.67)	0.2341*** (5.32)	0.1984*** (4.45)
lnIS	− 1.322*** (7.24)	0.1213*** (4.56)	− 0.5562*** (4.16)	− 0.9453*** (-6.11)
lnEDU	− 0.0764 (0.6542)	− 0.2453*** (6.65)	− 0.1344 (-0.79)	0.1223**** (5.87)
lnUR	− 0.1123*** (4.34)	− 0.1453*** (− 4.16)	− 0.0443** (-5.66)	− 0.0346** (− 1.96)
lnEI	− 0.1165 (0.65)	0.0144* (1.97)	− 0.0652 (-0.85)	− 0.1355 (− 0.77)
lnFDI	0.1453*** (4.34)	− 0.1122 (1.11)	0.1324*** (6.33)	0.1785*** (6.44)
Sargan	0.1346	0.2311	0.1421	0.1458

***,**, and * represent a significance level of 1%, 5%, and 10%

Table 7 shows that whether from the national perspective or from the regional level, the first-order lag of the environmental pollution level has a significant positive effect on its antecedent. This shows that the areas with serious environmental pollution in the previous period will continue to have serious pollution in the next period. Most of the regression results of other variables are consistent, which also shows the reliability of the individual fixed effect model chosen in this paper.

Conclusions and applications

Conclusion

The article studies the relationship between higher education, industrial structure, and environmental pollution. According to the empirical analysis results, the following conclusions are drawn.

From a national perspective, the industrial structure and environmental pollution are negatively correlated. The increase in the proportion of the tertiary industry will reduce environmental pollution. However, there is heterogeneity between regions. The central and western regions have the same characteristics as the whole country. Environmental pollution is negatively correlated, but the lack of it in the eastern region is the opposite. The increase in the proportion of the tertiary industry will increase pollution emissions.

From a national perspective, the coefficient of higher education is negative but not significant, indicating that the increase in the proportion of higher education in the labor force has not really brought about an improvement in the environment. From the perspective of each region, the coefficients of the eastern and central regions are positive, but the central region is not significant, and the western region has a significantly negative impact, which is completely different from the national impact. This shows that the development of higher education in the eastern region can effectively reduce the level of environmental pollution in the eastern region. The higher education in the central region has no obvious effect on the environmental pollution in the central region. Matching industrial needs, resulting in a waste of human capital resources, thereby increase environmental pollution.

Urbanization has a significant mitigating effect on the national and regional environmental pollution, but the mitigating effect in the central and western regions is smaller than that in the eastern region; although environmental regulation has a certain inhibitory effect on environmental pollution, the coefficient in the eastern region is significantly positive. In the situation of "more pollution, more control,", the increase of foreign direct investment will aggravate environmental pollution. Although the elasticity coefficient in the eastern region is negative, there is a trend of improving environmental pollution, but it has not passed the significance test.

Recommendations

(1) Implement differentiated policies for regions with different development levels, and make higher education development plans. The eastern and central regions make full use of good educational resources, continue to strengthen investment in higher education, adjust the professional structure of colleges and universities to adapt to the optimization and upgrading of high-tech industries, and provide intellectual support for economic development; the western region increases investment in higher education funds and attaches great importance to the construction of infrastructure around colleges and universities which will enhance the policy preference for high-quality personnel training plans. Northeast China is facing a critical period of industrial structure upgrading and transformation and should focus on the optimization and adjustment of the structure of higher education majors, so that the structure of higher education matches the structure of industry, and the higher education and economic development are coordinated.

(2) According to the different characteristics of regional urban development, take different targeted measures to improve the efficiency of pollution control. For the

western region with a low level of urbanization with low economic development, the degree of environmental pollution is relatively light, and it is more sensitive to investment in pollution control. For areas with a high level of urbanization, such as Beijing, Zhejiang, and other places, in addition to increasing the investment in pollution control funds, introduce advanced production technology to reduce the discharge of environmental pollutants. Meanwhile, pay attention to the internal optimization and strive to improve the efficiency of pollution control. For areas with a moderate level of urbanization, especially in areas with a high degree of industrialization, environmental issues need to be listed as the primary problem to be solved.

Promote the common development of new industries and environmental protection industries, and control industrial enterprises with a high degree of pollution. Meanwhile, the government's assessment needs to comprehensively consider environmental quality in addition to the total economic volume, so as to reduce the cost of environmental pollution by local governments for the purpose of economic development. This approach enables the healthy and sustainable development of regional urbanization.

(3) Attention should be paid to the improvement of economic growth quality, and the recycling of resources should be continuously integrated to improve the recycling rate of energy, so as to strengthen the circular economy. For development, reduce energy waste, and reduce resource consumption, so as to reduce the discharge of environmental pollutants and curb the deterioration of environmental quality (Saboori et al. 2017). Continuously optimize the upgrading of the industrial structure; promote industrial transformation; transform the industry from the secondary industry to the service industry; improve the quality of industrial employees; improve personnel skills, knowledge, and skills; and adapt to the employment requirements and standards of new industries. Reduce the amount of production activities in the secondary industry or industry, change production methods, and ultimately reduce the emission of environmental pollutants. Therefore, only by accelerating the development of circular economy and the optimization and upgrading of the industrial structure can we effectively reduce the discharge of the three industrial wastes, thereby reducing the degree of environmental pollution, relieving the pressure of environmental pollution protection, and improving the quality of the environment.

(4) Improve technological innovation capabilities. Scientific innovation is the premise of promoting industrial structure upgrading, the main way to reduce environmental pollution. For example, the rise of western cities represented by Chengdu and Guiyang in recent years has accelerated economic growth, which is the positive impact of technological innovation. The government should give support in this regard, establish a technology-specific service platform, and form a technology investment R&D system involving the government, enterprises, financial institutions, and other parties, so as to stimulate the potential of industrial innovation. Technology is the primary productive force, and the core for enhancing industrial competitiveness. To develop green industries, it is necessary to accelerate the improvement of scientific and technological progress capabilities. Realize the transformation of green economy through scientific and technological progress, improve agricultural development technology, reduce environmental pollution, save the cost of environmental pollution control, and promote economy transformation from a resource-based development model to a technology-based model; through the promotion and application of green technology, reduce the cost of traditional agriculture and the ability of industry to destroy the entire ecological environment, realize the innovation of industrial development model, improve energy efficiency and labor productivity level (Rasoulinezhad and Saboori 2018; Taghizadeh-Hesary et al. 2021), eliminate technical barriers, encourage enterprises that can improve their competitiveness, and enhance their motivation and enthusiasm for technological innovation; through the research and development of green products, they can improve their competitiveness, increase their profits, and achieve a win–win situation in both economic and ecological benefits. The development of science and technology depends on high-tech talents, and high-tech talents are the pioneers and promoters of scientific and technological development. To develop high technology, China must cultivate high-tech talents and strengthen the construction of high-tech talents. Therefore, China can develop existing human resources and improve the scientific and technological level of employees through various forms of vocational training and education; through the establishment of green industry and related majors and courses in colleges and universities, it can cultivate high-end green industry development. For scientific and technological talents, through the talent introduction project, attract high-tech talents at home and abroad, become a leader in high-tech development, promote technological innovation in green industries, develop green products with high-end technical level, and improve the scientific and technological content of product structure, and enhance the competitiveness of China's industrial structure.

(5) Explore the upgrading of industrial structure under COVID-19.

In the context of the post-pandemic era, on the one hand, the potential for industrial growth is huge, and the fluctuation of demand elasticity is small, which can lead to changes in new fields and industries and provide an effective path for other traditional industries to improve operational efficiency and efficiency and achieve transformation and upgrading. In the internal cycle of the economy, it is an important way to effectively expand and develop domestic demand. It can increase the contribution rate of consumption to economic growth, effectively change the situation that our economic growth is mainly driven by investment, and prevent the instability of economic development. On the other hand, under the background of the epidemic, it is to accelerate the construction of a new development pattern with the domestic cycle as the main body and the domestic and international dual cycles to promote each other, so as to promote the continuous upgrading of industrial structure adjustment, thereby improving the level of environmental pollution.

Limitations and prospects

(1) The research objects used in this paper are 30 provinces and cities in China except Tibet, but the more the research objects and the smaller the area, the more the characteristics between the environment and urbanization can be reflected. However, some provinces cover a large area, and there are geographical differences within the region. Therefore, this paper believes that the prefecture-level and even county-level regions can be used as the research object, so as to weaken the influence of spatial differences on variables.

(2) This paper does not subdivide higher education and conduct research by type, which makes the research conclusions lack pertinence. In order to have more practical guiding significance, the classification analysis of higher education can be considered in the follow-up research.

(3) Due to space limitations, this paper does not forecast the future development trend of each province. The follow-up research can provide targeted suggestions for the provinces to achieve environmental pollution improvement in the future through prediction.

Author contribution Wenxuan Ma: conceptualization, methodology, software, data curation, writing—original draft preparation, writing—reviewing and editing, software, visualization, investigation, and validation.

Data availability All the data is publicly available, and proper sources have been cited in the text.

Declarations

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