Air Pollution, Environmental Regulations and Economic Growth — Estimation of Simultaneous Equations Based on Panel Data of Prefecture-Level Cities

Ligang WANG

*School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190,
China*

E-mail: tyzfwtg@163.com

Qi ZHANG

*School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190,
China*

E-mail: zhangqi190@mailsucas.ac.cn

Lin WANG**

School of Accounting, Guangdong University of Foreign Studies, Guangzhou 510006, China

E-mail: lindear1616@163.com

Xi ZHANG*

School of Economics, Beijing Technology and Business University, Beijing 100048, China

E-mail: zhangxi@btbu.edu.cn

Abstract The article selects the panel data of 289 prefecture-level and above cities in China from 2003 to 2017, establishes simultaneous equations and uses the 3SLS estimation method to study the relationship between air pollution and economic growth. On the whole, industrial sulfur dioxide and soot emissions have an inverted U-shaped relationship with per capita GDP, and the increase in sulfur dioxide emissions has played a significant role in hindering economic growth. From a regional perspective, the sulfur dioxide emissions in the eastern and western regions conform to the environmental Kuznets curve, and the per capita GDP at the turning point in the western region is significantly lower than the overall national level. The smoke and dust emissions in the eastern, central and western regions all conform to the environmental Kuznets curve, while the per capita GDP at the turning point in the western region is significantly lower than that in the eastern and central regions. In the eastern region, both sulfur dioxide and smoke and dust emissions significantly hinder economic growth, and this hindrance is mainly caused by the spatial transfer of labor. Through further analysis, it is found that environmental regulations can significantly suppress the negative impact of air pollution on economic growth. Finally, the article puts forward some suggestions, such as environmental governance according to local conditions and strengthening environmental regulations.

Keywords air pollution; economic growth; environmental regulation; environmental Kuznets curve

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* Corresponding author

** Common corresponding author

1 Introduction

Since the reform and opening up, China has experienced rapid economic growth, the scale of production has continued to expand, and the people's living standards have improved rapidly. But behind the rapid growth are a series of hidden dangers. Excessive consumption of resources and environmental pollution continue to intensify. The "China National Environmental Analysis (2012)" report shows that in 2012, China accounted for 7 of the world's 10 most severely polluted cities. Among the 500 cities across the country, less than 5 have air quality that meets the standards recommended by the World Health Organization. Environmental pollution has also caused serious economic losses. From 2003 to 2010, the cost of environmental pollution in various regions of China accounted for about 8%~10% of per capita real GDP, and developed regions were significantly higher than underdeveloped regions^[1]. In order to vigorously promote environmental governance and ensure the safety of people's lives, the central government has made comprehensive arrangements. In 2013, the "Air Pollution Prevention and Control Action Plan" was released, also known as the "Atmospheric Ten Measures". In March 2018, the first meeting of the 13th National People's Congress voted to pass a constitutional amendment, which included new development concepts, ecological civilization and requirements for building a beautiful China into the constitution. The National Ecological Environment Protection Conference held in Beijing in May 2018 officially confirmed Xi Jinping's ecological civilization ideology. In June 2018, the State Council issued the "Three-Year Action Plan to Fight Air Pollution", aiming to keep more blue skies for the masses.

With unremitting efforts, China's air pollution control has been effective. In 2020, the overall national air quality will improve. The ratio of good days in cities at prefecture-level and above is 87%, and the average concentration of PM_{2.5} in cities that do not meet the standard was 28.8% lower than in 2015. The coal resource-based cities represented by Taiyuan City have also "pulled out the clouds and mist to the blue sky." In the context of continuous improvement in air quality, we have to ask: Does China's air pollution conform to the classic environmental Kuznets curve, and has it crossed the inflection point? What is the feedback effect of air pollution on economic growth? China has a vast territory, with great differences in geographic location, resource endowments, and population size. How to tap the heterogeneity of the relationship between air pollution and economic growth in different regions? These are all questions that the article needs to explore.

This paper selects the panel data of 289 prefecture-level and above cities in China from 2003 to 2017, uses simultaneous equations to explore the relationship between air pollution and economic growth, and analyzes the heterogeneity of the eastern, central and western regions. At the same time, it examines the role of environmental regulations in it. The chapters of the article are arranged as follows: The second part is the literature review, the third part is the model design and data sources, the fourth part is the empirical analysis, and the fifth part is the conclusions and suggestions.

2 Literature Review

For a long time, scholars have entered in-depth research on the relationship between air pollution and economic growth, mainly including the verification of the environmental Kuznets curve and exploring the impact of air pollution on economic growth.

2.1 The Impact of Economic Growth on Air Pollution

In the impact of economic growth on environmental pollution, it is mainly to verify the existence of the environmental Kuznets curve (EKC). There are a number of valuable results in both theory and empirical aspects. In terms of theoretical research, scholars mainly introduce environmental pollution or environmental quality variables into economic growth models, such as the neoclassical economic growth model^[2–5], endogenous economics Growth model^[6–9]. Behind the model, the principle of forming the inverted U shaped curve is the same. Personal utility is a function of consumer goods and environmental quality, and people always prefer more consumption or a better environment. In the initial stage of economic growth, per capita income is very low, resource consumption is low, pollution emissions are low, and environmental quality is good. At this time, the marginal utility of consumer goods is greater than the marginal utility of environmental quality, so people are willing to exchange more consumer goods at the cost of environmental pollution. In the later period of economic growth, the per capita income level is very high. With the continuous increase of consumer goods and the intensification of environmental pollution problems, the marginal utility of environmental quality surpasses the marginal utility of consumer goods. At this time, people are willing to consume less in exchange for better environmental quality. This will increase investment in environmental governance and improve environmental quality. Therefore, the relationship between environmental pollution and per capita income is an inverted U shaped curve^[10–12].

In terms of empirical research, Grossman and Krueger^[13] made pioneering contributions. This paper uses the urban regional data of 42 countries to study the relationship between air quality and per capita GDP. It is found that the concentration of sulfur dioxide and smoke has an inverted U relationship with per capita GDP. This relationship is mainly explained from the scale effect, technology effect and structure effect: With the increase of per capita income and the expansion of production scale, the resource consumption increases, resulting in the intensification of environmental pollution, but the improvement of economic development level reduces environmental pollution through technological progress and the adjustment and upgrading of industrial structure. After that, scholars expand on this basis to verify the existence of Environmental Kuznets Curve by selecting different samples or adding other variables. Using the data of 30 provinces and cities in China from 1996 to 2000, Bao and Peng^[14] found that except for the chemical oxygen demand of pollutants in industrial wastewater, the emissions of industrial wastewater, smoke, dust, sulfur dioxide and solid waste all conform to the Kuznets inverted U shaped curve. Shen and Zhang^[15] used the spatial econometric analysis method to investigate the impact of economic growth and openness on industrial pollution emissions. It was found that the Environmental Kuznets curve was verified in 25 provinces such as Shanghai and Jiangsu, but not supported in 5 provinces such as Beijing and Tianjin. Shao, et al.^[16] used the PM_{2.5} concentration data of various provinces and cities in China from 1998 to 2012 and the dynamic spatial panel data model. They found that there was a significant U shaped curve relationship between haze pollution and economic growth, and most eastern provinces were in the stage of haze pollution aggravating with the improvement of economic growth. Some scholars also use other nonlinear models for research, such as panel smooth transformation model^[17] and threshold regression model^[18].

2.2 The Impact of Air Pollution on Economic Growth

The impact of air pollution on economic growth has two directions: On the one hand, the negative externality of environmental pollution hinders economic growth^[19]; On the other hand, environmental pollution will expand the scale of relevant environmental protection industries. At the same time, the government's environmental regulation forces enterprises to innovate, so as to improve production efficiency and promote economic growth. The hindering effect of environmental pollution on economic growth mainly comes from that environmental pollution will damage people's health, especially air pollution and water pollution^[20], thus reducing labor productivity^[21, 22]. Matus^[23] assessed the impact of air pollution on China's economic health by using emission prediction and policy analysis model, and found that air pollution has caused absolute losses to the national economy. Qi, et al.^[24] found that environmental pollution had a significant negative impact on national health and affected economic growth through health by studying the panel data of 28 provinces in China from 1992 to 2011. The health damage of environmental pollution will also affect labor supply and labor productivity. The difference of environmental pollution between cities will lead to the transfer of labor force between cities, which will affect the production level of cities. Gaurav, et al.^[25] found that high-level labor is more likely than low-level labor to leave the city where they currently live due to air pollution, resulting in a spatial mismatch of labor, reducing average productivity, and negatively affecting the macro economy.

Because of the negative externality and positive utility of environmental pollution on economic growth, the overall impact direction of environmental pollution on economic growth is uncertain. By establishing the simultaneous equations of pollution and output, Bao and Peng^[14] found that industrial wastewater, chemical oxygen content of pollutants in wastewater and soot emission have negative effects on economic growth, while the emissions of industrial soot, sulfur dioxide and solid waste have no significant impact on economic growth. Gao and Yang^[26] found that SO₂ and PM₁₀ have significant negative effects on economic growth; NO₂, PM_{2.5} and O₂ have significant positive effects on economic growth; although CO has a positive effect on economic growth, it is not significant. Wang^[27], Li, et al.^[28] also found that the direction and degree of the impact of pollutants on economic growth are different.

Through literature review, it is found that scholars have deeply explored the relationship between air pollution and economic growth. However, most of them establish a single equation to verify the Environmental Kuznets curve between per capita GDP and air pollution, and there are few studies on the impact of air pollution on economic growth. Based on this, the marginal contributions of this paper are: 1) Using the panel data of 289 prefecture level and above cities in China from 2003 to 2017, establish simultaneous equations to explore the correlation between air pollution and economic growth from the urban level; 2) Considering the feedback effect of economic growth on air pollution, this paper focuses on the impact of air pollution on economic growth, and explores the role of environmental regulation.

3 Models and Data Sources

3.1 Model Building

In order to study the impact of air pollution on economic growth, the article establishes a

simultaneous equation set of air pollutant emissions and output levels, and conducts the study in consideration of their feedback effects:

$$P_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \alpha_3 X_{it} + \varepsilon_{it}, \quad (1)$$

$$Y_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 K_{it} + \beta_3 L_{it} + \mu_{it}. \quad (2)$$

Formula (1) is the air pollutant equation, where P_{it} is the pollutant emission and Y_{it} is the output level. At the same time, the quadratic term Y_{it}^2 of the output level is introduced in the equation to verify whether the environmental Kuznets curve (EKC) is valid. X_{it} is a series of control variables. ε_{it} is a random disturbance term used to control other factors that may affect pollutant emission.

Formula (2) is the output equation, based on the classic Cobb-Douglas production function setting. K_{it} is physical capital and L_{it} is human capital. μ_{it} is a random disturbance term used to control other factors that may affect the output level. There can be a correlation between ε_{it} and μ_{it} .

In order to make the research more universal and representative, this paper selects the panel data of 289 prefecture-level and above cities in China from 2003 to 2017 for research.

3.2 Variable Selection and Data Sources

1) Selection of air pollution indicators. In terms of measuring the degree of air pollution, industrial sulfur dioxide emissions and industrial smoke and dust emissions are mainly selected. Pollutant emissions from industrial production are the main source of air pollution (the cause of industrial pollution is selected). The main air pollutants include aerosol state pollutants and gas state pollutants. Sol-state pollutants mainly refer to suspended particulate matter, floating dust, etc., while gaseous state pollutants mainly refer to sulfur-oxygen compounds and nitrogen-oxygen compounds. Therefore, the selection of sulfur dioxide and smoke and dust emissions are representative of the types and emissions of air pollutants to a large extent. The emissions of industrial sulfur dioxide and industrial smoke and dust of prefecture-level cities have been published since 2003, and the data comes from the “Statistical Yearbook of Chinese Cities”.

2) Selection of economic growth indicators. Taking into account the differences in the size of the population of each city, the per capita GDP of each city is selected as the proxy variable of economic growth, and the 2003 CPI is used as the benchmark for deflation. The data comes from the “China City Statistical Yearbook” and Wind database.

3) Selection of control variables for the air pollutant equation. The control variables of this equation mainly include: 1) Environmental governance. Government policy supervision and control of environmental protection is an important factor affecting pollution emissions^[14]. Therefore, the proportion of urban annual investment in environmental pollution source governance in GDP is selected to represent the level of environmental governance. The data from 2003 to 2007 are from the “China City Statistical Yearbook”. From 2008 to 2017, there is a lack of environmental governance data at the prefecture-level city level. The annual environmental governance investment at the provincial level is used, and the average value is taken according to the number of prefecture-level cities to replace. The data comes from the “China

Environmental Statistics Yearbook”. 2) Foreign direct investment. When facing the increasingly strengthened environmental regulations in the country, companies can reduce the cost of environmental governance not only through innovation but also through relocation. Therefore, the differences in environmental regulatory standards in various regions have brought about the shift of pollution-intensive industries^[13, 29, 30], that is, “Pollution haven”. The article uses foreign direct investment to measure this effect. The data comes from the “China City Statistical Yearbook”. 3) Industrial structure. Industrial production, an important source of air pollutants, belongs to the secondary industry of the national economy. In the initial stage of economic growth, factors of production and resources flow to the secondary industry with high profit margins, which continuously expands its scale and proportion. The acceleration of the process of industrialization means the massive consumption of natural resources and excessive discharge of waste. As the economy grows to a certain stage, the traditional economic growth model at the cost of serious resource consumption and increased environmental pollution is no longer sustainable and requires adjustment and optimization of the industrial structure. At this time, the proportion of the tertiary industry continued to rise, and the level of natural resource consumption and pollution emissions began to decline. This article uses the proportion of the secondary industry in GDP to represent the industrial structure. The data comes from the “China City Statistical Yearbook”. 4) Urban greening level. Plants can not only absorb harmful gases such as SO₂ and NO₂, but also reduce wind speed. After the wind speed is reduced, the particles in the air, especially the particles with larger diameters, are easily deposited on the ground or the surface of the branches and leaves of plants; while the shrubland and grassland are more conducive to preventing the falling dust from floating into the air again^[31]. Therefore, the improvement of urban greening can reduce the pollutant content in the air to a certain extent. The article uses the green coverage rate of the built-up area to indicate the greening level of the city. The data comes from the “China City Statistical Yearbook”. 5) Population density. Under normal circumstances, an increase in the size of the population means an increase in the intensity of human activities and an increase in resource consumption, which will make air quality worse^[32]. But when the population size reaches a certain level, the pollutant content in the air will decrease instead. Because of the high investment in large-scale urban environmental protection treatment, spatial gatherings make pollution treatment have economies of scale, thereby reducing the intensity of industrial pollution^[33]. Affected by the area of the administrative area, the population density is more reasonable than the population size. The data comes from the “China City Statistical Yearbook”.

4) Selection of control variables for the output equation. According to the Cobb-Douglas production function, the selected control variables include: 1) Material capital. The fixed asset investment amount of the year is used instead, and the 2003 CPI is used as the benchmark for deflation. The data comes from the “China City Statistical Yearbook” and Wind database. 2) Human capital, that is, labor input, expressed by the number of employees in enterprises at the end of the year, and the data comes from the “China City Statistical Yearbook”.

The variable definitions are shown in Table 1.

Table 1 Variable names and definitions

Variable type	Variable name	Unit	Variable symbol	Variable definitions
Endogenous variables	Industrial SO ₂ emission	100 tons	SO ₂	Industrial SO ₂ emissions
	Industrial smoke and dust emission	100 tons	Dust	Industrial smoke and dust emissions
	GDP per capita	Ten thousand yuan/person	pGDP	Real GDP per capita (treated at constant prices in 2003)
Exogenous variables	Foreign direct investment	One hundred million U.S. dollars	FDI	The total amount of foreign capital actually utilized in the year
	Industrial structure	%	second_GDP	The proportion of the secondary industry in GDP
	Environmental governance	%	PCI	The total investment in pollution source treatment accounted for the proportion of GDP that year
	Urban greening level	%	land_ratio	Green coverage rate in built-up area
	The population density	Person/km ²	density	The population density
	Physical capital	100 million yuan	Fix_I	Total investment in fixed assets (treated at constant prices in 2003)
	Human capital	The thousand person	Emp	Number of employees at the end of the year

4 Empirical Analysis

4.1 Descriptive Statistics

Table 2 shows the results of descriptive statistics. You can see the observed value, mean, standard deviation, minimum and maximum of each variable. It is observed that there is a large gap in industrial SO₂ and industrial smoke and dust emissions between cities and years, and the difference in per capita GDP is also large.

Table 2 Descriptive statistics

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
SO ₂	4210	560.881	585.956	0.02	6831.62
Dust	4159	322.339	1181.025	0.34	51688.12
pGDP	4260	2.715	2.193	0.008	22.857
FDI	4081	6.906	17.41	0	308.256
second_GDP	4283	48.308	11.071	9	90.97
PCII	4209	1.912	2.27	0.001	31.328
land_ratio	4234	36.798	14.131	0.36	386.64
density	4282	423.952	326.156	4.7	2661.54
Fix_I	4253	761.364	1000.909	16.567	12403.93
Emp	4288	49.001	73.558	4.05	986.87

4.2 Correlation Analysis

Table 3 shows the results of the correlation analysis. Without controlling other variables, the correlation between the variables is preliminarily explored. It can be seen that without controlling for other variables, there is a significant positive correlation between industrial SO₂ emissions and per capita GDP, and there is also a significant positive correlation between industrial smoke and dust emissions and per capita GDP. From the point of view of control variables, for the air pollutant equation, the correlation between almost all control variables and industrial SO₂ and industrial smoke and dust emissions is significant at the 1% significance level, indicating that the selection of control variables is reasonable. It can improve the goodness of fit of the model to a certain extent. This is just a preliminary inquiry result, and the specific relationship needs to be tested by regression analysis.

4.3 Simultaneous Equation Regression Analysis

Use 3SLS to estimate the equations. Tables 4 and 5 are the estimated results of the pollution equation and the output equation in the simultaneous equations. The results will be discussed separately next.

Table 3 Correlation analysis

Variable	SO ₂	Dust	pGDP	FDI	second_GDP	PCII	land_ratio	density	Fix_I	Emp
SO ₂	1.000									
Dust	0.175***	1.000								
pGDP	0.134***	0.041***	1.000							
FDI	0.248***	0.035**	0.516***	1.000						
second_GDP	0.246***	0.065***	0.286***	-0.025	1.000					
PCII	-0.138***	-0.01	0.069***	-0.121***	-0.041***	1.000				
land_ratio	0.037**	0.012	0.268***	0.144***	0.131***	0.058***	1.000			
density	0.118***	-0.016	0.238***	0.388***	0.129***	-0.194***	0.181***	1.000		
Fix_I	0.283***	0.075***	0.608***	0.790***	0.018	-0.107***	0.176***	0.363***	1.000	
Emp	0.306***	0.048***	0.428***	0.757***	-0.081***	-0.143***	0.107***	0.409***	0.750***	1.000

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 4 Estimated results of pollution equation

Variable	(1)	(2)
	Industrial SO ₂	Industrial smoke and dust
	SO ₂	Dust
pGDP	153.422*** (-28.324)	304.511*** (-60.808)
pGDP ²	-8.771*** (-2.138)	-22.953*** (-4.608)
FDI	5.397*** (-0.86)	-1.629 (-1.846)
second_GDP	12.123*** (-1.211)	0.656 (-2.572)
PCII	-36.263*** (-5.361)	-27.874** (-11.551)
land_ratio	-2.461*** (-0.765)	-3.619** (-1.645)
density	-0.118*** (-0.032)	-0.269*** (-0.07)
Constants	-155.803*** (-51.184)	66.85 (-109.254)
R ²	0.062	0.021
EKC shape	Inverted U shape	Inverted U shape
Turning point (ten thousand yuan)	8.746	6.6334
Observations	3,847	3,799

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

1) The impact of air pollution on economic growth. According to the results in Table 5, industrial smoke and dust emissions play a certain role in hindering economic growth, although this effect is not significant. Excessive smoke and dust emissions will damage machinery and equipment and shorten their service life; on the other hand, they will also pose a threat to human health, thereby reducing the productivity of factors and hindering economic growth. Industrial SO₂ emissions have a slight positive impact on economic growth, but they are not significant. The possible reason is that the expenditure for environmental remediation and the purchase of protective equipment exceeds the damage caused by environmental pollution.

2) Verification of the environmental Kuznets curve. According to the results in Table 4, it can be seen that both SO₂ and dust conform to the inverted U shape of the environmental Kuznets curve. For industrial SO₂ emissions, the inflection point is 87,460 yuan. At present, the per capita GDP of many prefecture-level cities has exceeded this inflection point and has begun to enter the downward phase of the curve. For industrial smoke and dust emissions, the inflection point is 66,334 yuan, and most prefecture-level cities exceed this inflection point.

Table 5 Estimated results of output equation

Variable	(1)	(2)
	Industrial SO ₂ pGDP	Industrial smoke and dust pGDP
SO ₂	0.0001 (−0.0002)	
Dust		−0.0001 (−0.0002)
Fix_I	0.001*** (0.000)	0.001*** (0.000)
Emp	−0.001** (−0.001)	−0.002*** (−0.001)
Constants	1.634*** (−0.074)	1.692*** (−0.069)
R ²	0.386	0.386
Observations	3,847	3,799

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3) The influence of control variables on economic growth. The positive impact of material capital on economic growth is in line with the classical assumptions, while the negative impact of the employed population on economic growth has also been discussed by some scholars. For example, Gong, et al.^[34] believed that with the increasingly fierce labor market competition, the increase in marginal employment brought about by economic growth continued to decrease. Cai, et al.^[35] believed that the data indicating the employment index is used incorrectly, that is, using the total employed population at the end of the period to replace labor input, it is easy to draw the conclusion that employment elasticity has decreased, and thus the negative relationship between labor input and economic growth.

4) The influence of controlled variables on air pollution. (i) Foreign direct investment. FDI has played a significant role in promoting industrial SO₂ emissions, verifying the “pollution safe haven” effect. However, FDI has played a certain role in reducing industrial smoke and dust emissions, although this effect is not significant. (ii) Industrial structure. The proportion of the secondary industry in GDP has played a significant role in promoting industrial SO₂ and industrial smoke and dust emissions, verifying the above hypothesis. (iii) Environmental governance. The increase in investment in pollution source treatment as a proportion of GDP will significantly reduce industrial SO₂ and smoke and dust emissions. (iv) Urban greening level. The increase in green coverage in built-up areas has significantly im-

proved air quality. (v) Population density. From the perspective of SO₂ and smoke and dust, the increase in population density has significantly improved air quality, which verifies the scale effect of environmental governance brought about by the spatial agglomeration of population mentioned above.

4.4 Heterogeneity Analysis

Tables 6 to 9 show the estimated results of the pollution equation and output equation of the simultaneous equations by region. From the perspective of pollutant SO₂, both the eastern and western regions have an inverted U shaped curve, and the per capita GDP at the turning point in the western region is significantly lower than the overall national level, while the relationship between SO₂ emissions and output in the central region is not in line with the environment Kuznets curve. In terms of smoke and dust emissions, the eastern, central and western regions all have an inverted U shaped curve. This feature of the western region is not significant, while the per capita GDP at the turning point in the western region is significantly lower than that of the eastern and western regions.

Table 6 Estimation results of industrial SO₂ pollution equation by region

Variable	(1) East SO ₂	(2) Central SO ₂	(3) West SO ₂
pGDP	180.022*** (-27.661)	-284.824*** (-38.150)	452.100*** (-105.804)
pGDP ²	-14.990*** (-2.063)	28.617*** (-2.583)	-59.222*** (-10.285)
FDI	5.110*** (-0.777)	8.677*** (-2.573)	24.080*** (-2.817)
second_GDP	10.436*** (-1.372)	18.789*** (-1.568)	-0.227 (-3.424)
PCII	-39.988*** (-6.700)	29.773*** (-6.874)	-9.963 (-14.351)
land_ratio	-0.213 (-0.678)	-0.873 (-1.38)	-17.572*** (-3.743)
density	0.125*** (-0.033)	-0.291*** (-0.047)	0.07 (-0.137)
Constants	-343.807*** (-58.874)	141.884** (-69.376)	594.524*** (-150.831)
R ²	0.168	0.011	0.012
EKC shape	Inverted U shape	U shape	Inverted U shape
Turning point (ten thousand yuan)	6.0047	4.9745	3.817
Observations	1,932	1,050	865

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7 Estimated results of output equation by region

Variable	(1)	(2)	(3)
	East	Central	West
	pGDP	pGDP	pGDP
SO ₂	−0.0005** (−0.0002)	0.003*** (0.000)	−0.001*** (−0.0002)
Fix.I	0.001*** (0.000)	0.003*** (0.000)	0.001*** (0.000)
Emp	0.002*** (−0.001)	−0.029*** (−0.002)	−0.005*** (−0.002)
Constants	2.033*** (−0.093)	−0.318** (−0.127)	1.825*** (−0.095)
R ²	0.454	0.240	0.139
Observations	1,932	1,050	865

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.**Table 8** Estimation results of industrial smoke and dust pollution equation by region

Variable	(1)	(2)	(3)
	East	Central	West
	Dust	Dust	Dust
pGDP	293.581*** (−34.532)	413.299* (−227.186)	82.967 (−59.507)
pGDP ²	−21.341*** (−2.569)	−27.978* (−15.7)	−6.633 (−5.782)
FDI	−2.193** (−0.968)	−17.751 (−16.067)	7.716*** (−1.592)
second_GDP	−4.946*** (−1.698)	12.09 (−9.130)	2.817 (−1.948)
PCII	−26.947*** (−8.395)	−45.905 (−42.712)	−13.834* (−8.196)
land_ratio	−1.692** (−0.841)	−11.185 (−8.760)	−3.247 (−2.118)
density	−0.097** (−0.041)	−0.662** (−0.286)	−0.053 (−0.078)

Table 8 (continued)

Variable	(1)	(2)	(3)
	East	Central	West
	Dust	Dust	Dust
Constants	109.268 (−73.139)	−8.182 (−436.162)	125.117 (−86.062)
R^2	0.226	0.236	0.058
EKC shape	Inverted U shape	Inverted U shape	Inverted U shape
Turning point (ten thousand yuan)	6.8783	7.3861	6.2541
Observations	1,903	1,035	861

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.**Table 9** Estimated results of output equation by region

Variable	(1)	(2)	(3)
	East	Central	West
	pGDP	pGDP	pGDP
Dust	−0.008*** (−0.002)	0.001*** (0.000)	0.006*** (−0.001)
Fix_I	0.002*** (0.000)	0.003*** (0.000)	0.001*** (0.000)
Emp	−0.004** (−0.002)	−0.033*** (−0.004)	−0.022*** (−0.004)
Constants	3.524*** (−0.350)	1.503*** (−0.171)	0.462* (−0.267)
R^2	0.399	0.469	0.21
Observations	1,903	1,035	861

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

From the perspective of the output equation, in the eastern and western regions, SO_2 emissions significantly hinder urban economic growth, and the two are negatively correlated. This shows that the per capita GDP in the eastern and western regions has exceeded the inflection point of the curve and entered a decline stage. Smoke and dust emissions significantly hinder economic growth in the eastern region, while in the central and western regions, there is a positive correlation between the two. The main reason is that the smoke and smog situation in the eastern region is particularly serious. This difference in environmental quality between regions will cause the spatial transfer of labor, especially high-level labor, and thus harm economic growth^[25].

4.5 Further Discussion

Table 10 Further analysis of the impact of air pollutants on economic growth

Variable	(1) pGDP	(2) pGDP
SO ₂	−0.0002*** (−0.0001)	
PCII	0.1365*** (−0.0107)	0.1492*** (−0.0093)
SO ₂ *PCII	0.0001*** (0.000)	
Dust		−0.0001 (−0.0001)
Dust*PCII		0.00003 (−0.00002)
Fix_I	0.0014*** (0.000)	0.0015*** (0.000)
Emp	−0.0000 (−0.0006)	0.0001 (−0.0006)
City fixed effect	Yes	Yes
Constants	1.4070***	1.3024***
	−0.0534	−0.034
R^2	0.55	0.5522
Observations	4082	4033

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 10 is a further analysis of the impact of SO₂ on economic growth. Column (1) is the impact of SO₂ emissions on per capita GDP, and at the same time introduces the cross-term of SO₂ and PCII, which is the proportion of environmental governance investment in GDP. Column (2) shows the impact of industrial smoke and dust emissions on per capita GDP, and at the same time introduces PCII and the cross term with smoke and dust emissions Dust. The coefficient of SO₂ in column (1) is −0.0002, and the coefficient of the cross term is 0.0001, both of which are significant at the 1% significance level. It shows that with the continuous increase of investment in environmental governance and the continuous strengthening of environmental regulations, the hindrance of SO₂ to economic growth has been weakening. The coefficient of Dust in column (2) is −0.0001, and the coefficient of the cross term is 0.00003, but it is not significant, indicating that the increase in environmental regulation can restrain the negative impact of industrial smoke and dust emissions on economic growth to a certain extent. However, this inhibitory effect is not as strong as on sulfur dioxide emissions. This result also confirms

the general view of the academic community: A strong environmental policy is an effective inducement means to reduce pollution emissions^[12].

5 Conclusions and Recommendations

The article selects the panel data of 289 prefecture-level and above cities in China from 2003 to 2017, establishes simultaneous equations and uses the 3SLS estimation method to study the relationship between air pollution and economic growth. Through research, it is found that, on the whole, industrial sulfur dioxide and smoke and dust emissions are in line with the inverted U-shaped curve of environmental Kuznets, and the inflection point of smoke and dust emissions is lower. Industrial smoke and dust emissions play a certain role in hindering economic growth, mainly by damaging the health of residents and reducing the production of factor productivity. In terms of different regions, the sulfur dioxide emissions in the eastern and western regions both exhibited an inverted U-shaped curve, and the per capita GDP at the turning point in the western region was significantly lower than the overall national level. The smoke and dust emissions in the eastern, central and western regions all follow an inverted U-shaped curve, while the per capita GDP at the turning point in the western region is significantly lower than that in the eastern and central regions. In the eastern region, both sulfur dioxide and smoke and dust emissions significantly hinder economic growth, and this hindrance is mainly caused by the spatial transfer of labor. After further analysis of the impact of air pollutants on economic growth, it was found that with the continuous increase in environmental quality investment, the increase in environmental regulation can restrain the negative impact of industrial sulfur dioxide and soot emissions on economic growth to a certain extent.

Based on the empirical conclusions of the article, combined with the current environmental situation in China, the following suggestions are made: First, environmental governance measures need to be adapted to local conditions. The environmental pollution situation in different regions is different, and the sources and proportions of pollutants are also different. Each region, province and city need to formulate appropriate environmental governance policies according to their own conditions. Promote industrial emission reduction from end-to-end governance to source governance. For the western region, the inflection point of the environmental Kuznets curve is much lower than that of the central and eastern regions. We can learn from the experience of the central and eastern regions to develop the economy under the premise of controlling pollution emissions. Encourage enterprises to develop clean technologies to achieve both environmental and economic considerations. Second, strengthen environmental regulation and appropriately increase investment in environmental governance. The empirical results show that environmental regulations can suppress the negative impact of air pollutants on economic growth. It is necessary to formulate strict environmental standards, strengthen environmental law enforcement, improve the exit mechanism of high energy consumption and high pollution enterprises, and fundamentally curb pollution-intensive production methods. At the same time, it is necessary to promote the combination of government supervision and market economic measures, and strengthen the role of environmental regulations in promoting industrial structure upgrading and economic growth.

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