Hindawi
Complexity
Volume 2022, Article ID 4604467, 14 pages
https://doi.org/10.1155/2022/4604467

Research Article

The Impact of Urban-Rural Income Inequality on Environmental Quality in China

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Received 16 December 2021; Revised 16 February 2022; Accepted 28 February 2022; Published 21 April 2022

Academic Editor: Wei Zhang

As the per capita income level increases, both environmental quality and income inequality will change significantly, which arouses people's attention on the relationship between income inequality and environmental quality. Based on mathematical derivations, we first prove that when the relationship between per capita income and environmental pollution is nonlinear, and environmental pollution is not only related to per capita income, but also, among other potential determinants, to income inequality. Then, we use the two-way fixed estimator to estimate the impact of income inequality on environmental quality by decomposing the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model. (1) The impact of income inequality on environmental pollution is significantly positive, that is, as the income gap widens, industrial pollutant emissions, carbon dioxide emissions, and PM2.5 in the air will increase; (2) there is an "Inverted U-shaped" impact relationship between income inequality and environmental quality, that is, environmental pollution increases first and then decreases with the increase of per capita GDP; (3) per capita income is the intermediate variable between income inequality and environmental quality. The relationship between income inequality and environmental quality should be fully considered when formulating relevant policies. The government should adopt differentiated environmental policies targeted at low-and-high income groups to achieve a win-win situation of economic growth and environmental protection.

1. Introduction

Since reform and opening up, China's economy has grown at a higher rate. However, this extensive growth pattern with high investment and high pollution has caused many complications. Among them, the most prominent are pollution and unbalanced income distribution. On the one hand, the income inequality has continued to widen under the strategy of "let some people get rich first." On the other hand, the climate problem and environmental pollution have become increasingly serious. Environmental sustainability becomes an important topic within relevant literature [1,2]. China has become the country with the largest total carbon emissions in the world. The smog is also increasing considerably. Environmental quality and income inequality are challenges to China's sustainable economic development, social justice and stability. In the report to China's 19th National Congress, General Secretary Xi Jinping put forward the economic development goal of "a significant increase in the proportion of middle-income groups, and a significant reduction in the gap between urban and rural development and the gap in the living standards of residents." Furthermore, he also put forward the ecological environment development goal of "a fundamental improvement in the ecological environment." However, it is worth exploring whether there is a conflict between these two development goals?

With the increase of per capita income in China, environmental quality and income inequality have both changed significantly. The exit researches summarize the above-mentioned characteristic facts into two curves [3]. The first is the Kuznets (KC) curve. Kuznets analyzed the inverted U-shaped relationship between economic development and income distribution and proposed the Kuznets curve [4]. The income gap first widens and then decreases with the increase in per capita income. The second is

Environmental Kuznets curve (EKC). Crossman and Krueger found an inverted U-shaped relationship between environmental quality and per capita income, that is, environmental quality will first decrease and then increase as per capita income increases [5]. After that, Crossman and Krueger used data from multiple countries and regions to conduct empirical analysis and confirmed the existence of this U-shaped relationship [6]. The impact of per capita income on income gap and environmental quality is so similar. Moreover, over the past few decades China has witnessed a significant change in income inequality and environmental quality that has triggered people's thinking about their relationship. If there is a significant relationship between the two, the direction of their impact should have a major guiding role in income distribution and the formulation of environmental governance policies. The great income inequality and severe environmental pollution are two important issues that need to be addressed urgently in China at the current stage, clarifying the internal relationship between the two plays an important role in policy guidance for the construction of ecological civilization and the improvement of people's livelihood.

2. Literature Review

Do income inequality and environmental quality affect each other? In fact, the relationship between income inequality and environmental quality has been widely disputed in existing research studies for a long time. When selecting different sample data from different regions, the empirical conclusions drawn are often significantly different. Boyce is the first to consider the income gap as one of the factors affecting environmental quality [7]. He believes that relatively powerful and wealthy people generally get more benefits from economic activities that damage the environment, while relatively poor people mainly bear the burden. Later, Scruggs questioned this and believed that the impact of income inequality on environmental quality depends on the dual effects of people's income preferences and the rules set by the social system [8]. Since then, the relevant literature study has carried out a large number of theoretical analysis and empirical tests on this basis, but the existing researches do not have a unified theoretical framework. Some studies show that income inequality will worsen the environmental quality [9–14]. Some researches provided opposite conclusions that income gap and environmental quality are positively correlated [15–17]. Others even question the deterministic relationship between income gap and environmental quality, and believe that the relationship is vague and heterogeneous [18–21]. After reviewing these literature studies, it can be found that there are three main channels for the impact of income disparity on environmental quality:

The first influence mechanism is personal preference behavior. The income gap will affect the consumption preference behavior of personal goods and services, and then affect the environmental quality [22–24]. People with different incomes have different environmental quality preferences and personal environmental pressures [25], and their willingness to pay for environmental quality is also different. Affluent people have stronger environmental preferences, environmental quality has higher income elasticity [26], and the unit currency brings less environmental pollution, thus promoting the improvement of environmental quality. However, it has also been suggested that the high-income elasticity of demand for environmental quality does not necessarily mean that the willingness to pay for environmental protection increases [27]. Income does affect the demand for environmental quality, in which absolute income will affect the ability to protect environmental protection, and relative income will affect the willingness to protect. But there may be a conflict between the willingness to protect the environment and the ability to protect the environment. Roca (2003) established a model of the relationship between personal preferences and environmental quality. He believed that wealthy people could transfer consumption-related environmental pollution to other places through trade and territorial isolation, without affecting their living environment [28]. Even high-income households may have carbon-intensive lifestyles, such as regular vacations in places with higher environmental quality or golf entertainment [24].

The second influence mechanism is social norm awareness. Environmental quality is a public good. When the income gap reaches a certain level, social norms will change, thus affecting citizens' environmental awareness. Wilkinson and Pickett (2010) argue that income equality means a healthier, trusting society. When there is a large income gap, it will bring a series of negative consequences [29]. Social instability factors increase, citizens' sense of social responsibility decreases, and citizens' awareness of environmental protection will also be weakened. At the same time, the focus of public opinion will also change. A larger income gap will cause public opinion to pay attention to economic and social issues, while paying less attention to environmental issues and ignoring environmental protection [30].

The third impact mechanism is the national environmental policy. Income inequality affects national environmental policy decisions, which in turn affects environmental quality. Personal interests will be embodied in political demands, and different income groups have different demands on environmental policies. McAusland (2003) believes that the poor and the rich bear the opportunity cost of pollution control according to the endowment of their polluting products, but both enjoy the same results of environmental improvement. Therefore, the poor are more inclined to strict environmental policies than the rich [31]. However, those who often bear the cost of pollution are not satisfied with their demands for environmental policies. A fairer distribution of wealth and power can increase the influence of those who bear more pollution costs and help improve environmental quality [6, 32, 33].

To sum up, the income gap will have an impact on environmental quality through various channels such as personal preference behavior, social norm awareness, and national environmental policies. When using sample data from different countries and regions, the empirical conclusions drawn are often quite different. The impact of income disparity on environmental quality seems to be affected by factors such as the income level of the region, and there is still considerable controversy about the impact of income disparity on environmental quality. Moreover, most of the existing literature conducts empirical research based on a single environmental pollutant index, but there are many types of environmental pollution, and a single environmental pollution index cannot scientifically and comprehensively represent the comprehensive level of environmental pollution, the general law of income gap and environmental quality still to be confirmed.

Under the framework of the EKC curve, this study uses panel data of 28 provinces in China from 1997 to 2015 to conduct empirical research to explore the impact of income inequality on environmental quality. Compared with previous research, this study has made innovative attempts in the following three aspects:

Firstly, most of the existing literature is based on a certain single environmental pollutant indicator for empirical research, but there are many types of environmental pollution, water pollution, gas pollution, solid pollution, etc. This study attempts to avoid the contingency caused by measuring environmental pollution with a single indicator. We use the PCA method to integrate multiple industrial environmental pollution indicators into a comprehensive indicator to avoid possible accidental results. We also use carbon dioxide emissions and PM2.5 in the air to test for robustness.

Secondly, we guess that the impact of income inequality on environmental quality will vary with the change in per capita income. Therefore, mathematical derivation and the mediation effect model is used to test the influence mechanism of the impact of income inequality on environmental quality.

Thirdly, considering that income inequality and environmental quality may be causal to each other, we further use the generalized moment estimation (GMM) method to test endogenous problems.

3. Background

3.1. Environmental Quality. The environmental pollution in China is relatively serious. Figure 1 is a broken line chart of the average annual change of my country's provincial industrial pollutant emissions from 1997 to 2015. It can be seen that the level of industrial pollution in China has mostly increased first and then decreased. This is mainly due to the efforts of the governments to tackle environmental pollution in recent years, and successively put forward policies to strictly control the discharge of industrial pollutants. However, in terms of the absolute value of environmental pollutant emissions, compared with other countries in the world, China's industrial pollution is still very serious. Environmental protection still needs to be strengthened, and environmental quality still needs to be improved right away.

From the five pollution indicators of industrial wastewater, industrial solid, industrial smoke and dust, industrial sulfur dioxide, and industrial waste gas, the differences between the indicators are more obvious, and the trend of change is also different. Therefore, this study uses the principal component analysis (PCA) method to synthesize a comprehensive indicator of environmental pollution from the above five indicators [34]. To a certain extent, this can avoid the differences between the various indicators and accidental research results produced by a single indicator measurement.

3.2. Income Inequality. The special dual social structure in China restricts the two-way allocation of urban and rural factors. It exacerbates the polarization of urban and rural incomes to become increasingly prominent, which has attracted widespread attention. Figure 2 shows the provincial-level urban-rural income gap and the ratio of urban-rural income gap between 1997 and 2015, respectively. It can be seen from Figure 2 that the income gap between urban and rural areas in China has widened year by year from 1997 to 2015. In 1997, the income difference-value (D-value) between urban and rural residents was 2914.6 yuan. By 2015, the D-value had reached 18,050.5 yuan. Not only is the absolute value of the D-value increasing year by year, the growth rate of the D-value is also increasing. The ratio-value of urban and rural residents (R-value) in China has decreased after reaching a peak, but the absolute R-value is still very prominent. The peak of R-value reached 3.12 in 2007, that is, the average income of urban residents was more than three times the average income of rural residents. In 2015, the R-value was 2.58. Even though it has eased compared to previous years, the absolute value of the urban-rural income gap is always positive. China has become one of the countries with the most serious urban-rural income gap in the world.

4. Methods and Samples

4.1. Mathematical Inference. The changing trends of environmental pollution and income inequality are similar, and both increase first and then decrease. The changing trend of environmental pollution conforms to the hypothesis of the KC curve, and the changing trend of the income gap is also close to the hypothesis of the EKC curve. Therefore, we guess that the widening of the income gap may aggravate environmental pollution, and environmental quality has higher income elasticity. This influence relationship will change with per capita income level.

Based on the above conjecture, we make further mathematical inferences. Per capita income will affect personal environmental preference behavior, which in turn affects environmental quality. Suppose that personal environmental pressures are different, and their willingness to pay for environmental quality is also different. That is, people with different incomes have different impacts on environmental quality. Refer to Heerink and others. [22], we assume that the relationship between personal income (Y_i) and personal environmental pollution (E_i) is

$$E_i = f(Y_i) + u_i, \quad i = 1, 2, 3, \ldots, \text{n}, \tag{1}$$

Where n is the population. If the environmental pollution generated by all individuals is added up, the overall

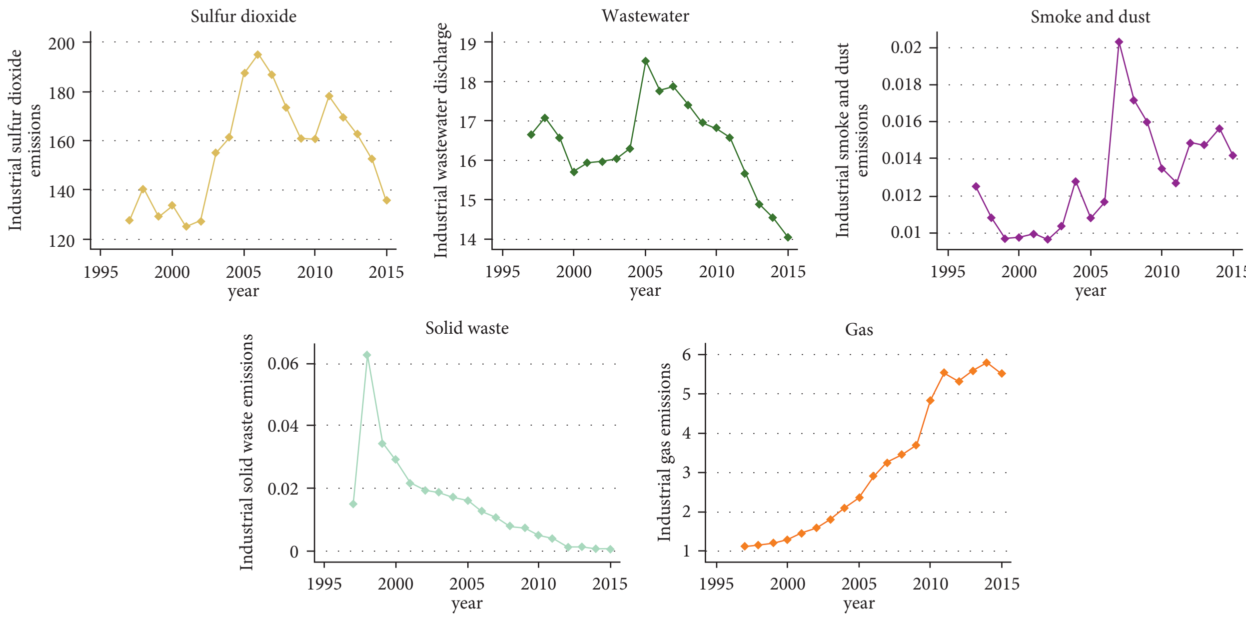

Figure 1: Industrial pollutant emissions from 197 to 2015 in China.

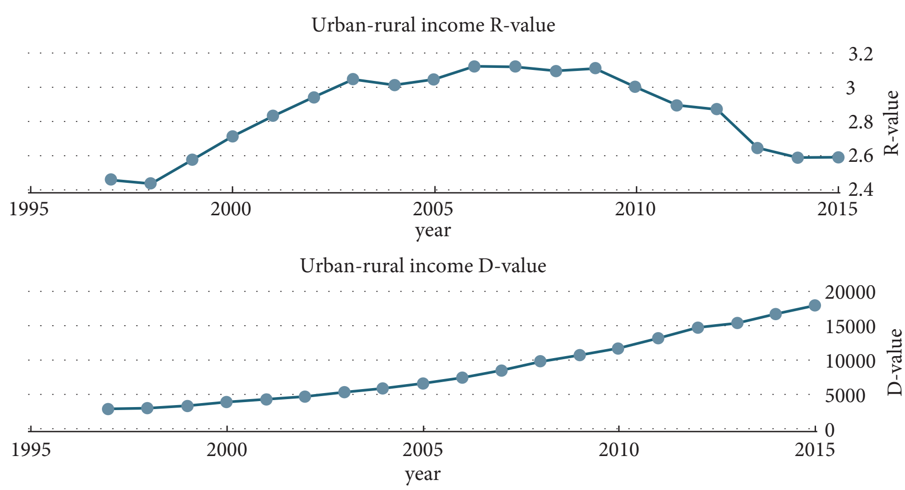

Figure 2: Urban-rural income inequality from 1997 to 2015 in China.

environmental pollution level of the area can be obtained. u_i is another factor that affects environmental preference behavior besides income. Sum up the population n to get the overall environmental pollution level E. Then, divide E by the population and average it to get $\overline{E}$:

$$\overline{E} = \frac{1}{n}\sum_{i=1}^{n} f(Y_i) + \frac{1}{n}\sum_{i=1}^{n} u_i = f(\overline{Y}) + \frac{1}{n}\sum_{i=1}^{n}\{f(Y_i) - f(\overline{Y})\} + \overline{u}, \tag{2}$$

where $\overline{E}$ is the average level of environmental pollution: $\overline{E} = 1/n\sum_{i=1}^{n} E_i$, $\overline{Y}$ is average income: $\overline{Y} = 1/n\sum_{i=1}^{n} Y_i$, $\overline{u}$ is average level of other factor. $\overline{u} = 1/n\sum_{i=1}^{n} u_i$

Use the difference between the individual income level and the average income level to construct the income gap, so that

$$V_f(Y) = \frac{1}{n}\sum_{i=1}^{n}\{f(Y_i) - f(\overline{Y})\}. \tag{3}$$

Therefore, combining (1), (2), and (3), The level of environmental pollution can be expressed as a function of average income $\overline{Y}$ and income gap $V_f(Y)$:

$$\overline{E} = f(\overline{Y}) + V_f(Y) + \overline{u}, \tag{4}$$

where $\overline{E}$ denotes the average level of environmental pollution after adding up. $f(\overline{Y})$ denotes a function of per capita income. $V_f(Y)$ represents the average level of the difference between individual income and average income. When the regional income gap widens, $V_f(Y)$ becomes bigger. When the regional income gap narrows, $V_f(Y)$ will decrease. Therefore, $V_f(Y)$ can be used to measure the level of income inequality.

Based on the above mathematical derivation, we can know that the income gap does have an impact on environmental pollution. When f is a nonlinear function, that is, when the relationship between per capita income and environmental pollution is nonlinear, environmental pollution is not only related to per capita income, but also related to income inequality. At the same time, the relationship between income gap and environmental pollution will change with the relationship between per capita income and environmental pollution. We can conclude that the level of per capita income will affect the relationship between income gap and environmental pollution.

4.2. Empirical Research. According to the above theoretical analysis, this study will further combine the provincial panel data to analyze the impact of China's income inequality on environmental quality. In the modeling process, relevant control variables need to be added. Referring to the STIRPAT model [35], we decompose the influencing factors of environment (E) into three factors: population size (P), wealth level (A), and environmental technology level (T):

$$E = aP^b A^c T^d e. \tag{5}$$

After taking the logarithm of the left and right at the same time, we get:

$$\ln E = \mu + b \ln P + c \ln A + d \ln T + \varepsilon. \tag{6}$$

This model allows for the proper separation of the influencing factors under the condition of consistent theory. Therefore, we will decompose the three factors of population size (P), wealth level (A), and environmental technology level (T), and add appropriate control variables for empirical analysis.

First, we decompose the population size (P) into population density (PD) and urbanization level ($Urban$). When the population density is small, the self-repairing ability of the environment will be stronger. Urban areas have better infrastructure than rural areas to promote energy use. For example, natural gas infrastructure can effectively mitigate carbon emissions [36]. The urbanization level has significant influences on energy intensity and carbon emission [37]. Hence, population density and urbanization level have a significant impact on environmental quality:

$$\ln p = f(PD, \text{Urban}). \tag{7}$$

Then, we decompose the wealth level (A) into income level (GDP) and income inequality (G). Through (4), we know environmental pollution can be expressed as a function of average income level and income inequality. Therefore, this study decomposes the impact of wealth level (A) on the environment into two parts: income level and income inequality. The income level is measured by real GDP per capita. Both the primary and secondary terms of real GDP are added to the model. We want to test whether there is a nonlinear relationship between the environmental quality and income levels. If it exists (that is, β in (8) is not 0), it will prove that the income inequality will also affect environmental pollution. Because China is a dual economy, the main income inequality comes from the income gap between urban and rural residents [38, 39]. The income inequality index in this study is measured by the urban-rural income gap G.

$$\ln A = \alpha \ln(GDP) + \beta[\ln(GDP)]^2 + \gamma \ln G. \tag{8}$$

Finally, we decompose the technical level (T) into education level (EDU), trade openness (Trade) and economic structure (ES) [40, 41]. It has been proved energy efficiency R&D and environmental technology (T) are effective in curbing carbon emissions [42]. Trade openness transfers advanced technology from the developed world towards emerging and developing economies which may be help reduce energy pollutants. As the results, trade openness can affect energy efficiency and environmental quality by technological innovation. Compared to the primary and tertiary industries, the secondary industry has the greatest impact on environmental pollution. Areas with a larger proportion of the secondary industry may have worse environmental quality. Therefore, the economic structure will affect environmental pollution.

$$\ln T = f(EDU, \text{Trade}, ES). \tag{9}$$

After taking (7)–(9) into (6), we get the empirical model:

$$\begin{aligned} \ln(E_t) = {} & \beta_0 + \beta_1 \ln(GDP) + \beta_2[\ln(GDP)]^2 + \beta_3 \ln(G) + \beta_4 \ln(PD) + \beta_5 \ln(\text{Urban}) \\ & + \beta_7 \ln(\text{Industry}) + \beta_8(\text{Trade}) + \mu + \nu + \varepsilon. \end{aligned} \tag{10}$$

The following part of this study will focus on the following: firstly, the relationship between environmental pollution (E) and GDP per capita, that is, the values of β_1 and β_2. If β_1 is greater than 0 and β_2 is less than 0, it is confirmed that there is an "inverted U-shaped" relationship between per capita GDP and environmental quality. With the growth of per capita GDP, environmental pollution will increase first, and will gradually decrease after the inflection point appears, which is in line with the environmental Kuznets curve hypothesis. Secondly, we pay attention to the value of β_3. If β_3 is significantly not 0, it means that income inequality does have a significant impact on environmental pollution. Thirdly, we pay attention to whether the impact of income inequality on environmental pollution changes with per capita GDP.

4.3. Variables and Data. This study decomposes the STIRPAT model to get the benchmark (10). The explained variables, core explanatory variables, and control variables are as follows.

The explained variable is environmental pollution. Existing researches mainly use environmental pollutant emissions as indicators to measure environmental pollution, such as industrial wastewater emissions, industrial sulfur dioxide emissions, industrial waste gas emissions, industrial smoke and dust emissions, and industrial solid waste emissions. Since environmental pollution is an overall concept, and each indicator measures different aspects of environmental pollution, if a single indicator cannot fully measure the relationship between income inequality and environmental pollution. Therefore, this study comprehensively considers the above five pollution emission indicators and adopts the PCA method to design a comprehensive environmental pollution indicator (E). ◦

Core explanatory variables. (1) Income inequality. This study uses the ratio of urban residents' disposable income to rural residents' net income to measure the income inequality; (2) Per capita income. The actual per capita GDP (EGDP) is obtained after deduction based on 1997.

Control variables. (1) Population density, measured by the number of people per unit of land area (PD). (2) Urbanization level, measured by the proportion of the non-agricultural population in the total population (urban). (3) Education level, measured by the proportion of students in universities (EDU). (4) Economic structure, because the secondary industry has the greatest impact on environmental pollution compared to the primary and tertiary industries, this study uses the growth of the secondary industry in GDP to measure economic structure (industry). (5) Trade openness, measured by the proportion of foreign direct investment in GDP (trade).

This study takes the provincial panel data of 28 provinces in China except Tibet, Hong Kong, Macau and Taiwan from 1997 to 2015 as the research sample. The environmental pollutant emission data comes from the "China Environmental Statistical Yearbook," and the population density comes from "China City Statistical Yearbook," the rest of the data comes from "China Statistical Yearbook" and the National Bureau of Statistics. Table 1 below shows the symbols and meanings of the explanatory variables and explained variables of the study.

Table 2 shows descriptive statistics for all variables. The average value of the core explanatory variable income gap indicator is 2.847, that is The average of the ratio of urban residents' income to rural residents' income is 2.847, indicating that my country's urban-rural income gap is relatively serious; from the control variables, the standard deviation of per capita GDP is 10,000, which is a large difference, which further demonstrates the importance of my country's income distribution. Imbalance problem. The population density, the number of college students, the level of urbanization, the proportion of the secondary industry, and the standard deviation of trade openness are relatively large, and the differences between regions are relatively obvious, which further confirms the serious problem of regional development incoordination in China.

4.4. Comprehensive Index on PAC Method. Figure 3 shows provincial distribution map of five industrial pollutant emissions in 2015. It can be seen that there are big differences between the five environmental pollution emission indicators, so it is necessary to design a comprehensive environmental pollution indicator.

Because the dimensions of each environmental pollutant are different, we first standardize each pollutant data. The original data is subtracted from the average value and then divided by the standard deviation, which can eliminate the impact of different pollutant discharge dimensions. The specific calculation formula is:

$$\text{New\_}X = \frac{(X - \text{mean})}{sd}. \quad (11)$$

Since industrial waste gas emissions, industrial sulfur dioxide emissions, and industrial smoke and dust emissions are all gaseous pollutants, we first conduct principal component analysis of the above three gaseous pollutants to obtain a gas pollution the comprehensive index of environmental pollution. Then, we use the PCA together with the discharge of industrial waste water and the discharge of industrial solid waste to obtain the comprehensive index E of environmental pollution.

It can be seen from Table 3 that the cumulative contribution rate of the characteristic value of the first principal component reaches 0.7188. This shows that the first principal component can already contain most of the information of the gas pollutants. Therefore, we only select the first principal component to explain the three gases comprehensive indicators of pollutants.

The Kaiser-Meyer-Olkin sampling adequacy measure is an important indicator used to measure the strength of the correlation between variables. It is obtained by comparing the correlation coefficient and the partial correlation coefficient between two variables. KMO is between 0 and 1. The higher the KMO, the stronger the collinearity of the variables, the more suitable the principal component analysis method is. The SMC value represents the square of the multiple correlation coefficient between one variable and other variables. A higher SMC value indicates that the linear relationship between the variables is stronger, the collinearity is stronger, and the principal component analysis is more appropriate. It can be seen from Table 4 that the KMO and SMC values of the above three variables all meet the requirements, and are suitable for principal component analysis.

The ratio of the characteristic value of each principal component to the sum of the characteristic value of the extracted principal component is used as the weight to calculate the comprehensive index of gas pollutants. Because the pollutant emission index cannot be a negative value, the dispersion standardization of the comprehensive index of gas pollutants is carried out. The difference between it and the minimum value is divided by the difference between the maximum value and the minimum value in the data.

$$New\_Y = \frac{(Y - \min)}{(\max - \min)}. \quad (12)$$

Table 1: Variables symbols and meanings.

Variables		Meanings
	EWater	Industrial wastewater discharge per capita
	EGas	Industrial waste gas emissions per capita
Explained variable	EYF	Industrial smoke and dust emissions per capita
	ESO2	Industrial sulfur dioxide emissions per capita
	ESoild	Industrial solid waste discharge per capita
	E	Comprehensive index of environmental pollution
Core explanatory variables	G	Urban-rural income ratio
	EGDP	Real GDP per capita
	EGDP2	The square of real GDP per capita
	PD	The population density
Control variables	Urban	Urbanization level
	EDU	Education level
	Industry	Percentage of secondary industry
	Trade	Trade openness

Table 2: Descriptive statistics of variables.

Variables	Unit	Mean	se	min	Median	Max
EWater	Tons/person	16.383	8.932	3.252	14.254	66.262
EGas	100 million standard cubic meters per ten thousand people	3.150	2.819	0.408	2.334	25.79
EYF	Tons/10,000 people	0.013	0.009	0.001	0.011	0.067
ESO2	Tons/10,000 people	155.918	102.706	10.168	129.689	606.987
ESoild	Tons/person	0.015	0.040	0	0.002	0.544
G	—	2.847	0.604	1.599	2.756	4.759
EGDP	Chinese yuan/person	8878	10000	908.8	5786	80000
PD	Person/km^2	407.0	385.1	10.72	322.5	2276
Urban	1	0.474	0.158	0.215	0.450	0.896
EDU	1	0.0130	0.00800	0.00100	0.0120	0.0360
Industry	%	45.36	7.830	19.73	46.99	59.05
Trade	1	0.309	0.385	0.0320	0.126	1.722

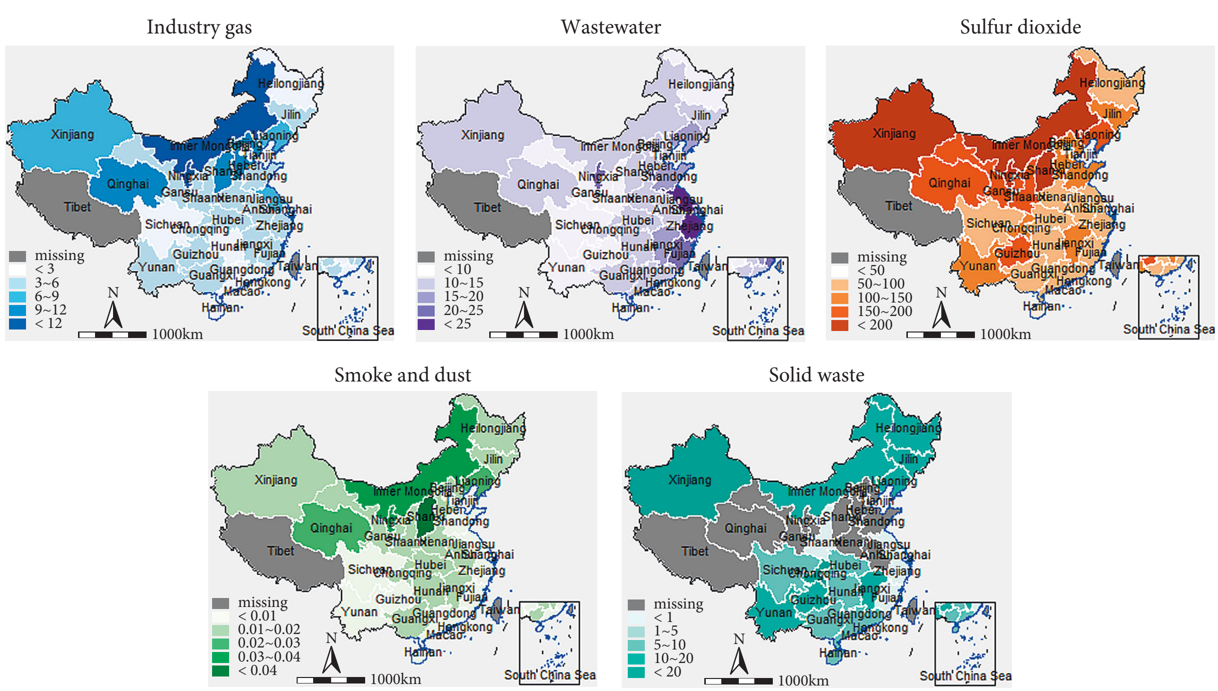

Figure 3: China's industrial pollutant emissions in 2015.

Table 3: Principal component explanation variance of gas pollutants.

Component	Eigenvalues	Variance contribution rate	Cumulative contribution rate
Component 1	2.15639	0.7188	0.7188
Component 2	0.465913	0.1553	0.8741
Component 3	0.377698	0.1259	1.0000

Table 4: KMO and SMC of each gas pollutant index.

Variables	KMO	SMC
ESO2	0.6791	0.4680
EYF	0.7334	0.3970
EGas	0.7161	0.4185
Overall	0.7076	——

After obtaining the main component comprehensive indicators of the three gas pollutant emissions, we obtain the comprehensive index *E* by combining them with industrial wastewater emissions and industrial solid waste emissions to repeat the above steps.

5. Results

5.1. Baseline Results. In order to judge the applicability of the fixed-effects model and the random-effects model in this study, this paper conducted Hausmann's test. The results showed that the null hypothesis that the disturbance term is not related to the explanatory variable was strongly rejected. We finally adopt the two-way fixed effects model including time-fixed and individual-fixed effects.

Table 5 is the result of regression using the two-way fixed effects model. The explanatory variable is the logarithm of the environmental comprehensive index *E*, ln(E). The core explanatory variable is the ratio of urban-rural income to the logarithm (lnG), and its square term (ln2G) in Model 3 to determine whether there is a quadratic curve in the impact of income inequality on environmental pollution. Model 1 includes only one item of income gap (lnG) and real per capita GDP (lnEGDP) and other control variables (population density, urbanization level, number of college students in colleges and universities, proportion of secondary industry, and trade openness). Model 2 and Model 3 are the empirical results of adding the square term of real per capita GDP (ln2EGDP) and the square term of income gap (ln2G) on the basis of Model 1.

It can be found from Model 2 in Table 5 that the actual GDP per capita does have an impact on environmental pollution. However, when the variable of the quadratic power of the actual GDP per capita is omitted in Model 1, the impact of income inequality on environmental pollution is not highlighted, which is in line with our theoretical analysis. If the per capita GDP and environmental pollution are linear, the income inequality will not affect environmental pollution. Only when the impact of per capita GDP on environmental pollution is nonlinear, the impact of income inequality on environmental pollution will be prominent, that is, the impact of income inequality on environmental pollution will change with the change of per capita income.

Table 5: Basic results.

	Model 1	Model 2	Model 3
lnG	0.0140	0.047**	0.0570
	(0.02)	(0.02)	(0.06)
ln2G			−0.00500
			(0.03)
lnEGDP	−0.043**	0.250***	0.251***
	(0.02)	(0.06)	(0.06)
ln2EGDP		−0.014***	−0.014***
		(0.00)	(0.00)
lnPD	−0.00200	0.00100	0.00100
	(0.01)	(0.01)	(0.01)
lnUrban	0.081***	0.047**	0.047**
	(0.02)	(0.02)	(0.02)
lnEDU	0.025***	0.00700	0.00700
	(0.01)	(0.01)	(0.01)
lnIndustry	0.096***	0.060***	0.060***
	(0.02)	(0.02)	(0.02)
lnTrade	−0.038***	−0.037***	−0.037***
	(0.00)	(0.00)	(0.00)
Cons	−0.148	−1.633***	−1.639***
	(0.16)	(0.31)	(0.31)
N	570	570	570
R2	0.448	0.479	0.479

Note. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

After adding the quadratic power of GDP per capita in Models 2 and 3, income inequality has a significant impact on environmental pollution. Comparing models 2 and 3, it can be found that the quadratic term of income inequality is not significant, that is, there is no quadratic influence of income inequality on environmental pollution, and the relationship between income inequality and environmental pollution is linear.

By analyzing the regression results of Model 2 in Table 5, it can be found that there is a nonlinear relationship between environmental pollution and real GDP per capita. The coefficient of the first term is positive and the coefficient of the second term is negative. The function image is similar to the "inverted U shape", that is, environmental pollution. As the growth of per capita GDP increases first and then slows down, it conforms to the "inverted U-shaped" hypothesis of the environmental Kuznets curve, which further enhances the reliability and persuasiveness of the regression data and research methods in this paper. Secondly, the level of urbanization, the proportion of the secondary industry, and the degree of openness to trade all have a significant impact on environmental pollution.

In-depth analysis of the above results shows that there is a significant positive linear relationship between environmental pollution and income inequality, that is, for every 1%

increase in income inequality, environmental pollution will increase by 4.7%. It can be considered that the positive impact of income inequality on environmental pollution is mainly due to the following two reasons: first, environmental quality is a public good. As the income gap widens, social norms will also change, thereby affecting citizens' environmental awareness. Income equality means a healthier and trusting society. When the income gap increases, social instability increases, citizens' sense of social responsibility decreases, and citizens' awareness of environmental protection also weakens. Second, relative to material needs, the impact of environmental pollution on residents' lives is chronic. When the income gap widens, the sense of social security decreases. Residents pay more attention to short-term material needs and ignore the long-term benefits of protecting the environment. However, in recent years, my country's economic development has made remarkable progress. The economic development quality issues such as income inequality and environmental pollution brought about by rapid economic growth have attracted widespread attention. The report of the 19th National Congress of the Communist Party of China clearly pointed out that "my country's economy has shifted from a stage of rapid growth to a stage of high-quality development." Socialism with Chinese characteristics has entered a new era, and China's economic development has also entered a new era. The 2019 Central Economic Work Conference further emphasized the need to promote high-quality economic development, which means that China's economy has entered a new era of quality first. High-quality economic development inevitably puts forward stricter requirements on income inequality and environmental pollution. The positive relationship between income inequality and environmental pollution will inevitably increase with the gradual improvement of the quality of economic development, and the two will promote each other and accelerate the income generation. A win-win situation of narrowing the gap and improving environmental quality to gradually achieve the goal of high-quality economic development in China.

5.2. Robust Test

5.2.1. Alternative Explained Variable. The above comprehensive indicators of environmental pollution only consider industrial emissions pollution, but after entering the twenty-first century, climate issues have become one of the most important environmental issues in the world. Global warming will lead to the redistribution of global precipitation, the melting of glaciers and frozen soil, and the rise of sea levels, which not only endangers the balance of natural ecosystems, but also threatens the survival of mankind. Carbon emissions are often used as a measure of environmental quality [43]. In addition, in recent years, the haze problem has also been very serious in China. As one of the main air pollutants, PM2.5 will seriously affect the health of residents and sustainable development [44]. On January 4, 2014, the National Disaster Reduction Office and the Ministry of Civil Affairs included the health-hazardous haze weather in the 2013 natural disaster notification for the first time.

In order to comprehensively study the relationship between environmental pollution and income inequality, this study takes per capita carbon dioxide emissions (ECO2) and the content of PM2.5 in the air (pm25) as the explained variables for robustness testing. Similar to basic regression in Section 4, we adopt the two-way fixed effects model including time-fixed and individual-fixed effects. The PM2.5 data comes from the Atmospheric Composition Analysis Group. The carbon emission data comes from China Emission Accounts and Datasets CEADs. Figure 4 shows the provincial distribution map of carbon dioxide emissions and PM2.5 in 2015.

In Table 6, Model 1 and Model 2 are the regression results of per capita carbon dioxide emissions (ECO2) and PM2.5 content in the air (PM2.5) as the explained variables, respectively. Similar to the above results, the income gap has a significant positive impact on per capita carbon dioxide and PM2.5. It can be seen from Model 1 that for every 1% increase in the income gap, per capita carbon dioxide emissions will increase by 5.6 units. It can be seen from Model 2 that for every 1% increase in the income gap, the content of PM2.5 in the air will increase by 14.784 units. The above empirical results show that the widening of the income gap will not only increase industrial pollution, but also increase per capita carbon dioxide emissions and increase the content of PM2.5 in the air. It further proves that the widening of income gap will indeed bring about the aggravation of environmental pollution, which makes the conclusion of this study more robust.

5.2.2. Alternative Explanatory Variable. To ensure the robustness of the results, we alternatively use the difference-value of urban-rural income to measure income inequality [45, 46]. We use the logarithm of the difference-value between urban and rural income as the explanatory variable to estimate the effects of the income inequality on environmental quality. The regression results are displayed in Table 7 below.

Similar to the above results, the difference-value between urban and rural residents' income has a significant positive impact on environmental pollution. This evidence also provides support for the main conclusion that there is an "inverted U-shaped" impact relationship between income inequality and environmental quality.

5.3. Endogenous Test. When the covariance between the explanatory variable and the disturbance term is not 0, there will be an endogenous problem. Since environmental pollution affects human health capital and thus income inequality, there may be a two-way causal endogenous problem between environmental pollution and income inequality. Therefore, this article uses Hausmann's test and heteroscedasticity robust Durbin-Wu-Hausman test to determine whether income inequality is an endogenous explanatory variable. Both test results show that "all explanatory variables are exogenous" can be rejected at the

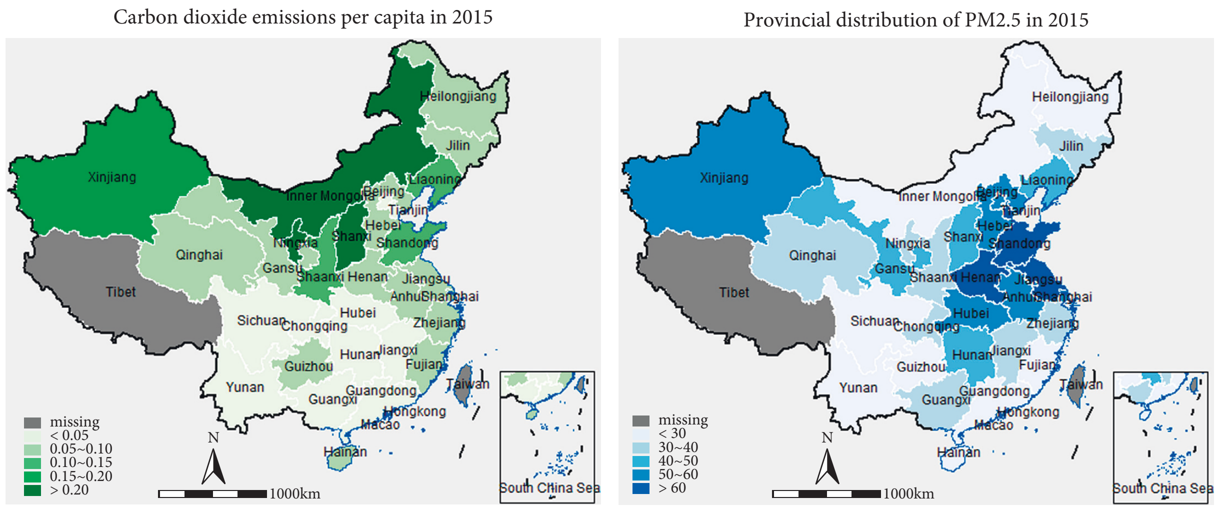

FIGURE 4: Regional distribution map of carbon dioxide emissions and PM2.5 in 2015.

TABLE 6: Regression results of per capita carbon dioxide emissions and PM2.5

	Model 1 ECO2	Model 2 pm25
lnEGDP	0.268*** (0.07)	−8.690 (11.82)
ln2EGDP	−0.010*** (0.00)	0.840 (0.54)
lnG	0.056** (0.02)	14.784*** (4.35)
lnPD	0 (0.01)	1.136 (0.97)
lnUrban	0.0110 (0.02)	1.335 (4.80)
lnEDU	0.024** (0.01)	−1.671 (1.98)
lnIndustry	-0.0320 (0.02)	−3.462 (3.43)
lnTrade	−0.047*** (0.01)	1.188 (0.94)
Cons	−1.313*** (0.37)	30.75 (65.80)
N	570	480
R2	0.546	0.572

Note. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

TABLE 7: Regression results of the difference between urban and rural residents.

	ln(E)
lnD	0.226*** (0.06)
lnEGDP	−0.010*** (0.00)
ln2EGDP	0.094*** (0.02)
lnPD	0.00200 (0.01)
lnUrban	0.00500 (0.02)
lnEDU	0.029*** (0.01)
lnIndustr	-0.0280 (0.02)
lnTrade	−0.013*** (0.00)
Cons	−1.713*** (0.36)
N	570
R2	0.572

Note. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

1% level. Therefore, the income gap (G) is considered as an endogenous variable.

Further, this paper uses the Generalized Moment Estimation Method (GMM) for regression analysis to solve the problem of endogeneity. When the disturbance term has heteroscedasticity or autocorrelation, GMM is more effective than the two-stage least square method. We use the hysteresis of endogenous explanatory variables as an instrumental variable. On the one hand, the endogenous explanatory variable is related to its lagged variable. On the other hand, because the lagged variable has occurred, it is a "predetermined" variable, which may not be related to the current disturbance.

It can be seen from Table 8 that when the endogenous effects of income inequality and environmental pollution are eliminated, the impact of income inequality on environmental pollution is still positive, and the degree of environmental pollution will increase by 2.8 for every 1% increase in income inequality. This coefficient is smaller than the coefficient of basic regression, indicating that GMM eliminates part of the endogenous influence.

6. Discussion

People with different incomes have different preferences for environmental quality, different personal environmental pressures, and different willingness to pay for environmental

Table 8: Endogenous test.

	GMM
lnG	0.028^{**} (0.01)
lnEGDP	0.160^{***} (0.05)
ln2EGDP	-0.008^{***} (0.00)
lnPD	-0.011^{***} (0.00)
lnUrban	0.102^{***} (0.02)
lnEDU	-0.037^{***} (0.01)
lnIndustr	0.123^{***} (0.01)
lnTrade	-0.013^{***} (0.00)
Cons	-1.614^{***} (0.25)
N	540
R2	0.387

Note: ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

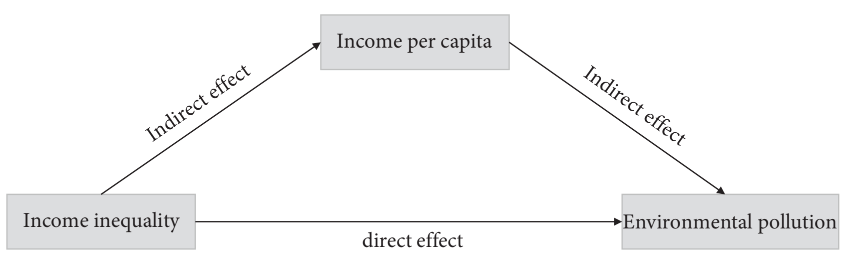

Figure 5: The impact mechanism of income inequality on environmental pollution.

quality. When investigating the impact of income inequality on environmental pollution, the conclusions drawn by different scholars using sample data from different countries and regions for empirical testing often differ greatly. The impact of income inequality on environmental pollution will vary with changes in income levels. Therefore, we conjecture that income inequality will affect the quality of the environment by influencing the consumption preferences of people with different incomes.

In order to further identify the impact mechanism of income inequality on environmental pollution, we use the mediation effect model to test whether the income inequality uses per capita GDP as an intermediary variable to affect environmental pollution. At present, the most commonly used method to test the mediation effect is the causal steps approach of Baron and Kenny [47]. As shown in Figure 5, income inequality will directly affect environmental pollution and indirectly affect the environment through per capita income.

The first step is to use income inequality as an explanatory variable and environmental pollution as an explained variable to test the total effect of income inequality on environmental pollution:

$$Y = aX + e1. \tag{13}$$

The second step is to use income inequality as the explanatory variable and per capita income as the explained variable to test the impact of income gap on the intermediary variable, namely, per capita income:

$$M = bX + e2. \tag{14}$$

The third step is to use both per capita income and income gap as explanatory variables, and environmental pollution as the explained variable. After testing and controlling the intermediary variables, the direct impact of income inequality on environmental pollution is estimated by

$$Y = a'X + cM + e3. \tag{15}$$

The above steps are followed in order. As shown in Table 9[3], the second column is the empirical result of the first step, and the third column is the empirical result of the second step. The fourth column is the empirical result of the third step. The results in the second column show that the direct impact of income inequality on environmental pollution is positive and significant. The results in the third

Table 9: Mediating effect.

	E	EGDP	E
G	0.011^{**}	0.646^{***}	0.019^{***}
EGDP			-0.011^{*}
EGDP2			−0.001
Cons	0.615^{***}	-1.307^{***}	0.645^{***}
Control variables	YES	NO	YES
N	570	570	570
Time-fixed	YES	YES	YES
Regional fixed effect	YES	YES	YES

Note. ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

column show that a certain degree of income inequality can increase per capita income, which is basically in line with China's current economic development; The results in the fourth column show that after the introduction of the impact of per capita GDP, the impact of income inequality on environmental pollution is still positive, and the coefficient has become larger, indicating that the mediating effect of per capita income has increased the impact of income inequality on environmental pollution. The test results show that a, *b*, and *c* in the above three steps are not 0, that is, the mediating effect of per capita income is significant.

7. Conclusions

Under the framework of the EKC curve, this study assumes that different income groups have different impacts on environmental pollution. Based on the mathematical derivation and functional relationship between income and environmental pollution, we prove that income inequality has a significant impact on environmental pollution, and this impact increases with per capita. The comprehensive environmental indicators of industrial pollution emissions synthesized by the PCA method and the urban-rural income gap is the main explanatory variable for empirical analysis. The results show: (1) The impact of income inequality on environmental pollution is significantly positive, that is, with the increase of income gap, industrial pollutant emissions, carbon dioxide emissions, and PM2.5 content in the air will increase; (2) There is an "inverted U-shaped" relationship between environmental pollution and income per capita. That is, with the increase of per capita GDP, environmental pollution will first increase and then decrease; (3) The impact of income inequality on environmental pollution will change with the change of per capita GDP. The income gap will affect environmental pollution through the mediating effect of income.

Through the analysis of the above research conclusions, we summarize the following policy implications:

First, governments should consider income distribution among regions, industries, and urban and rural areas when formulating environmental policies. With the increase of income gap, industrial pollutant emissions, carbon dioxide emissions, and PM2.5 content in the air will increase. The reduction of income gap can promote the improvement of environmental quality. Narrowing the income gap between urban and rural areas can help reduce the emission of a variety of industrial pollutants, curb carbon dioxide emissions and PM2.5, and significantly improve the overall environmental quality. Due to China's special urban-rural dual economy, the resource allocation gap has caused a serious urban-rural income gap and brought a series of economic and social problems. While improving the quality of the environment, the implementation of environmental policies should try to avoid damage to the rural economy. The regional differences between rural and urban areas should be taken into account in the formulation and implementation of environmental policies. More stringent environmental policies should be implemented in urban areas and more arrangements should be made to reduce emissions. At the same time, the government should help the countryside more and increase transfer payments to rural areas. Increase the proportion of middle-income families, improve the social security system, and gradually build a fair economic and social environment.

Second, the government needs to introduce corresponding policies and measures to prevent the "inverted U-shaped" curve from exceeding the ecological threshold. They should fully consider the relationship between economic growth and income inequality when formulating economic policies. There is an "inverted U-shaped" impact relationship between per capita income and environmental pollution, that is, environmental pollution will first increase and then decrease as per capita GDP increases. For regions with relatively backward economic development such as the central and western regions in China, their per capita income level has not reached the EKC turning point, and the increase in income level will increase the income gap. For the eastern and coastal areas in China, the per capita income level may have reached the EKC turning point or has exceeded the turning point, and economic growth will narrow the income gap at this time. Although studies have shown that economic growth will ultimately improve environmental quality, it cannot be explained that this process will happen automatically. If the environmental degradation exceeds a certain ecological threshold, the problem of environmental degradation will become irreversible, which means that the environment will not be able to be restored, or it will be restored at a high price.

Third, implement differentiated environmental policies for low-income groups and high-income groups to achieve a win-win economic and environmental outcome. The impact of income inequality on environmental pollution will change with changes in per capita GDP. On the one hand, it needs to stimulate the development of rural economy and increase the income level of rural residents. So as to stimulate the environmental quality needs of low-income groups, raise public awareness of environmental protection, increase the public's enthusiasm for participating in environmental protection, and achieve the goal of a win-win economic and environmental outcome. On the other hand, the implementation of differentiated environmental policies appropriately increases the responsibility of high-income groups in environmental protection and governance, such as the trial of collecting and income from individuals based on a progressive system. The linked environmental pollution tax enables high-income people to fully fulfill their social responsibilities commensurate with their economic and social status.

Abbreviations:

STIRPAT: Stochastic Impacts by Regression on Population, Affluence, and Technology
PCA: Principal component analysis
EKC: Environmental Kuznets curve.

Data Availability

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Consent

Not applicable.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

DX contributed toconceptualization, designing, and resources. FY wrote the original draft and provided software. HY contributed to methodology and validation. All authors read and approved the final manuscript.

Acknowledgments

This work was supported by grants from National Social Science Foundation of China (grant no. 19AJL016).

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