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Urban-rural income disparities and atmospheric contamination: Aggravating or restraining?

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This article constructed the local effect and significant interaction model of the urban-rural income disparities with atmospheric contamination and conducted theoretical analysis and empirical tested the urban-rural income disparity influences regional atmospheric contamination. Data were collected from 30 Chinese provinces from 2005 to 2019, and panel regression was employed. The empirical results found that the widening income disparities between urban and rural areas will significantly increase local atmospheric contamination, and there is a significant spatial dependence on regional atmospheric contamination. When the atmospheric contamination in the immediate region is severe, the local atmospheric contamination also worsens. At the same time, the spatial spillover effect of the central area on the surrounding atmospheric contamination is significant and positively affected by the urban-rural income disparities in the central area. Expanding the urban-rural disparities will significantly increase the atmospheric contamination in central and surrounding areas. The regression results were still robust after replacing the core variables and the spatial weight calculation method. Furthermore, results found the income disparities between urban and rural areas to increase agricultural chemicals investment and rural non-agricultural economic output. It significantly and positively influenced atmospheric contamination. The income disparities between urban and rural areas of atmospheric pollution around the region were heterogeneity. The widening income disparities can significantly increase atmospheric contamination levels in less technologically advanced and more polluted areas.

KEYWORDS

atmospheric contamination, climate change, urban-rural income disparities, China, spatial lag model

1 Introduction

China has emerged as the country's second economy, with urbanization or industrialization as an essential propeller of the Chinese economic growth miracle. However, with the increase in economic speed and scale expansion, increasingly severe resource, environmental and ecological problems have arisen, resulting in the inability of the natural environment to satisfy the increasing requirements of people for a better life. Since 2013, when the air quality index "exploded" in many places in China, atmospheric contamination represented by haze has had a significant impact on human health, climate environment, and sustainable urban development. It has become China's most prominent environmental problem (Lelieveld et al., 2015; Qin and, 2021). The economic cost of deteriorating air quality now amounts to 1%–8% of China's GDP annually (Heck et al., 2011), atmospheric contamination poses a significant threat to natural resources and the environment, and the inflection point of the environmental Kuznets curve seems to be far away.

Solving the problem of environmental pollution has become the key to answering the new exam questions for China's economic development (Zhang and Wang, 2022). The equality hypothesis states that the allocation of environmental quality results from the interaction of wealth, income, and market forces, and one of the ways to improve the allocation of environmental quality is to decrease the income distribution disparities (Zhong and Zhao, 2013). With the tremendous growth of China's economy and the rapid progress of urbanization and industrialization, the polarization of the income disparities has also been brought about (Wan et al., 2022). China's urban-rural income disparities have long been significant, and the limited and unbalanced income distribution exists to a certain extent (Sun and Sun, 2016). Although the distribution pattern has been optimized in the past few years, the urban-rural income disparities have shrunk to 2.56 by 2020, but the urban-rural income disparities is still relatively noticeable. The urban-rural income disparities and atmospheric contamination have become essential factors affecting economic growth and social development in China's transition process. At the same time, whether the two major dilemmas of the gradual expansion of the urban-rural income disparities and the increasingly severe atmospheric contamination can achieve a successful transformation and form a mutually beneficial and virtuous cycle development system is the key to the current researchers to cracking (Zhu and Zhang, 2019). Consequently, this paper aims to analyze whether the urban-rural income disparities impact atmospheric contamination from the perspective of spatial spillover and through what mechanism, and summarizes and analyzes the conclusions to provide feasible suggestions for reducing the income disparities and improving atmospheric contamination in China.

The article's subsequent structure is as follows: The second section examines the pertinent literature concerning the connection between income inequality and environmental pollution; the third section is the mechanism analysis; the fourth section is the econometric model and processing data; the fifth section contains the specific measurement analysis and interpretation of the measurement results; the sixth section provides the article's key conclusions and policy recommendations.

2 Literature review

The simultaneous deterioration of income distribution and environmental quality has emerged in different countries and regions and has led scholars to explore the relationship between the two (Yang, 2020). Pertinent researchers domestically and internationally have found that income disparities impact the environment's pollution, but the views formed are not unified due to different research samples and methods. The existing research is mainly divided into the following three viewpoints:

First, the growing income disparities make it difficult to reduce environmental pollution. Most existing literature studies are based on (Grossman and Krueger's 1995) Environmental Kuznets Curve (EKC) theory, which was proposed to explore the relationship between income levels and environmental pollution. Specifically, economic growth will lead to increase environmental pollution before the per capita income reaches the curve's inflection point. Once the "inflection point" is crossed, the increase in per capita income will be conducive to improving the environment (Zhan, 2016). After the EKC theory was proposed, it was widely recognized by the academic community, and some scholars extended it. Some studies have found that income inequality has a significant impact on the environment in addition to income growth, and some scholars believe that income inequality directly affects the EKC curve (Coondoo and Dinda, 2008). Boyce (1994) was the first to analyze the crucial causes of environmental degradation caused by income inequality. First, high-income groups can benefit from environmental pollution, while low-income groups often bear the environmental costs.

On the other hand, the inequality of rights makes low-income people poorer. At the same time, the high-income group is more likely to grasp the rights, which improves their time preference for using environmental resources. As a result, income inequality has contributed significantly too significant environmental degradation. Many scholars have confirmed this conclusion from the empirical perspective. Torras and Boyce (1998) examined the effects of income inequality on environmental quality by using seven indicators, such as water and air quality, based on GEMS data and the PSDM model and discovered that reducing wealth disparity will increase environmental quality improvement, and the phenomenon is more pronounced in low-income countries. Li et al. (2006) verified that income disparities could aggravate environmental damage based on the extension of the Environmental Kuznets Curve (EKC) hypothesis, and the greater the income disparity, the worse the effect will be.

Second, the widening income disparities are advantageous to enhancing environmental quality. Some scholars have proposed that Boyce does not consider the attributes of public goods. The environment has the characteristics of public goods and high-quality goods. Suppose the income elasticity of demand for environmental goods is greater than 1. In that case, the increase of people's demand for it will be faster than the growth of their income, so income inequality degree of expansion, high-income groups will consume more environmental goods and cause less environmental degradation (Scruggs, 1998). The research of Heerink et al. (2001) at the household level shows that the relationship between environmental pollution and income is in the shape of an upside-down U, and the widening income disparities will improve ecological pollution. (Huebler's 2017). study at the national level showed that the greater the inequality within a country, the lower the per capita CO_2 emissions and energy intensity. Using the simultaneous quantitative regression of per capita CO_2 emissions and national panel data, the results also confirmed that the income disparities had a mitigating effect on the environment. In addition, in the process of China's rapid economic growth, due to the pollution transfer accompanied by industrial gradients and the environmental damage caused by industrialization in underdeveloped areas, the widening urban-rural income disparities does not essentially result in environmental degradation, and it is even possible that at a particular stage of the economic development process, the widening income disparities can inhibit the deterioration of the environment (Lv and Gao, 2005; Tian and Zhao, 2012).

Third, uncertainty concerning the environmental effects of the widening income disparities. Existing studies have investigated the consequences of income disparities on environmental pollution from various angles but often neglect that there are periodic changes in this impact (Sager, 2019). To a certain extent, the degree of development of different regions or countries can represent the level of economic development. Eriksson and Persson (2003) discovered that income equality in developing countries is conducive to lowering carbon emissions, whereas unequal income distribution in most developed countries aggravated environmental pollution. Ravallion (2000) investigated the effect of income distribution on environmental pollution. Such impact was ambiguous, and its effect depended on the change of marginal emissions. If the marginal emissions of low-income groups were higher, the bias of income distribution in favour of low-income groups could result in environmental degradation. Zhan (2018) believes that an inverted U-shaped pattern still characterizes China's economic growth and environmental pollution.

Meanwhile, the income disparities have a non-linear effect on environmental pollution. At this stage, the widening income disparities are not favourable for reducing pollution. Li (2017) also pointed out that when the per capita income level is low, the widening income disparities may be beneficial to pollution control, while when the per capita income is high, the widening income disparities will significantly exacerbate environmental pollution. However, the conclusions drawn by some domestic scholars using China's economic growth and SO_2 emissions data did not support the EKC hypothesis. It is believed that the deviation of the human total might lead to the wrong estimation of the EKC hypothesis (Xu, 2018).

Previous literature showed that the residents' income disparities specifically affect environmental degradation. Nonetheless, there are few studies on the causes of atmospheric contamination from the standpoint of urban-rural income disparities. In particular, atmospheric contamination is not purely local pollution. Under natural effects and economic activities such as industrial transfer, atmospheric contamination has a high spatial correlation (Shao et al., 2019). Most of the existing literature is based on local effects, still there are few studies on whether the urban-rural income disparities have significant spatial spillover effects on atmospheric contamination in surrounding regions. In view of this, it is believed that the urban-rural income disparities may affect the atmospheric contamination in adjacent areas. Compared to prior studies, this article has the following contributions: 1) Regarding the research objects, the panel data of 30 Chinese provinces from 2005 to 2019 were used as the research samples. Using $PM_{2.5}$ concentration to determine the degree of atmospheric contamination. The local effect and spatial spillover model of the urban-rural income disparities on atmospheric contamination were constructed to conduct a systematic empirical study on how the urban-rural income disparities affect regional atmospheric contamination. 2) Regarding indicators of income disparities, the literature on income disparities and environmental pollution in the past mainly used the Gini coefficient or Theil index to measure the overall income disparities. Nevertheless, considering many studies on income distribution, it is shown that most of the income disparities in China can be explained by urban-rural income disparities (Li and luo, 2007; Zhong et al., 2013). Consequently, the urban-rural income ratio was selected as a proxy variable to measure the income disparities and investigate atmospheric contamination's impact.

3 Mechanism

When the existing literature studies the effect of income disparities or inequality on environmental pollution, indicators of income disparity or inequality between different groups within the research object based on the standard ecological Kuznets curve were added (Hao et al., 2016). However, the urban-rural income disparities index used in this article reflects the per capita income disparities between rural residents and urban residents. Therefore, when analyzing the impact mechanism of the urban-rural income disparities on atmospheric contamination, this paper will concentrate on the impact of the urban-rural income disparities on the economic behaviour of rural and urban residents.

3.1 Increase the input of agricultural chemicals

The overall environmental demand formed by different social groups affects the regional environmental quality in the whole regional system. Therefore, regional ecological quality is not only affected by the general level of regional economy and income but also by income distribution. Regarding China, the strengthening of agricultural manufacturing capability and the constant advancement of urbanization are essential for relieving the uneven growth of urban and rural areas and lowering urban-rural economic disparities (Wang et al., 2019). In essence, agricultural production is still one of the primary sources of income increase for rural residents (Fang, 2014). At present, China's agricultural production is still dominated by smallholder production. Rural residents tend to choose more agricultural chemical input in urban and rural areas to ensure their income level (Huang et al., 2008). Applying agricultural chemicals has positively contributed to farm productivity and the stable supply of agricultural products.

Still, the excessive application of agricultural chemicals has caused the aggravation of agricultural non-point source pollution and the degradation of the rural ecosystem (Li et al., 2017). China's emissions have changed from single channel pollution to a three-dimensional pollution pattern. Pollutants can enter the soil, rivers, or atmosphere through farmland irrigation, underground infiltration, surface runoff, and straw burning, leading to environmental pollution control's difficulty again (Shen and Wang, 2016). In addition, the income disparities between urban and rural areas may interact with the intensity of agrochemical inputs. Specifically, the key reason the urban-rural income disparities can impact atmospheric contamination is that rural residents expect to adjust their income levels through the intensity of agrochemical application, thereby reducing the income disparities among urban populations. However, when the urban-rural income disparities are at the same level, rural residents with higher income levels have lower budget constraints when choosing more expensive agricultural chemicals or application technologies (Huang, 2008). Compared with low-income groups, their environmental awareness may be at a higher level, thus choosing to reduce agrochemical inputs in agricultural production (Li and Chen, 2017). Therefore, the increase in the per capita income of rural residents may weaken the positive effect of the income disparities between urban and rural areas on the intensity of pesticide application, thereby increasing atmospheric contamination.

3.2 Environmental costs of urban transfer

Unbalanced growth of urban and rural ecological civilization and insufficient rural environmental governance are becoming more obstacles to improving people's lives. The transfer of urban pollution to rural areas makes the rural areas suffer from the disadvantage of regional economic backwardness and damage to environmental interests when supporting urbanization construction, and this is the exact embodiment of the unequal development between urban and rural areas. On the one hand, there are differences in the degree of internalization of environmental costs. Enterprises produce the same product in different regions and bear additional environmental costs to obtain the constant appearance of "rent-seeking" behaviour, which results from the difference in environmental costs. Its direct expression is that developed areas and cities transfer the resource-inefficient and environmentally unfriendly technologies and products that have been or are becoming obsolete to underdeveloped rural areas in the form of "free riding." The fundamental reason for this phenomenon is that the supply of public goods under the dual structure of urban and rural areas is not equal (Zeng and Zeng, 2011).

On the other hand, due to the lack of environmental awareness in rural areas and the lack of resistance to environmental pollution damage, urban pollutants are directly transferred or indirectly transferred to rural areas along with polluting industries; that is, high-income groups communicate environmental costs to low-income groups (Zhong et al., 2013). In addition, the economic development in rural areas is relatively weak, the demand for the ecological environment is low, and the grass-roots government governance standards are still dominated by economic growth. Preferential policies and benefits have saved economic costs for enterprise development and become the main driving force for attracting polluting enterprises to move from cities to rural areas (Zhao, 2018). Therefore, due to the income disparities between urban and rural areas, there exist differences in essential public services and environmental regulations between urban and rural areas, which lead to pollution going to the countryside and further promote the increase of the total amount of atmospheric contamination.

4 Model construction, variable definition, and data sources

The extended STIRPAT model (Lin et al., 2017) was used to construct the panel fixed effects model to explore further the differences of urban-rural income disparities to atmospheric contamination. In the meantime, due to the spatial autocorrelation of atmospheric contamination, its pollution degree is not only affected by the influence of the income disparities in the region itself but also by the atmospheric contamination in the surrounding areas. Therefore, this paper adds spatial effects to estimate the spillover of atmospheric contamination in the region. Based on the conclusion, some suggestions are put forward to reduce the income disparities and improve the atmospheric contamination situation in China.

4.1 Model construction

To inquiry, the differences of the urban-rural income disparities to atmospheric contamination, panel data of 30 provinces except for Tibet from 2006 through 2017 were selected based on the conduction mechanism analyzed above, and a benchmark model of atmospheric contamination influenced by the urban-rural income disparities was constructed as follows:

$$\ln AP_{it} = \alpha_0 + \alpha_1 \ln Gap_{it} + \alpha_2 X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (1)$$

In the above formula, provinces and years are denoted by i and t, respectively. *lnGap* is the logarithm of the urban-rural income disparities of the province; *lnAP* is the atmospheric contamination; In addition, to effectively control the periodic impact of productivity on other unobservable influencing factors at the regional level, the fixed effect μ_i of the region is added, and the fixed effect ϑ_t of the year is similarly added; the random disturbance term is represented by ε_{it}.

In addition, to estimate the spatial spillover of regional urban pollution and the differences of the urban-rural income disparities to atmospheric contamination from the central area to the surrounding regions through spatial spillover, this paper adds a spatial lag model to model (1) as follows:

$$\ln AP_{it} = \rho W_{P_{ct}} + \beta_0 + \beta_1 \ln Gap_{it} + \beta_2 X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (2)$$

$$\hat{W}_{P_{ct}} = \gamma_0 + \gamma_1 \ln Gap_{it} + \gamma_2 X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (3)$$

In the above formula, $W_{P_{ct}}$ represents the degree of atmospheric contamination in the central area from the surrounding regions, which can also be expressed as $\sum_{n=1}^{n=30} W_{cn} P_{nt}$, which represents the impact of atmospheric contamination in the surrounding area on the central area c, P_{nt} represents the pollution observation value in year t in the area n; $\hat{W}_{P_{ct}}$ represents the centre. The spillover effect of regional atmospheric contamination on surrounding areas can also be expressed as $\sum_{n=1}^{n=30} W_{nc} P_{ct}$, P_{ct} represents the pollution observation value of the central area c in year t.

4.2 Variable description

Atmospheric contamination level (*Ap*): This paper uses Dalhousie University to measure $PM_{2.5}$ through sensors and uses the $PM_{2.5}$ data processed by ARCGIS to characterize the atmospheric contamination level in various regions.

Urban-rural income disparities (*Gap*): The core explanatory variable is measured by the ratio of the per capita disposable income of urban residents to that of rural residents. The larger the ratio, the larger the urban-rural income disparities. Conversely, the closer the ratio is to 1, the smaller the urban-rural income disparities.

Control variables: According to previous articles, What have been chosen as specific control variables are economic development level (*GDP*, per capita GDP of each province), environmental regulation (*Enr*, the rate of harmless disposal of municipal solid waste in each region), and industrial structure (*Ins*, The ratio of added value of the service sector).

4.3 Data sources and processing

Considering the continuity and availability of data, panel data from 30 provinces in China, excluding Tibet, from 2005 through 2019 were selected for the study. The $PM_{2.5}$ data to measure atmospheric contamination was obtained by Dalhousie University by measuring $PM_{2.5}$ with a sensor and processing with ArcGIS. The disposable earnings of urban and rural residents to calculate the urban-rural income disparities are derived from the China Economic and Social Big Data Research Platform. The regional control variables were obtained based on China Statistical Yearbook and provincial yearbooks. Except for *Ins* and *Enr*, $PM_{2.5}$, *Gap*, and *GDP* are all logarithmically processed. Descriptive statistics of the correlated variable are demonstrated in Table 1.

5 Results and discussion

5.1 Local effect test

Taking advantage of the panel data from 30 Chinese provinces between 2005 and 2019, we used a fixed-effects model to initially test the difference between income disparity to local atmospheric contamination as a benchmark result for spatial measurement. The consequences of the initial test are shown in Table 2. Regressions that do not control for other factors are presented in the first column, Regressions with control variables are presented in the second column, and columns (3) and (4) gradually add time and regional control factors for empirical testing. As can be seen from column (1) of Table 2, the coefficient of the nucleus interpretative variable *lnGap* is significantly positive, and the conspicuousness of *lnGap* is still stable after adding the control variable, manifesting that the widening income disparities will aggravate the local atmospheric contamination.

Regarding control variables, the coefficient of economic development level (*lnGDP*) is positive, manifesting that the higher the localized economic development level, the more serious the atmospheric contamination. This may be because despite China's increasing efforts in ecological protection, the rapid economic development, especially the transformation of the industrialization process, is accompanied by an increase in the discharge of pollutants, and the amendment of the

TABLE 1 Descriptive statistics.

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
lnAp	450	3.657662	0.3858838	2.258227	4.450019
lnGap	450	0.640085	0.1282257	0.4580383	2.988545
lnGDP	450	9.377671	1.006835	6.213408	11.58977
Enr	450	4.336658	0.3630465	2.572612	4.60517
Ins	450	0.4605628	0.0920179	0.297917	0.836883

TABLE 2 Local effect test.

Variables	OLS	OLS	FE	FE
	(1)	(2)	(3)	(4)
lnGap	0.205*** (0.0747)	0.221*** (0.0778)	0.266*** (0.0437)	0.265*** (0.0654)
lnGDP		0.0568** (0.0240)	0.0720*** (0.0185)	0.0709*** (0.0185)
Enr		−0.285*** (0.0770)	−0.368*** (0.141)	−0.414*** (0.144)
Ins		−0.140 (0.106)	−0.139** (0.0682)	−0.133* (0.0691)
Time effect	No	No	Yes	Yes
Regional effect	No	No	No	Yes
Constant	3.893*** (0.0921)	4.136*** (0.311)	2.975*** (0.322)	2.798*** (0.398)
Observation	450	450	450	450
R2	0.015	0.029	0.074	0.075

***, **, and * represent the significance level of parameters at 1%, 5%, and 10%, respectively, and the values in parentheses are the robust standard errors of heteroskedasticity.

atmospheric circumstances is not enough to offset the consumption of natural resources by development. The coefficient of environmental regulation (*Enr*) is negative and significant at 1%, indicating that atmospheric contamination will significantly improve with the strengthening of environmental regulation. This may be because environmental regulation can effectively control the behaviour of polluting the environment, reduce the pollution situation, and thus alleviate the degree of atmospheric contamination. The difference between industrial structure (Ins) to atmospheric contamination is negative. Since the industrial structure in this paper is calculated by the specific gravity of the appreciation of the service sector, the increase in the ratio of the service sector means that the ratio of the secondary industry decreases and the ratio of pollution-intensive enterprises in the secondary industry also decreases, thus reducing the pollution situation. Moreover, the development of green and environment-friendly industries in the tertiary industry favours the evolution of atmospheric circumstances, thereby reducing the degree of atmospheric contamination.

TABLE 3 Spatial Moran index of national atmospheric contamination from 2005 to 2019.

Year	Moran index	Z-value	*p*-value
2005	0.138	5.198	0.000
2006	0.161	5.900	0.000
2007	0.154	5.671	0.000
2008	0.150	5.605	0.000
2009	0.158	5.814	0.000
2010	0.158	5.783	0.000
2011	0.148	5.492	0.000
2012	0.117	4.562	0.000
2013	0.156	5.724	0.000
2014	0.187	6.724	0.000
2015	0.180	6.448	0.000
2016	0.162	5.923	0.000
2017	0.147	5.476	0.000
2018	0.116	4.514	0.000
2019	0.118	4.588	0.000

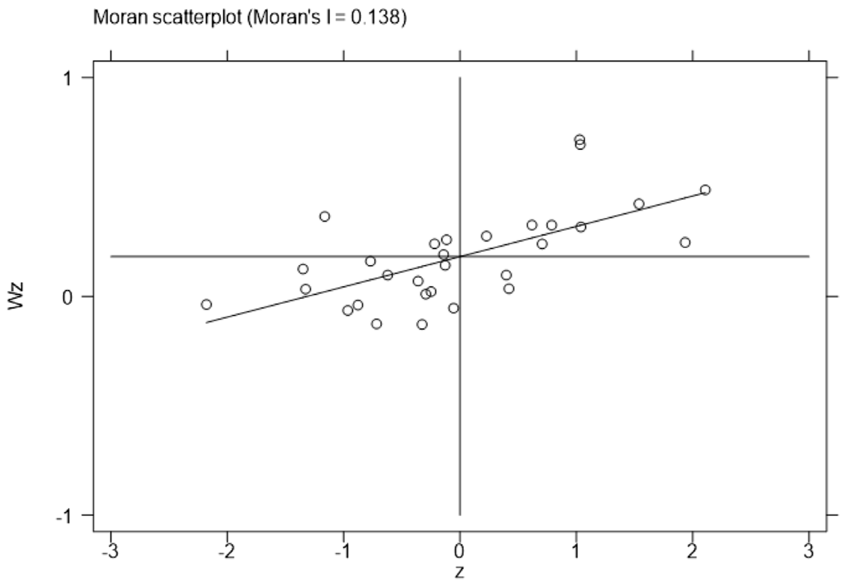

FIGURE 1
LISA map of regional atmospheric contamination in 2005.

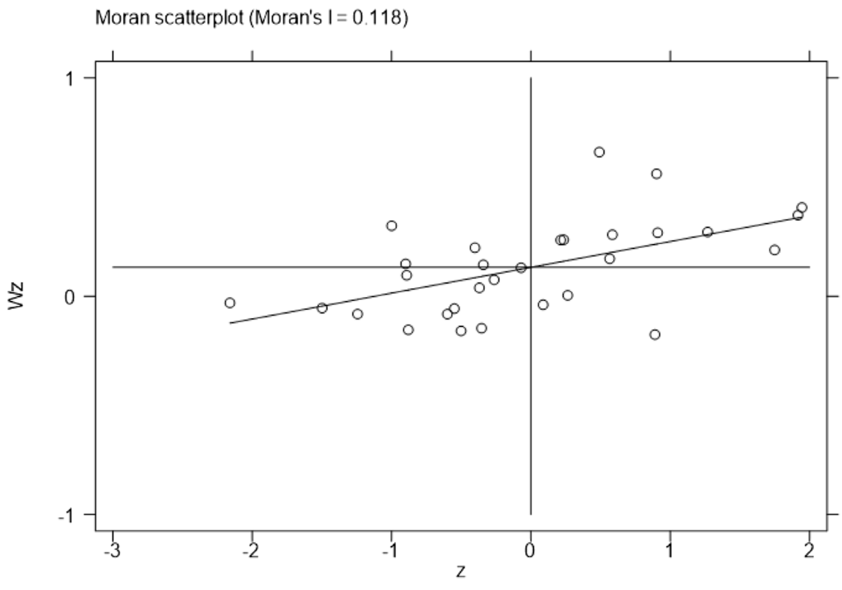

FIGURE 2
LISA map of regional atmospheric contamination in 2019.

 10.3389/fenvs.2022.1015857

TABLE 4 Selection of spatial econometric models.

	SEM	SLM	SDM
Moran's I	16.024***(0.000)	—	—
Lagrange multiplier	251.865***(0.000)	229.169***(0.000)	—
Robust Lagrange multiplier	39.612***(0.000)	16.915***(0.000)	—
Log-likelihood	−1773.5150	−1777.3679	−1732.4752

***, **, and * represent the significance level of parameters at 1%, 5%, and 10%, respectively, and the values in parentheses are the robust standard errors of heteroskedasticity.

TABLE 5 Spatial measurement test of income disparities on atmospheric contamination.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	W_p	W_p	W_p	$\hat{W}_p$	$\hat{W}_p$	$\hat{W}_p$
β	0.581*** (0.0970)	0.795*** (0.0420)	0.636*** (0.0849)			
γ				0.706*** (0.0691)	0.899*** (0.0206)	0.654*** (0.0790)
ρ	0.736*** (0.0640)	0.839*** (0.0299)	0.689*** (0.0740)			
Time effect	Yes	No	Yes	Yes	No	Yes
Regional effect	No	Yes	Yes	No	Yes	Yes
Observation	450	450	450	450	450	450
R2	0.066	0.439	0.213	0.204	0.309	0.322

***, **, and * represent the significance level of parameters at 1%, 5%, and 10%, respectively, and the values in parentheses are the robust standard errors of heteroskedasticity.

5.2 Spatial effect test

5.2.1 Spatial correlation inspection and model selection

In this paper, the spatial weight matrix based on geographical distance is represented by the reciprocal of geographical distance between provincial capitals. The larger the distance, the smaller the weight. On this basis, Moran's I index method was used to calculating the spatial correlation of regional atmospheric contamination, and LISA maps of regional atmospheric contamination in 2005 and 2019 were drawn. The results are shown in Table 3; Figures 1, 2.

As seen from Table 3, the Moran index of atmospheric contamination in China's provinces is significantly positive, indicating a positive spatial connection between atmospheric contamination in Chinese regions so that a spatial model can be used for regression, as can be seen from the LISA plots in Figures 1, 2, most of the regions in the selected sample interval are located in the first and third quadrants, manifesting that there are spatial clusters of high and high agglomeration and low and low agglomeration in regional atmospheric contamination.

The selection process for the spatial econometric model is demonstrated in Table 4. From the Lagrangian multipliers of the LM test and the robust Lagrangian multiplier statistics, it can be seen that the spatial lag model (SLM) is more suitable rather than the spatial error model (SEM); from the log-likelihood function value of the LR test, what is clear is that the log-likelihood function values of SLM and SEM are larger than those of spatial Durbin model (SDM) in magnitude, manifesting that SLM and SEM have a higher degree of fitting than SDM. Based on the above, the SLM is selected to test the spatial effect.

5.2.2 Spatial measurement test of local atmospheric contamination caused by income disparities

Considering the spatial correlation of atmospheric contamination, the differences of income disparity to atmospheric contamination were tested based on the SLM selected above. The inspection results are demonstrated in Table 5. Columns (1)–(3) of Table 5 represent the test results of model (2), and columns (4)–(6) represent the test results of model (3). From the regression results of model (2), it is apparent that the differences in income disparity to local atmospheric contamination are still conspicuously positive, and the magnitude is larger than that of the local effect test. It shows that atmospheric contamination in surrounding districts can affect the aggravation of local atmospheric contamination caused by income disparity. The spatial overflow coefficient ρ is prominently positive at the 1% criterion, which also proves the existence of spatial

TABLE 6 Robustness test.

Variable	(1)	(2)	(3)	(4)
	W_p	$\hat{W}_p$	W_p'	$\hat{W}_p'$
β	0.427*** (0.0285)		0.426*** (0.0284)	
γ		0.575*** (0.0659)		0.666*** (0.0656)
ρ	0.350*** (0.0233)		0.306** (0.130)	
Time effect	Yes	Yes	Yes	Yes
Regional effect	Yes	Yes	Yes	Yes
Obs	450	450	450	450
R2	0.122	0.139	0.156	0.235

***, **, and * represent the significance level of parameters at 1%, 5%, and 10%, respectively, and the values in parentheses are the robust standard errors of heteroskedasticity.

correlation of atmospheric contamination. That is, the atmospheric contamination in the surrounding areas and the atmospheric contamination in the central district have agglomeration and mutual influence. The more serious the atmospheric contamination in the circumjacent districts, the worse the atmospheric contamination in the central district.

From the regression results of model (3), what is clear is that the income disparities will not only significantly exacerbate the local atmospheric contamination but also adversely affect the spillover effect on the surrounding areas. Videlicet speaking, the widening income disparities will also augment atmospheric contamination in the surrounding regions. After controlling for time and regional effects, the impact of income disparity on pollution spillovers (0.654) is more significant than its impact on local atmospheric contamination (0.636). This may be because local policy resources, etc., will limit the adverse effects of the income disparities on local atmospheric contamination. However, the impact of income disparity on the spatial spillover effect of atmospheric contamination is less limited, so the magnitude of the impact is greater.

5.3 Test for robustness

To examine the empirical test's robustness, the empirical results are retested by replacing the atmospheric contamination measure index and substituting for the spatial matrix. The test conclusions are shown in Table 6, where (1) and (2) are the measurement methods that use regional CO_2 emissions instead of PM2.5 to measure the core variable of atmospheric contamination, respectively.; columns (3) and (4) substitute the adjacency space weight matrix for the geographic distance space weight matrix for measurement. The significance and marks of the main variables are in keeping with the basic standard outcome, indicating that the regression consequence is stabilized.

5.4 Further analysis

To further analyze the impact mechanism of urban-rural income disparities on atmospheric contamination and whether the impact of income disparities on atmospheric contamination will be heterogeneous due to different levels of regional development and pollution levels, this paper conducts further analysis through the mechanism test and heterogeneity test.

5.4.1 Mechanism inspection

To verify the channels through which income disparity aggravates atmospheric contamination, this paper builds a model (4) based on the spatial lag model by adding the interaction terms between income disparity and agrochemical inputs, as well as income disparity and rural non-agricultural economic output. The regression conclusions are in column (1) of Table 7.

$$ln\,AP_{it} = \rho W_{P_{ct}} + \psi_0 + \psi_1\, ln\,Gap_{it} + \psi_2 lnGap^{*}lnpes + \psi_3 lnGap^{*}lnnof + \psi_4 X_{it} + \mu_i + \vartheta_t + \varepsilon_{it} \quad (4)$$

From the coefficient of the interaction term *lnGap*lnpes* in the first column of Table 7, what is clear is that the widening income disparities can accelerate the level of atmospheric contamination by increasing the input of agricultural chemicals. This may be because the widening income disparities between urban and rural areas have boosted farmers' eagerness to grow their earnings by boosting the utilization of pesticides and fertilizers to increase crop output levels, thereby increasing farmers' income levels. The coefficient of the interaction term *lnGap*lnnof* is significantly positive at the 1% level, indicating that the income disparities can affect atmospheric contamination through rural non-agricultural economic output; this may be because as the income disparities between urban and rural areas widen, urban residents have higher requirements

TABLE 7 Further analysis.

Variables	Mechanism test	Technical level heterogeneity		Pollution degree heterogeneity	
	(1)	(2)	(3)	(4)	(5)
lnGap	0.425*** (0.0284)	0.157*** (0.0350)	0.395*** (0.0265)	0.340*** (0.0994)	0.216** (0.108)
lnGap *lnpes	0.204* (0.110)				
lnGap *lnnof	0.154*** (0.0328)				
ρ	0.509*** (0.0639)	0.608*** (0.0772)	0.327*** (0.0218)	0.580*** (0.0657)	0.364*** (0.122)
Time effect	Yes	Yes	Yes	Yes	Yes
Regional effect	Yes	Yes	Yes	Yes	Yes
Observation	450	225	225	225	225
R2	0.141	0.185	0.165	0.158	0.163

***, **, and * represent the significance level of parameters at 1%, 5%, and 10%, respectively, and the values in parentheses are the robust standard errors of heteroskedasticity.

for environmental quality, and it is more likely that cities will transfer environmentally polluting industries to rural areas. Therefore, rural non-agricultural economic output increases, and atmospheric contamination increases. Continue to move to the countryside. At the same time, due to the strong willingness of rural residents to increase their income and the weak environmental protection awareness, the development of polluting industries cannot be effectively regulated and controlled, making for further growth in the total amount of atmospheric contamination. Therefore, rural non-agricultural economic output has increased, and atmospheric contamination has been continuously transferred to rural sections. In the meantime, due to the strong willingness of country dwellers to grow in their earnings and the weak awareness of environmental protection, the development of polluting industries cannot be effectively regulated and controlled, making for further growth in the total amount of atmospheric contamination.

5.4.2 Heterogeneity test

The differences between urban-rural income disparities to atmospheric contamination may be heterogeneous due to regional differences. This paper conducts heterogeneity tests according to differences in regional productivity and pollution levels. First, the total factor productivity measured by DEA represents the technological level development degree of the region and divides the whole sample into samples with high technical levels and samples with low technical levels according to the median of total factor productivity. If the total factor productivity is higher than the median factor productivity of the whole sample, it is defined as a sample with a higher technical level; if the total factor productivity is less than the median factor productivity of the whole sample, it is defined as a sample with a lower technical level. The specific conclusions are displayed in columns (2) and (3) of Table 7. It's obvious from the results that the differences in urban-rural income disparities to atmospheric contamination in regions with higher technological development levels are smaller in magnitude than that in areas with lower technological levels. This may be because areas with higher productivity have advantages in technical conditions, more optimized industrial structure, and a stronger awareness of residents' environmental protection, which can effectively control atmospheric contamination and reduce the aggravating influence of income disparities on atmospheric contamination.

Then, the median of PM2.5 was used to divide the whole sample into high and low pollution samples. The contamination degree is greater than the median of the contamination of the whole sample, defined as a sample with a high degree of contamination; The contamination level was less than the median contamination level of the whole sample, which was defined as a less contaminated sample. The specific conclusions are displayed in columns (4) and (5) of Table 7. Based on the results in the table above, the affection for the income disparities in the areas with higher pollution is more significant, and the magnitude is greater than that in the areas with higher pollution in plain sight. This may be because polluting industries are more concentrated in areas with higher pollution levels, and income disparities' negative externalities increase industrial output. In addition, pollution-intensive industries cannot be effectively improved or transferred within a short time, thus worsening atmospheric contamination.

6 Conclusion and policy implications

This paper constructs the model of the local effect and spatial effect of the income disparities between urban and rural

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areas on atmospheric contamination. OLS model, fixed effect model and spatial lag model were used to test the impact of income disparities between urban and rural areas on regional atmospheric contamination by using panel data collected from 2005 to 2009 in 30 provinces of China. It is obvious from the empirical results that the income disparities between urban and rural areas cannot only positively increase local atmospheric contamination but also has a positive spatial dependence on atmospheric contamination. In other words, the atmospheric contamination in the circumjacent areas will affect the atmospheric contamination in the central area. The more serious the atmospheric contamination in the circumjacent areas, the more severe the atmospheric contamination in the central area.

Furthermore, widening the local income disparities between urban and rural areas will significantly exacerbate the local atmospheric contamination situation and adversely affect the overflow effects in the circumjacent areas. In other words, the widening income disparities will also increase atmospheric contamination in the circumjacent areas, and the effect will be more significant. This may be because compared with the restrictions on atmospheric contamination, such as local resources, the impact of local income disparities on the spatial overflow effects of atmospheric contamination is less restricted, so the impact is more serious. After replacing core variables and spatial matrices, replacing $PM_{2.5}$ with regional CO_2 emissions to measure the degree of atmospheric contamination, and using the adjacent spatial weighting matrix to replace the geographic distance spatial weighting matrix, the above conclusions are still robust.

To further comprehend how income disparities between urban and rural areas affect atmospheric contamination and whether the influence of income disparities on atmospheric contamination differs from region to region. This paper conducts a mechanism test on the two aspects of agricultural chemical input and rural non-agricultural economic output. Then, the heterogeneity test was carried out regarding the difference in productivity and the difference in the degree of pollution. Mechanism test results indicate that the widening of income disparities between urban and rural areas increases atmospheric contamination through two mechanisms, which may be because the widening of the income disparities between urban and rural areas increases residents living in rural areas eager to increase their income and urban residents' demand for environmental quality. Therefore, rural residents increase crop output by increasing pesticides and fertilizers, and cities are more likely to transfer environmental pollution industries to the countryside. Therefore, the input of agricultural chemicals and rural non-agricultural economic output increase, and atmospheric contamination continues to transfer to the countryside, leading to a further increase in the total amount of atmospheric contamination. Heterogeneity test results showed that total factor productivity lower region as well as the pollution degree of heavy income disparities influence on atmospheric pollution which is more serious, this may be due to the region compared with high productivity, low productivity of regional technical level is relatively backward, the industrial structure unreasonable, the residents' environmental awareness is relatively weak. The worsening influence of income disparities on atmospheric contamination cannot be effectively controlled. However, the polluting industries in areas with higher pollution degrees are more intensive than those with lower pollution degrees, and there is no effective way to improve them in a short time. Therefore, the negative influence of the income disparities on atmospheric contamination in areas with higher pollution degrees is more significant and of greater magnitude. Based on the previous theoretical analysis and empirical test, this article suggests the following policy implications:

It is important to narrow the gap in environmental protection awareness among regions, improve the income distribution system, reasonably adjust the income level of extreme income groups, control the severe phenomenon of rural population loss, and establish an incentive mechanism suitable for attracting talents and retaining talents in rural areas.

Promoting regional coordinated development and forming an excellent spatial linkage effect is necessary. The influence of the urban-rural income disparities on atmospheric contamination has a remarkable spatial correlation, along with a reasonable layout of regional industrial division that can effectively avoid the adverse effect of repeated construction of polluting industries on atmospheric contamination. In addition, a scientific and reasonable environmental protection system should be formulated to promote the steady progress of environmental governance, encourage the development of environmentally friendly industries and the transformation and upgrading of polluting industries, and allow the industrial linkage full play of their effect to drive the optimization and improvement of the overall atmospheric mass in the region. Improve the level of environmental governance in an all-around way, and explore a legal system suitable for regional economic development.

Paying attention to improved technological innovation ability is imperative. Explore innovative and green new technologies, strengthen the cultivation and incubation of high-quality talents, up step the share of middle-income groups, promote the transformation and application of energy-efficient utilization results, drive the evolution of emerging green industries, along with taking full advantage of the positive role of technology as well as the high composite person with the ability to reduce the urban-rural income disparities and to promote industrial transformation and upgrading.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

CW, ZZ, and GM were responsible for the data collection and arrangement of relevant literature, data analysis and article writing. PZ commented on the study choice, and EE helped to write the revised draft of the article.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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