Does Environmental Regulation Inhibit Haze Pollution in the Pearl River Delta?

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Abstract: Environmental regulation is an important tool for the government to achieve haze pollution control. Based on data from 2006 to 2016 in the Pearl River Delta (PRD), this study first explores the spatial correlation characteristics of haze pollution, and then empirically analyzes the actual impact of environmental regulations on haze pollution. It is found that the Moran values of haze pollution are positive in most of the years in the PRD, and the haze pollution in the region increases by 0.234% for each additional 1% of haze pollution in the adjacent areas. Thus, haze pollution reflects the spatial clustering phenomenon. The higher the pollution emissions in various regions, the more severe the haze pollution in the region, and environmental regulations have a significant impact on the haze pollution in the PRD. The relationship between haze pollution and GDP per capita in the PRD does not conform to the Environmental Kuznets Curve (EKC), and the “U” relationship between economic development level and environmental pollution (haze pollution) does not appear. In addition, urban population size and industrial structure are also important factors affecting haze pollution in the PRD.

1. Introduction
The Pearl River Delta, situated on the south coast of China, is the most dynamic and potential region in China’s economy development pattern[1]. In 2015, the annual average concentration of PM2.5 in the region decreased from 120 ug/m\(^3\) to 34 ug/m\(^3\), achieved the national secondary standard and the World Health Organization level standard, and exceeded the national assessment target two years ahead of schedule[2]. Is the result of the management of haze pollution in the PRD due to effective government policies? What role does environmental regulation play in the management of haze pollution? The research on this issue is still in its infancy. The existing literature mainly use the traditional econometrics to conduct empirical analysis, the spatial spillover characteristics of haze pollution are less considered, and there is less in-depth study about the spatial spillover characteristics of haze pollution in the PRD. Therefore, this paper firstly uses spatial exploratory data analysis to analyze the spatial distribution characteristics and cluster situation of haze pollution in the PRD, and adopts spatial econometric method to construct empirical analysis about the effect of environmental regulation on haze pollution. The study could empirical test of the role and impact of environmental regulation on haze pollution, and provide the direction for the optimization of haze pollution control policies in the PRD.
2. Literature Review

Many scholars have in-depth analyzed the effects of environmental regulation and policies on air pollution management internationally. Mendelsohn and Muller(2013) analyzed that effects of Air Pollution Policy in the United States and found the opportunity to improve it to be more economically efficient[3]. Tanaka(2015) also explored the role of air pollution regulation policies in pollution control in the United States and China[4]. Lu(2016) explored that the weakening policy change led to more pollution and the strengthening policy change improved air quality in restricted areas in China[5]. Meanwhile, Alam and Nurhidayah(2017) found that the international law of the atmosphere plays an important role in reducing the air pollution problem[6]. Waluś et al.(2018) believed that many regulations were used to restrict the emission of machine exhaust gases and the effects were improved in the European Union[7]. However, there are not many systematic studies on the impact of environmental regulation on haze pollution. Only a few scholars such as Du(2015) and Pu(2017) believed that haze treatment-related legal measures, such as improving the legal system, specifying legal principles and strengthening legal implementation degree, can realize the effective management of haze pollution[8-9], and the study of haze pollution is still in early stage in China [10], which ignores the spatial spillover effect and spatial cluster characteristics of haze pollution.

3. Research Design

3.1. Model Building

In this paper, the spatial exploratory analysis method is used to analyze the correlation of haze in various areas of the PRD, and the global spatial autocorrelation and local spatial autocorrelation of haze pollution in the PRD are analyzed[11]. This paper constructs a spatial measurement model that affects haze pollution by environmental regulations and considers the impact of per capita GDP, foreign investment, industrial structure and urban population size on haze pollution. The expression of SLM model is as shown in formula (1) and SEM expression (2).

\[
\ln PM_{10u} = \rho W \ln PM_{10u} + \alpha_0 + \alpha_1 \ln ER_g + \alpha_2 \ln pcgdp_g + \alpha_3 \ln^2 pcgdp_g + \alpha_4 \ln FDI_g + \alpha_5 \ln IC_g + \alpha_6 \ln PS_g + \epsilon_g, \epsilon_g \sim N(0, \sigma^2_g)
\]

(1)

\[
\ln PM_{10u} = \beta_0 + \beta_1 \ln ER_g + \beta_2 \ln pcgdp_g + \beta_3 \ln^2 pcgdp_g + \beta_4 \ln FDI_g + \beta_5 \ln IC_g + \beta_6 \ln PS_g + \epsilon_g, \epsilon_g = \lambda W \xi + \mu_g, \epsilon_g \sim N(0, \sigma^2_g)
\]

(2)

Where, \(\ln PM_{10u}\) refers haze pollution. \(\ln ER\) means environmental regulation, \(\ln FDI\), \(\ln IC\) and \(\ln PS\) means foreign direct investment, industrial structure and population size, respectively. \(\ln gdp\) and \(\ln^2 gdp\) represent the first and second terms of per capita GDP respectively. \(\ln PM_{10u}\) is the spatial lag term of the explained variable (haze pollution), \(\delta\) means the spatial lag coefficients. \(\ln ER\), \(\ln FDI\), \(\ln IC\), \(\ln PS\), are the spatial lag term of explanatory variables. \(\mu_g\), \(\lambda\), \(\epsilon_i\) are the area effect, time effect and random disturbance term respectively. \(\epsilon_i\) obeys normal distribution. \(W_{ij}\) is the spatial weight matrix, representing the neighboring relations between the area \(i\) and the area \(j\).

3.2. Indicator Measurement

Based on the study of Sun et al.(2014) [12], four indicators are chosen, namely, waste water emission (hundred million ton), sulfur dioxide emission (ten thousand ton), dust and soot emission (ten thousand ton) and solid waste emission (ten thousand ton). First, each indicator is normalized to eliminate incommensurability:

\[
UE_{ij}^* = \frac{UE_{ij} - \text{min}(UE_g)}{\text{max}(UE_g) - \text{min}(UE_g)}
\]

(3)

where \(UE_{ij}\) is the original value of emission of pollutant \(g\) in industry \(j\); \(\text{max}(UE_g)\) and \(\text{min}(UE_g)\) are the maximum and minimum emissions of pollutant \(g\) in all industries, respectively.

The adjustment coefficient \(W_{ij}\) of each indicator is calculated, and different weights are assigned to
different indicators in the industry.

\[ W_g = \frac{E_{jg}}{\sum_j E_{jg}} \frac{1}{Q_j / \sum_j Q_j} \]  

(4)

where \( E_{jg} \) is the emission of pollutant g in industry j; \( \sum_j E_{jg} \) is the total emission of pollutant g in all industries; \( Q_j \) is gross industrial output in industry j; \( \sum_j Q_j \) is gross industrial output in all industries.

According to the normalized values and weights of each indicator, the comprehensive intensity of environmental regulation in each industry is calculated:

\[ S_j = \sum_{g=1}^{G} W_g \times UE_j \]  

(5)

Through the summation of intensity of environmental regulation for each pollutant in each industry, the average intensity of environmental regulation is obtained.

PM10 is used as a measure of haze pollution, the actually amount of used foreign capital of each province is used to measure the level of investment introduction, industrial structure is measured by the proportion of the secondary industry in GDP, Gross Domestic Product (GDP) is indicated by actual GDP per capita, and population size (PO) is indicated by the total population of each region at the end of the year[13]. The data of haze pollution comes from “Report on Monitoring Results of the Air Monitoring Network of the Guangdong-Hong Kong Pearl River Delta Region”, and, the environmental regulation data and other economic data are from “Guangdong Statistical Yearbook” and the local statistical yearbooks of the Pearl River Delta cities. In addition, the logarithm of all variables is used to eliminate heteroscedasticity. The descriptive statistical analysis of the variables is shown in Table 1.

Table 1. Descriptive statistics of variables

| Variables   | Variable definitions | Minimum  | Maximum  | Mean    | Std. Deviation |
|-------------|----------------------|----------|----------|---------|----------------|
| lnPM10      | haze pollution       | 39.00    | 122.00   | 64.21   | 15.66          |
| lnER        | environmental regulation | 0.22     | 8.96     | 2.68    | 2.02           |
| lnpcgdp     | FDI                  | 9.50     | 12.03    | 11.05   | 0.53           |
| ln²pcgdp    | per capita GDP       | 90.26    | 144.68   | 122.46  | 11.49          |
| lnFDI       | The square of per capita GDP | 12.41    | 15.31    | 13.95   | 0.72           |
| lnIC        | industrial structure | 3.22     | 4.15     | 3.85    | 0.21           |
| lnPS        | population size      | 4.98     | 7.25     | 6.22    | 0.61           |

4. Empirical Results

4.1. Spatial correlation analysis

The global Moran values of the haze pollution in the PRD from 2006 to 2016 are shown in Table 2. It can be seen from Table 2 that the global Moran values of haze pollution is positive and most of them pass the significance test, excepting the year of 2007, 2008 and 2012, which reflects haze pollution has a spatial positive correlation in the PRD. From the global Moran values from 2006 to 2016, this positive correlation is relatively volatile before 2012, and it shows a relatively stable positive correlation after 2013. The Moran values of haze pollution in most years is positive, indicating that the spatial cluster characteristics of haze pollution in the PRD is high haze pollution high concentration and low haze pollution low concentration.

Figure 1 reports the distribution of Moran scatters for haze pollution in the PRD in 2006, 2011 and 2016. It can be seen from Figure 1 that the Moran scatters of haze pollution are distributed in the first and third quadrants in more than half of the regions during the observation year. In 2006 and 2011, there are 5 regions located in the first and three quadrants, of which there are 3 regions in the first quadrant and 2 regions in the third quadrant. In 2016, 4 regions are located in the first and three quadrants, of which 2 regions in the first and third quadrant respectively. In general, it can be found
that there are 55.56%, 55.56% and 44.44% regions respectively are located in the first and three quadrants in 2006, 2011 and 2016 through the haze polluted Moran scatter plot, which once again proves haze pollution is spatially relevant in the PRD.

Table 2. Results of Moran’s I test for haze pollution in the PRD from 2006 to 2016

| Years | Moran’s I   | P value |
|-------|-------------|---------|
| 2006  | 0.0466653   | 0.232   |
| 2007  | -0.0208714  | 0.310   |
| 2008  | -0.280418   | 0.296   |
| 2009  | 0.274396    | 0.086   |
| 2010  | 0.294795    | 0.029   |
| 2011  | 0.211341    | 0.090   |
| 2012  | -0.0527163  | 0.347   |
| 2013  | 0.475183    | 0.033   |
| 2014  | 0.281115    | 0.070   |
| 2015  | 0.199380    | 0.113   |
| 2016  | 0.126292    | 0.170   |

Figure 1. Moran scatter plots of haze pollution in the PRD 2006, 2011, 2016

4.2. Estimation results of spatial econometric models

The LM test no spatial lag test value is 34.2899, and the 1% significance level test is passed. The LM test no spatial error test value is 10.9123, but the significance test is not passed, indicating that the SLM is more than the SEM model. The SLM model is used to analyze the impact of environmental regulation on haze pollution in the PRD, and the effects are analyzed from four effects, no fixed effect(NFE), spatial fixed effect(SFE), time fixed effect(TFE) and time and space double fixed effect(TSFE). The empirical results are shown in Table 3.

Firstly, geographical proximity has a significant positive impact on haze pollution in the PRD. From the four model analysis results of the SLM, we can find that the spatial lag coefficients ρ of the four models are 0.510998, 0.234993, 0.048982, and 0.093889, respectively, and the NFE model and SFE model pass the significance test at the 10% level, which indicates that there is a spatial correlation between haze pollution in the PRD region. From the ρ value of SFE model, it can be found that haze pollution increases 1% in adjacent areas, the haze pollution in the region will increase 0.234%, and haze pollution has spatial correlation and spatial spillover characteristics. The results do not show the inverted “U” between economic development level and haze pollution in the four effect analysis of the SLM model, and the relationship between haze pollution and GDP per capita and the secondary term of GDP per capita is not significant. What is more, the impact of environmental regulation on haze pollution is very significant in the PRD. From the empirical results of the spatial fixed effect model and the non-fixed effect model, it can be seen that environmental regulation is positively correlated with the haze pollution at the significant level of 10%. Since the level of environmental regulation in this paper is measured by the level of pollutant emissions, which shows that environmental regulation is negatively related to regional haze pollution, and environmental regulation is conducive to reducing...
regional haze pollution. In addition, the empirical results of the spatial fixed effect show that industrial structure and urban population size are significantly positively correlated with haze pollution, indicating that the higher proportion of industries in the industrial structure and the larger the urban population is, the more serious haze pollution in the region.

Table 3. Empirical results of spatial model

| Variable | NFE | SFE | TFE | TSFE |
|----------|-----|-----|-----|------|
| intercept | 193.291671 | 0.447840 |  |  |
| lnER | 5.344453*** | 2.233172** | 3.240642*** | 0.366849 |
| Lnpcgdp | -111.421322 | 81.475674 | -114.755313 | 39.954523 |
| Ln³pcgdp | (-0.647694) | (0.749178) | (-1.397761) | (0.354263) |
| lnFDI | 4.777926 | -4.101044 | 5.551094 | 0.828320 |
| lnIC | (0.604978) | (-0.811602) | (1.464675) | (0.163403) |
| lnPS | -1.739622 | 0.172831 | -7.869647*** | -5.049940 |
| lnGDP | (-0.321311) | (0.038221) | (-2.691777) | (-1.164477) |
| ln²GDP | 51.925208*** | 17.706618 | 16.011239** | -47.620278*** |
| lnFDI | (3.025678) | (0.970926) | (2.270003) | (-2.467158) |
| lnGDP | 19.338727*** | 47.289237** | 12.713660*** | -45.434682* |
| ln²GDP | (2.985578) | (2.641183) | (4.785536) | (-1.653678) |
| lnFDI | (6.394456) | (2.166578) | (0.411838) | (0.793437) |
| ln²GDP | 0.510998*** | 0.234993** | 0.048982 | 0.093889 |
| ln³GDP | 0.3980 | 0.4824 | 0.4269 | 0.2108 |
| Log likelihood | -378.40289 | -352.2204 | -364.49488 | -333.35931 |

Note: ***, **, * represent the significant level of 1%, 5%, 10%, and the values in parentheses represent the t value.

5. Research conclusions and policy recommendations

Based on the empirical analysis of environmental regulation and haze pollution in the PRD from 2006 to 2016, it can be found that the Moran values of haze pollution are positive in most of the years in the PRD, and the haze pollution in the region increases by 0.234% for each additional 1% of haze pollution in the adjacent areas. Thus, the haze pollution reflects the spatial clustering phenomenon, and environmental regulations have a significant impact on the haze pollution in the PRD. The relationship between haze pollution and GDP per capita in the PRD does not conform to the Environmental Kuznets Curve (EKC), and the “U” relationship between economic development level and environmental pollution (haze pollution) does not appear. In addition, urban population size and industrial structure are also important factors affecting haze pollution in the PRD. The higher proportion of industries in the industrial structure and the larger the urban population is, the more serious haze pollution in the region.

Based on the empirical results of the relationship between haze pollution and environmental regulation in the PRD, the following policy recommendations are proposed. First, it is necessary to further strengthen the legislative work on haze management and improve more regulations for haze pollution control. Second, the government should further adjust industrial structure, reduce the proportion of industry in economic development, and thus reduce haze pollution in various regions. Third, the government should further control the size of the urban population to control haze pollution in the PRD. With the rapid development of urban development in recent years, a large number of migrants have flooded into the PRD region, which has increased the haze pollution in the PRD region. Therefore, the government should further strictly control the size and number of populations in various regions, and prevent and control the serious haze pollution caused by the increase in population.
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