Atmospheric Pollution, Spatial Spillover and Public health——A Spatial Econometrics Analysis Based on the Data of Prefecture-level Cities in China

Yuechao Zhao[1, *], Jun Shen[2]

E-mail addresses: 731683145@qq.com (Y. Zhao), shenjun130@hotmail.com (J. Shen).

[1]Graduate School, Shanxi University of Finance &Economics, Taiyuan 030006, China.
[2]Collaborative Innovation Center for Resource-based Economy Transformation, Shanxi University of Finance &Economics, Taiyuan 030006, China;

Abstract: Atmospheric pollution has become an important factor affecting public health. Based on the data of 282 prefecture-level cities in China from 2003 to 2020, this paper use exposure-reaction function and spatial econometrics method to estimate the mortality of residents' respiratory disease, study the spatial spillover effect and its impact on public health. The empirical results show that the atmospheric pollution has caused serious negative impact on public health in different regions of China. In particular, the residents in the middle and eastern region are the most affected. On the whole, atmospheric pollution has exerted significant negative spatial spillover effect on public health. Therefore, different atmospheric governance policies should be adopted based on the specific regional needs. While implementing inter-regional industrial transfer, the government needs to pay more attention to industrial upgrading, control urban population density reasonably, and keep improving the overall public health level and social well-being of the whole society.

Keywords: Atmospheric pollution; Public health; Spatial spillover; Exposure-reaction function; Spatial econometrics.

1 Introduction

The extensive economic development model has also brought serious atmospheric pollution to China [1]. Atmospheric pollution has attracted high concern of environmental scholars and policy makers. The research on atmospheric pollution mainly focuses on four aspects, including the atmospheric pollution's impact on residents' health [2-4] and economic development [5-7], temporal and spatial variation characteristics [8, 9], and the causes of atmospheric pollution [10, 11]. At the same time, the atmospheric pollution's spatial spillover effect is often ignored by scholars in the environmental science. The atmospheric pollution in a city can easily spread to its neighboring cities Therefore, local atmospheric pollution will inevitably have an impact on residents' health in the neighboring cities. Estimation results may be deviated according to the traditional econometric methods that ignore spatial dependence.

In addition, there are regional or group differences in the health effects of atmospheric pollution.

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*Corresponding author at: Graduate School, Shanxi University of Finance &Economics, No.140, Wucheng Road, 030006 Taiyuan, Shanxi, China.

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If the atmospheric pollution does impact the health, we cannot ignore the structural effect, that is, the differences of atmospheric pollution's impact on health in different regions or groups. Studies have found that the households with different economic statuses have different impacts on atmospheric pollution. The poor families in developing countries are more obviously affected by atmospheric pollution. While studying the atmospheric pollution's impact on the residents of different ages, some scholars found that the impact on children was the greatest, followed by adolescents and adults and they further tested the differences of residents' health in rural, suburban and urban areas, only to find that the atmospheric pollution has the greatest impact on suburban residents. Therefore, it can be said that the heterogeneity of residents' health seems different in some individuals but actually is caused by factors such as the economic development level, health care expenditure and education level to a great extent.

Based on the above analysis and the PM2.5 concentration data of 282 prefecture-level cities in China from 2003 to 2020, this paper uses both spatial econometrics and epidemiology method to estimate the mortality of residents' respiratory disease caused by atmospheric pollution and study the spatial spillover effect.

2 Methods and Data

2.1 Model specification

Based on Grossman production function, this paper constructs a basic model of atmospheric pollution that affects public health, including environmental, economic, educational, health, social and other factors. In order to reduce the impact of heteroscedasticity, all variables are made with logarithm. Model 1 is expressed as:

$$\begin{aligned} Lnph_{it} = \alpha_t + v_i + \beta_1 Lnpm_{it} + \beta_2 Lngdp_{it} + \beta_5 Lnindu_{it} + \beta_6 Lntech_{it} \\ + \beta_7 Lnpop_{it} + \beta_8 Lnmedi_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

Where, $Lnph$ represents public health, $Lnpm$ represents PM2.5 concentration, $Lngdp$ represents per capita GDP, $Lnindu$ represents industrial structure, $Lntech$ represents science and education level, $Lnpop$ represents population density, $Lnmedi$ represents medical level, i represents year, t represents region and ε represents residual term. However, economic growth and public health are not simply in a linear relationship. Therefore, this paper introduces quadratic term and cubic term of the per capita GDP to build Model 2, which is expressed as:

$$\begin{aligned} Lnph_{it} = \alpha_t + v_i + \beta_1 Lnpm_{it} + \beta_2 Lngdp_{it} + \beta_3 \left(Lngdp_{it}\right)^2 + \beta_4 \left(Lngdp_{it}\right)^3 \\ + \beta_5 Lnindu_{it} + \beta_6 Lntech_{it} + \beta_7 Lnpop_{it} + \beta_8 Lnmedi_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

Where, β_3 and β_4 represent the coefficients of per capita GDP's quadratic term and cubic term respectively.

The most commonly spatial regression models at present include Spatial Autoregression Model

(SAR), Spatial Error Model (SEM) and Spatial Durbin Model (SDM). To be specific, the SAR model takes into account the significant spatial effects caused by the relationship between adjacent regions while the SEM model aims to correct the spatial autocorrelation caused by model error term. On the basis of Model 2, the SAR Model 3 and the SEM Model 4 are constructed and expressed:

$$\text{SAR：} Lnph_{it} = \alpha_t + v_i + \delta\sum\nolimits_{j=1}^{n} W_{ij} Lnph_{it} + \beta_1 Lnpm_{it} + \beta_2 Lngdp_{it} + \beta_3 \left(Lngdp_{it}\right)^2 + \beta_4 \left(Lngdp_{it}\right)^3 + \beta_5 Lnindu_{it} + \beta_6 Lntech_{it} + \beta_7 Lnpop_{it} + \beta_8 Lnmedi_{it} + \varepsilon_{it} \quad (3)$$

$$\text{SEM：} Lnph_{it} = \alpha_t + v_i + \beta_1 Lnpm_{it} + \beta_2 Lngdp_{it} + \beta_3 \left(Lngdp_{it}\right)^2 + \beta_4 \left(Lngdp_{it}\right)^3 + \beta_5 Lnindu_{it} + \beta_6 Lntech_{it} + \beta_7 Lnpop_{it} + \beta_8 Lnmedi_{it} + \mu_{it}$$

$$u_{it} = \lambda\sum\nolimits_{j=1}^{n} W_{ij} u_{it} + \varepsilon_{it} \quad (4)$$

Where, W represents the spatial weight matrix. $W \cdot Lnph$ represents the spatial lag vector of public health. δ and λ represent the spatial autoregressive coefficients of SAR and SEM models respectively. Both dependent variable and explanatory variables of SDM model have spatial lag. In consideration of many variables in the model, this paper lists the general expression of Model 5:

$$\text{SDM: } Lnph_{it} = \alpha_t + v_i + \delta\sum\nolimits_{j=1}^{n} W_{ij} Lnph_{it} + X_{it}\beta + \sum\nolimits_{j=1}^{n} W_{ij} X_{it}\theta + \varepsilon_{it} \quad (5)$$

Where, X represents the explanatory variable of this paper, $W \cdot Lnph$ represents the spatial spillover effect of public health, and $W \cdot X$ indicates the peripheral area's impact of a region on atmospheric pollution in this area.To build a reasonable spatial weight matrix is critical to the accurate estimation. this paper constructs the SDM Model 6 based on the inverse distance spatial weight matrix.

2.2 Variables and data

The measurement of public health is a complex issue. Atmospheric pollution mainly affects residents' health through the respiratory system. Therefore, this paper uses the mortality of residents' respiratory disease to represent public health. PM2.5 concentration is used to represent the level of atmospheric pollution. With a very small diameter, PM2.5 can enter the respiratory system and even the viscera, making it an important inducement for residents' suffering from respiratory system disease and other diseases.

The panel data of this paper include 282 prefecture-level administrative regions in China from 2003 to 2020. The data are mainly from China City Statistical Yearbook, China Population and Employment Statistics Yearbook, statistical yearbooks of different provinces and the national health services surveys over the past years.

3 Results and Discussion

3.1 Spatial autocorrelation

Spatial econometric model is used in this paper to study the impact of atmospheric pollution on public health. Spatial autocorrelation analysis is needed before spatial econometrics analysis. At present, there are many indexes available to measure the degree of spatial autocorrelation, such as global or local Moran's *I*, Geary *C* and Global *G*, of which, global Moran's I index is the most commonly used one in existing research and therefore is used in this paper for spatial autocorrelation analysis.

The result shows that the Moran's I value of mortality of 10,000 residents' respiratory system diseases was significantly greater than 0 and increased year by year. This shows that there is a significant positive spatial autocorrelation in the mortality of 10,000 residents' respiratory system disease and the spatial agglomeration effect of public health increases year by year.

3.2 Results discussion

Before the model estimation, LM was used to test the OLS model to determine the most appropriate spatial econometric model. In this paper, Model 1 and 2 undergo LM test, the results of which are shown in Table 1. It can be seen from the table that the no lag and no error of the two models passed the 1% significance LM test. The model passed the robust no lag test, but did not pass the robust no error test. The above means that the SLM model is superior to the estimation of the SEM model. At the same time, the LR-test results show that the model is fixed in both time and space. This paper also proposes a more general estimation of SDM model.

Table 1: The LM test of Model 1 and 2

Models	1		2	
LM test	χ^2	P value	χ^2	P value
no lag	6.778	0.009	7.262	0.007
no lag (robust)	4.771	0.029	5.078	0.024
no error	3.537	0.060	3.909	0.048
no error (robust)	1.531	0.216	1.725	0.189
LR spatial	22481.947	0.000	22463.9827	0.000
LR time	99.854	0.000	105.173	0.000

Table 2 shows the estimated results of atmospheric pollution on public health based on several spatial econometric models. According to the results of Model 6, the atmospheric pollution significantly reduces public health. For every 1% increase in PM2.5 concentration, the mortality of 10,000 residents' respiratory disease increases by 1.129%. If it is converted into absolute quantity, for every standard deviation increased of PM2.5 concentration in the air of this area, about 19,000 residents will increase nationwide. atmospheric pollution is the most important factor affecting public health. By comparing Model 1-6, we can find that the atmospheric pollution's impact on public health would be seriously underestimated without considering spatial effects. However, atmospheric pollution in neighboring areas has improved local residents' public health. According to the results of Model 6, for every 1% increase in PM2.5 concentration in neighboring areas, the mortality of 10,000 residents' respiratory disease in this area decreases by 0.840%, which has not been found in previous studies.

Table 2: The estimated results of atmospheric pollution on public health based on spatial econometric models

Models	1	2	3	4	5	6
lnpm	1.116*** (179.383)	1.119*** (178.949)	1.114*** (162.071)	1.119*** (172.384)	1.102*** (162.643)	1.129*** (134.593)
lngdp	0.019*** (3.565)	0.648** (2.275)	0.663** (2.250)	0.659** (2.233)	0.700** (2.430)	0.602** (2.382)
ln2gdp		-0.062** (-2.001)	-0.064** (-1.978)	-0.063** (-1.968)	-0.067** (-2.117)	-0.060** (-2.192)
ln3gdp		0.002* (1.792)	0.002* (1.774)	0.002* (1.766)	0.002* (1.881)	0.002** (2.039)
lnindu	-0.011 (-1.614)	-0.016* (-2.211)	-0.015* (-2.052)	-0.016* (-2.084)	-0.007 (-0.910)	-0.011* (-1.649)
lntech	-0.009** (-2.350)	-0.006 (-1.521)	-0.006 (-1.402)	-0.006 (-1.463)	-0.005 (-1.361)	0.001 (-0.079)
lndens	1.011*** (77.276)	1.010*** (77.316)	1.013*** (74.684)	1.010*** (74.674)	1.030*** (77.442)	1.007*** (82.204)
lnmedi	-0.010** (-2.147)	-0.009** (-2.034)	-0.009* (-1.893)	-0.009* (-1.924)	-0.009* (-1.898)	-0.003 (-0.820)
Delte			0.057** (2.356)		-0.028 (-0.403)	0.608*** (36.995)
Lambda				0.184** (2.284)		
W*lnpm					0.084 (0.995)	-0.840*** (-37.435)
W*lngdp					-1.769*** (-2.985)	-2.320*** (-3.495)
W*ln2gdp					1.977*** (9.092)	0.259*** (3.592)
W*ln3gdp					-0.073*** (-9.162)	-0.010*** (-3.676)
W*lnindu					-0.426*** (-10.445)	-0.047*** (-3.221)
W*lntech					-0.045*** (-2.752)	-0.022*** (-3.104)
W*lndens					0.219* (1.862)	-0.613*** (-22.055)
W*lnmedi					-0.140*** (-3.297)	-0.004 (-0.391)
TF	Y	Y	Y	Y	Y	Y
SF	Y	Y	Y	Y	Y	Y
Nobs	5076	5076	5076	5076	5076	5076
Log-like	7534.425	7541.129	7543.675	7541.709	7612.330	8019.216

Note: 1. TF represents time is fixed, SF represents space is fixed, Log-like represents log-likelihood. 2.T values are presented in parentheses. 3. ***, **, and * are statistically significant at the 1%, 5%, and 10% levels, respectively.

3.3 Regional differences

In order to analyze the regional differences of atmospheric pollution's impact on public health, this paper makes a spatial econometric analysis of three major economic regions in China (eastern, central and western regions). Through the above analysis, it is found that Model 6 is the most accurate one, so it is used for spatial econometric analysis of the three regions. It can be seen from the Table 3 that atmospheric pollution has the greatest impact on residents in the eastern region, followed by the central and western regions. This is basically consistent with our understanding that the atmospheric pollution in the eastern and central regions has been more serious than that in the western regions, and severe atmospheric weather has occurred in the eastern and central regions for many times. From the perspective of spillover effect, atmospheric pollution's spillover effect in the central region is 0.108 with 1% significance while that in the eastern and western regions is not significant. Shanxi and Henan in the central region are the areas with the most serious atmospheric pollution, where the effect of atmospheric pollution control is poor due to their location in the middle of China and their main industrial structure which is the secondary industry. The pollution interaction among these regions is serious.

Table 3: Spatial econometric regression results for eastern central and western regions

Models	East region	Central region	Western region
lnpm	0.984***(109.507)	0.974***(37.120)	0.962***(34.214)
lngdp	0.014***(4.726)	-0.013**(-2.098)	0.012(1.630)
ln2gdp	2.071***(5.838)	-0.328(-0.265)	0.271(0.622)
ln3gdp	-0.212***(-5.759)	0.063(0.468)	-0.027(-0.554)
lnindu	0.974***(111.210)	1.050***(53.019)	1.386***(83.108)
lntech	0.001(0.045)	-0.065***(-4.382)	-0.003(-0.220)
lndens	0.007***(5.612)	-0.003(-0.641)	0.001(0.501)
lnmedi	-0.008***(-2.673)	0.001(0.168)	0.001(0.043)
Delte	0.649***(37.381)	-0.236***(-6.722)	0.377***(13.412)
Teta	0.006***(10.050)		
W*llnpm	-0.655***(-32.029)	0.209***(4.058)	-0.359***(-6.172)
W*llngdp	-0.008(-1.445)	-0.077***(-6.604)	-0.011(-0.822)
W*lln2gdp	-1.297*(-1.859)	-0.188(-0.082)	-3.794***(-2.958)
W*lln3gdp	0.123*(1.726)	0.056(0.227)	0.418***(2.923)
W*llnindu	-0.639***(-31.849)	0.261***(5.858)	-0.687***(-14.973)
W*llntech	0.027***(2.411)	-0.195***(-7.582)	-0.059**(-2.029)
W*llndens	-0.004(-1.601)	-0.003(-0.353)	-0.015***(-2.826)
W*llnmedi	0.004(0.681)	-0.002(-0.153)	0.022(1.069)

Note: 1.T values are presented in parentheses. 2. ***, **, and * are statistically significant at the 1%, 5%, and 10% levels, respectively.

4 Conclusions and policy implications

Based on the panel data of 282 prefecture-level cities in China from 2003 to 2020, this paper estimates the mortality of residents' respiratory disease caused by atmospheric pollution, the spatial spillover effects of atmospheric pollution and its impact on public health by using exposure-reaction function and spatial econometrics model. The results show that there are regional differences in residents' public health. The public health level is the highest in the western region but the lowest in eastern region. Spatial autocorrelation test finds that public health shows significant positive spatial autocorrelation and the spatial agglomeration effect of mortality of residents' respiratory disease increases year by year. Therefore, to improve the residents' public health should still be focused on atmospheric pollution control. In view of the regional differences and spatial effects, we need to take differentiated atmospheric management for different regions on the one hand, and on the other hand, break the restrictions of administrative regions to achieve joint prevention and control among regions. Considering the "leakage" and "warning" effects, the government should pay more attention to industrial upgrading, eliminate backward industries and industries producing substantial atmospheric and highlight the impact on residents' public health while implementing the inter-regional industrial transfer.

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