

# Has Urban Shrinkage Slowed Down Haze pollution?

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## ABSTRACT

Urban shrinkage index was calculated with data about the urban population of 250 prefecture-level Chinese cities from 2012 to 2017. In total, 55 shrinking cities were selected. First, the impacts of urban shrinkage on haze pollution were looked into in theory. Second, the spatial distribution and spatial autocorrelation of urban shrinkage were analyzed. Finally, the spatial error model (SEM) and the fully modified least squares (FMOLS) regression were used to empirically examine the impacts of urban shrinkage on haze pollution at national and regional levels, respectively. The results indicated that shrinking cities showed spatial agglomeration, with northeast China having the largest number of shrinking cities. From a national perspective, SEM revealed that urban shrinkage reduced haze pollution. Increase in the proportion of secondary industries, economic development and built-up areas intensified haze pollution, while increase in green area in parks reduced such pollution. From a regional perspective, except for west China, the impacts of urban shrinkage on haze pollution were significantly negative. Urban shrinkage in central China had the greatest impacts on haze, followed by northeast and east China. Haze pollution was intensified by the increase in the proportion of secondary industries in east, central and west China, alleviated by economic development in east and west China, slowed down by the increase in green area in parks in northeast, east and west China, and aggravated by the rise in built-up areas in northeast, central and west China. Targeted suggestions were proposed to reduce haze pollution, adapt to urban shrinkage and build quality small cities based on local conditions.

**Keywords:** *Urban Shrinkage; PM<sub>2.5</sub>; Spatial Error Model*

## 1. INTRODUCTION

China witnessed rapid urbanization. The urbanization rate of its permanent population exceeded 60% by the end of 2020. Increasing urban population lead to environmental pollution, including haze pollution. New-type urbanization proposed in 2020 focuses on promoting human-centered urbanization guided by quality improvement. It points out that efforts should made to coordinate the cultivation of emerging cities and the quality improvement of shrinking cities, steadily reduce the districts of shrinking cities, and adjust shrinking counties (cities) after conducting prudent survey. Currently, Chinese cities face severe haze pollution. Will urban shrinkage slow down haze pollution? The answer to this question has important practical significance for building a beautiful China and meeting the people's growing needs for a better life.

## 2. LITERATURE REVIEW

In 1988, German scholar Häußermann and Siebel (1988) first proposed the term "shrinking city" to describe massive population loss and hollowing out of cities [1]. In recent years, shrinking cities also appeared in China [2]. Urban shrinkage is receiving more and more attention from academia and government departments at home and abroad.

Domestic and foreign scholars' research on urban shrinkage mainly focused on concept definition [3-6], driving mechanism [7-8] and countermeasures [9-10], with limited attention to its impacts.

There was also literature on the impacts of urban shrinkage on carbon emissions. For example, Liu et al. (2020) analyzed the CO<sub>2</sub> emissions of residents in shrinking prefecture-level cities based on data in 2005, 2010 and 2015. They found that urban shrinkage was positively correlated with residents' CO<sub>2</sub> emissions, and that the energy efficiency of shrinking cities may be lower than that of expanding cities of the same size [11].

Previous research laid the foundation for this study, but had the following shortcomings. First, there were few discussions on the impacts of urban shrinkage on air pollution, and even fewer researches on its impacts on haze pollution. Second, theoretical analysis of the impacts of urban shrinkage on haze pollution was absent. Third, there was no empirical research on the impacts of urban shrinkage on haze pollution.

This study makes up above-mentioned shortcomings as follows. First, it puts urban shrinkage and haze pollution in the same framework to explore the positive and negative effects of urban shrinkage on haze pollution theoretically. Second, it empirically examines the impacts of urban shrinkage on haze pollution at national and regional levels.

### 3. THEORETICAL ANALYSIS, METHOD AND MODEL SET-UP

#### 3.1. Theoretical Analysis

##### 3.1.1. Positive Impacts of Urban Shrinkage on Haze pollution

Population loss in shrinking cities reduces residents' demand for consumption (including energy consumption) and housing, thereby reducing construction. Besides, company relocation out of shrinking cities not only reduces the consumption of fossil energy such as coal and oil, but also decreases the demand for buildings like plants. Energy consumption increases emissions of particulate matters and sulfur dioxide (SO<sub>2</sub>), which directly aggravates haze pollution. Dust produced in the process of construction is the main contributor to PM<sub>10</sub> emissions [12]. Therefore, urban shrinkage reduces environmental pollution, including haze pollution through reduced energy consumption and construction. In addition, during urban shrinkage, trees on vacant land can regulate the climate, improve air quality, and provide space for improving ecosystem and reducing haze pollution.

##### 3.1.2. Negative Impacts of Urban Shrinkage on Haze pollution

In the process of urban shrinkage, the young and middle-aged migrate to other places, which lead to changes in population structure, namely increased proportion of the elderly. In daily life, the elderly has a relatively weak awareness of ecological and environmental protection, and may not buy energy-saving and environmentally friendly products. These are not conducive to the improvement of air quality. Population loss also means loss of knowledge and technology, which counts against technological progress and industrial transformation and upgrading. Company relocation out of shrinking cities reduces production scale,

employment population and tax revenue, which are disadvantages for preventing and controlling urban haze pollution.

#### 3.2. Method

##### 3.2.1. Spatial Autocorrelation

###### (1) Global Spatial Autocorrelation

Global spatial autocorrelation was analyzed with Global Moran's I index [13]. The formula is:

$$\text{Moran's } I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n \sum_{j=1}^n w_{ij} \sum_{i=1}^n (x_i - \bar{x})^2} = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n w_{ij}} \quad (1)$$

$S^2 = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2$  is the variance of observations, and  $\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$  the average value of all spatial unit observations.

$x_i$  and  $x_j$  represent observation values of the  $i$ -th and  $j$ -th spatial unit,  $n$  is the total number of spatial units, and  $w_{ij}$  is the spatial weight matrix. This paper employs the spatial adjacency weight matrix, whose principle of set-up is:

$$w_{ij} = \begin{cases} 1 & i \text{ and } j \text{ are adjacent} \\ 0 & i = j, \text{ or } i \text{ and } j \text{ are not adjacent} \end{cases} \quad (2)$$

###### (2) Local Spatial Autocorrelation

Local spatial autocorrelation was analyzed with local Moran's I index. The formula is:

$$\text{Moran's } I = \frac{(x_i - \bar{x}) \sum_{j=1}^n w_{ij} (x_j - \bar{x})}{S^2} \quad (3)$$

Its meaning of  $x_i$ ,  $x_j$ ,  $n$  and principle of  $w_{ij}$  set-up are the same as that of formula (1).

The correlation indexes of local spatial autocorrelation were divided into four types: HH (high-high), HL (high-low), LH (low-high) and LL (low-low).

##### 3.2.2. Spatial Econometric Models

Spatial econometric models were divided into spatial lag model (SLM), SEM, etc.

The SLM was:

$$Y = \rho WY + X\beta + \varepsilon \quad (4)$$

$Y$  is the explained variable,  $X$  the explanatory variable matrix,  $W$  the spatial weight matrix, and  $WY$  the spatial lag explained variable.  $\rho$  means the spatial autoregressive coefficient reflecting the spatial dependence of the observed value of the sample,  $\beta$  the coefficient of the explanatory variable, and  $\varepsilon$  the random error term that obeys a normal distribution.

The SEM was:

$$Y = X\beta + \varepsilon \quad \varepsilon = \lambda W\varepsilon + \mu \quad (5)$$

$\mu$  is the independent and identically distributed residual, and  $\lambda$  the spatial autoregressive coefficient reflecting the influence of residuals in adjacent areas on residuals in this area.

### 3.3. Model Set-up

To empirically test the impacts of urban shrinkage on haze pollution, the following econometric model was built:

$$\ln PM_{2.5} = \beta_0 + \beta_1 \ln US + \beta_2 \ln SE + \beta_3 \ln GDP + \beta_4 \ln PGA + \beta_5 \ln LAND + \varepsilon_i \quad (6)$$

In the above formula,  $PM_{2.5}$  represents the annual average concentration of  $PM_{2.5}$ , namely haze pollution (unit:  $\mu g/m^3$ ).  $US$  refers to urban shrinkage,  $SE$  to the proportion of secondary industries (unit: %), and  $GDP$  to the GDP per capita (2006 as base period, unit: CNY/person).  $PGA$  represents the per capita green area in parks (unit:  $m^2$ ),  $LAND$  the area of built-up areas (unit:  $km^2$ ) and  $\beta_0$  the constant term. Since natural logarithms were used for all variables,  $\beta_1, \beta_2, \beta_3, \beta_4$  and  $\beta_5$  are elastic coefficients to be estimated, and  $\varepsilon_i$  is the random error term.

### 3.4. Measurement of Urban Shrinkage

Both single index method [14] and multiple index method [15] can measure urban shrinkage. This study draws on Xiao (2019) [16] to measure urban shrinkage with the following formula:

$$US_{(t_0, t_1)} = \frac{P_{t_1} - P_{t_0}}{P_{t_0}} \quad (7)$$

$US_{(t_0, t_1)}$  means the population index between year  $t_0$  and  $t_1$ .  $P_{t_0}$  and  $P_{t_1}$  are urban population in  $t_0$  and  $t_1$ , respectively. The  $US$  change interval is  $[0, +\infty)$ . If  $US > 1$ , there was a population expansion. Otherwise, there was a population shrinkage.

### 3.5. Data Source

Based on the availability of data, we analyzed data about 250 prefecture-level cities from 2012 to 2017. Their shrinkage indexes was calculated with formula (7). Among them, 55 cities had a shrinkage index less than 1. This paper takes these 55 shrinking cities as a sample. Data about  $PM_{2.5}$  concentration come from the  $PM_{2.5}$  concentration ranking of Chinese cities released by Greenpeace, an independent campaigning organization, on January 10, 2018. The proportion of secondary industries and per capita GDP are from *China City Statistical Yearbook* (2008-2018). GDP per capita come from *China Statistical Yearbook 2018*. Urban population, per capita green area in parks and built-up areas are from

*China Urban Construction Statistical Yearbook* (2007-2017). Missing data were filled in by interpolation. The 55 cities were divided into four regions: northeast, east, central and west China

## 4. EMPIRICAL RESEARCH

### 4.1. Spatial Autocorrelation of Shrinking Chinese Cities

Adopting queen adjacency, the results processed in GEODA 0.9.5-i showed Moran's I index of shrinking Chinese cities in 2017 was 0.5381. Monte Carlo randomization tests were conducted for 999 times, whose P value was 0.0010. This indicates that there was spatial agglomeration in the shrinking cities in 2017.

The local spatial autocorrelation of urban shrinkage was investigated with Moran's I scatter plot, as presented in Fig. 1, where the horizontal axis indicates urban shrinkage, and the vertical axis indicates lagged urban shrinkage. 50 cities are located in the first or third quadrants, accounting for as high as 90.9%. This means there was obvious agglomeration of shrinking cities. Only 5 cities are located in the second and fourth quadrants, accounting for 9.09%. Among them, 1 is located in the second quadrant, which means LH agglomeration, and 4 are located in the fourth quadrant, which means HL agglomeration.

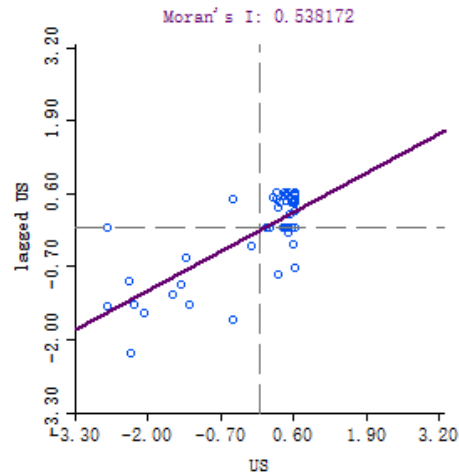


Figure 1. Moran's I index scatter diagram of urban shrinkage in China

### 4.2. Empirical Research on the Impacts of Urban Shrinkage on Haze pollution

#### 4.2.1. Spatial Diagnostic Test

As there have been many academic writings on the spatial agglomeration of urban haze pollution, we do not repeat it here. Above analyses show there was a significant spatial autocorrelation in China's urban shrinkage. Therefore, spatial econometric models

selected by spatial diagnostic tests were used to check the impacts of urban shrinkage on haze pollution. As shown in Table 1, both LM-error and Robust LM-error passed

the significance test at the 1% level, and neither LM-lag nor Robust LM-lag passed the significance test. Therefore, SEM was adopted [17].

**Table 1.** Spatial diagnostic test.

Variable	coefficient	t-Statistic	P value
Constant	1.8924	2.3051	0.0254
lnUS	-1.5674	-3.8946	0.0003
lnSE	0.2371	1.9437	0.0576
lnGDP	0.1008	1.2374	0.2218
lnPGA	-0.2373	-1.8846	0.0654
lnLAND	0.1167	2.10016	0.0408
R <sup>2</sup>	0.4693		
Spatial diagnostic test	MI/DF	Test value	P value
Moran's I	0.5209	4.6248	0.0000
LM-lag	1	0.6068	0.4359
Robust LM-lag	1	1.9676	0.1607
LM error	1	17.8706	0.0000
Robust LM-error	1	19.2315	0.0000

#### 4.2.2. Regression Results of Spatial Econometric Models

The regression results of spatial econometric models are shown in Table 2. The R<sup>2</sup> of SEM in the last column was 0.7137. In Table 1, the R<sup>2</sup> of non-spatial measurement model was 0.4693. Therefore, it was more appropriate to use SEM to verify the impacts of urban shrinkage on haze pollution. The spatial autoregressive coefficients of all columns were positive and all passed the significance test, which verified that there was spatial spillover effect in haze pollution, and showed that it was appropriate to use SEM for empirical analysis in this study.

The coefficient of urban shrinkage in each column was significantly negative, which indicates that urban shrinkage had positive impacts on haze pollution, that is, reduced haze pollution. This is because the decrease in

urban population reduced residents' demand for cars and thus reduced car exhaust emissions. In the meanwhile, as cities shrank, the area of green space increased due to land vacancy, which boosted ecological restoration, improved air quality and reduced haze pollution. In terms of control variables, the proportion of secondary industries was significantly positive, which revealed the increase in the proportion of secondary industries aggravated haze pollution. The coefficient of economic development was significantly positive, which means economic development lead to haze pollution through expanding production scale and increasing the demand for energy consumption. The coefficient of green space in parks was significantly negative, which reveals expanded area of green space in parks reduced haze pollution. The coefficient of built-up areas was significantly positive, which indicates expansion of built-up areas caused haze pollution due to smoke and dust emissions in real estate development, building construction, etc.

**Table 2.** Estimation results of SEM.

Variable	( 1 )	( 2 )	( 3 )	( 4 )	( 5 )
$\lambda$	0.4335*** ( 0.0001 )	0.4651*** ( 0.0000 )	0.4930*** ( 0.0000 )	0.5924*** ( 0.0000 )	0.6169*** ( 0.0000 )
Constant	3.7064*** ( 0.0000 )	2.5538*** ( 0.0000 )	0.9873 ( 0.1616 )	1.9588*** ( 0.0034 )	2.1173*** ( 0.008 )
lnUS	-1.0032*** ( 0.0043 )	-0.8888*** ( 0.0068 )	-0.7901** ( 0.0120 )	-0.6270** ( 0.0288 )	-1.005*** ( 0.0012 )
lnSE		0.3124***	0.2635***	0.2799***	0.2878***

		( 0.0018 )	( 0.0058 )	( 0.0005 )	( 0.0001 )
lnGDP			0.1742**	0.1663***	0.1027*
			( 0.0103 )	( 0.0046 )	( 0.0892 )
lnPGA				-0.3525***	-0.3398***
				( 0.0001 )	( 0.0000 )
lnLAND					0.0966**
					( 0.0105 )
R <sup>2</sup>	0.4139	0.5082	0.5662	0.6741	0.7137
LR test	11.2965***	12.9077***	14.8669***	22.1554***	23.5316***
	( 0.0000 )	( 0.0003 )	( 0.0001 )	( 0.0000 )	( 0.0000 )

Note: The value in ( ) is the p value. \*p<0.1. \*\*p<0.05. \*\*\*p<0.001.

#### 4.2.3. Analysis of Empirical Results by Region

To understand regional differences in the impacts of urban shrinkage on haze pollution, we conducted empirical tests on the four regions, namely northeast, east, central and west China. As there were small samples in each region, it was not suitable to use spatial quantitative analysis, so common data model was adopted. FMOLS was employed for estimation as it can correct sequence correlation and bias [18].

The regression results of each region are shown in Table 3. Except for west China, the impact of urban shrinkage on haze pollution was significantly negative. Urban shrinkage in central China had the greatest impacts on haze, followed by the northeast and the east. Urban shrinkage in the central, northeast and east rose by 1 percentage point, which reduced haze pollution by 3.6561, 0.8147 and 0.5525 percentage points. It shows that shrinking cities in central, north and east China effectively alleviated haze pollution by reducing energy consumption and urban construction. Although the impact of urban shrinkage in west China on haze pollution was not significant, it was negative. That is, urban shrinkage in the west had positive impacts on

mitigating haze pollution. The coefficients of the proportion of secondary industries in east, central and west China were significantly positive. An increase in this proportion by 1 percentage point intensified haze pollution in east, central and west China by 1.5139, 0.1019 and 0.5533 percentage points. The coefficients of economic development in east and west China were significantly negative, which indicates that economic development there alleviated haze pollution. The coefficients of per capita green area in parks in northeast, east and west China were negative, which reveals that green area in parks in these regions reduced the degree of haze pollution. The coefficients of built-up areas in north, central and west China were significantly positive, which means the increase in built-up areas in these regions aggravated haze pollution. However, the coefficient of built-up areas in east China was significantly negative. This is because among the four regions, east China had the smallest built-up areas and actual construction areas, but assumed the greatest pressure on population and resources. Therefore, expanding built-up areas in east China and strengthening the construction of municipal structures and public facilities will help ease space pressure on urban traffic, etc. and reduce haze pollution.

**Table 3.** Estimation results of FMOLS regression in each region.

Variable	Northeast	East	Middle	West
Constant	3.8665*** ( 0.0002 )	4.9588** ( 0.0382 )	2.5763*** ( 0.0078 )	3.7620*** ( 0.0082 )
lnUS	-0.8147** ( 0.0186 )	-0.5525* ( 0.0980 )	-3.6561** ( 0.0250 )	-0.3087 ( 0.9263 )
lnSE	0.0132 ( 0.8718 )	1.5139** ( 0.0290 )	0.1019* ( 0.0873 )	0.5533** ( 0.0208 )
lnGDP	0.0626 ( 0.3148 )	-0.4959** ( 0.0189 )	0.0147 ( 0.7743 )	-0.2666* ( 0.0832 )
lnPGA	-0.6109*** ( 0.0017 )	-0.5308* ( 0.0690 )	0.0464 ( 0.5325 )	-0.3029* ( 0.0903 )
lnLAND	0.1240***	0.1700**	0.1308**	0.3055**

	( 0.0050 )	( 0.0364 )	( 0.0166 )	( 0.0134 )
R <sup>2</sup>	0.8167	0.7667	0.5207	0.5297

Note: The value in ( ) is the p value. \*p<0.1. \*\*p<0.05. \*\*\*p<0.001.

## 5. CONCLUSIONS

Urban shrinkage index was calculated with data about the urban population of 250 prefecture-level Chinese cities from 2012 to 2017. In total, 55 shrinking cities were selected. First, the impacts of urban shrinkage on haze pollution were looked into in theory. Second, the spatial distribution and spatial autocorrelation of urban shrinkage were analyzed. Finally, the spatial error model (SEM) and the fully modified least squares (FMOLS) regression were used to empirically examine the impacts of urban shrinkage on haze pollution at national and regional levels, respectively. The results indicated that shrinking cities showed spatial agglomeration, with northeast China having the largest number of shrinking cities. From a national perspective, SEM revealed that urban shrinkage reduced haze pollution. Increase in the proportion of secondary industries, economic development and built-up areas intensified haze pollution, while increase in green area in parks reduced such pollution. From a regional perspective, except for west China, the impacts of urban shrinkage on haze pollution were significantly negative. Urban shrinkage in central China had the greatest impacts on haze, followed by northeast and east China. Haze pollution was intensified by the increase in the proportion of secondary industries in east, central and west China, alleviated by economic development in east and west China, slowed down by the increase in green area in parks in northeast, east and west China, and aggravated by the rise in built-up areas in northeast, central and west China.

## 6. POLICY IMPLICATIONS

Based on above conclusions, we proposed the following policy implications:

First, shrinking cities should conform to the trend of urban shrinkage. According to theories on urban development, cities experience birth, development, prosperity and decline, so urban shrinkage is irreversible. Therefore, shrinking cities should follow and take advantage of this trend to promote urban regeneration and improve urban vitality. (1) Demolish abandoned houses, workshops and other buildings to build high-quality green spaces; increase the area of parks, green spaces, wetlands, etc. to strengthen adsorption of particulate matters, beautify urban landscape and increase recreational spaces for residents. (2) Carefully plan urban area to improve the efficiency of urban spaces; encourage the concentration of residential areas to improve the efficiency of public facilities; encourage remote companies to relocate to urban areas to reduce the use of private cars by employees and thus reduce vehicle

exhaust emissions. (3) Invest more state finance in shrinking cities. With the outflow of population, enterprises and other elements, shrinking cities have weakened tax revenues and fiscal capacities, which is not conducive to the construction of public infrastructure and the supervision and prevention of haze pollution. Therefore, state finance can increase the financial strength of shrinking cities by increasing subsidies and reducing or exempting taxes, so that shrinking cities have sufficient funds for constructing public facilities and supervising and controlling haze pollution.

Second, targeted measures should be adopted based on local conditions. Northeast China had the largest number of shrinking cities, which may introduce preferential policies to retain outstanding talents and enterprises, promote the growth of local knowledge and technology, and build themselves into quality small cities. As far as the 55 sample cities are concerned, shrinking cities in the east had the highest proportion of secondary industries, which is not conducive to the treatment of haze pollution. Therefore, shrinking cities in the east should vigorously develop high-tech industries and modern service industries to establish a high-quality industrial system, and expand built-up areas and green space in parks to reduce ecological pressure, thus reducing haze pollution. Shrinking cities in central China should speed up their economic development while reducing the proportion of secondary industries and increasing the proportion of tertiary industries. They had the largest built-up areas among the four regions and positive coefficient of haze pollution. Therefore, they should reduce built-up areas and improve the efficiency of public facilities. In addition to increasing the proportion of tertiary industries, economic development and green space in parks, shrinking cities in west China also needs to reduce built-up areas and optimize the allocation of stock assets so as to reduce haze pollution.

## Compliance with Ethical Standards

This study was not funded by any organization.

Author Xiaohong Liu declares that she has no conflict of interest.

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