The influence of population agglomeration on air pollution: An empirical study based on the mediating effect model

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Abstract. With rapid urbanization and industrialization, the population of metropolis in China is increasing. Previous studies suggest that population agglomeration would have a significant impact on air pollution in cities. Using a panel dataset of 30 provincial capital cities during 2013-2017, as well as days of air quality equal to or above Grade II as air pollution indicators, the results show that an increase of population density will improve air quality in large cities. Through the mediation effect test, this paper found that tertiary industry is the mediation channel of population agglomeration to reduce air pollution. An increase of population density in big cities is conducive to increasing the proportion of tertiary industry, thereby reducing the proportion of seriously polluting secondary industry, and reducing air pollution.

1. Introduction

To promote sustainable development, it is necessary to achieve balanced development between regions. The connotation of achieving balanced development lies in promoting equality per capita between regions, rather than equality in the total amount. Therefore, population flows to big cities should be encouraged to engage in high value-added industries such as service industry. There are three benefits. Firstly, the agglomeration of population to big cities increase the per capita arable land area in rural areas, help the rural areas to achieve large-scale management and improve production efficiency. Secondly, it is conducive to the development of the tertiary industry represented by the service industry in big cities and promote the transformation of industrial structure. Thirdly, it is conducive to the migrant population to enjoy better public services and have career development. In short, this will be conducive to achieving per capita GDP or quality of life equality between urban and rural areas and between the East and the Midwest in China.

There is a view that air pollution in big cities will increase with the agglomeration of population. For one thing, it will cause damage to the health of the urban population. For another thing, it will reduce the happiness and sense of achievement of the residents. Therefore, it is necessary to control the size of the urban population to reduce air pollution. However, with the development of cities, air pollution in many big cities has not continued to deteriorate with the increase in population density. G M Grossman and A B Krueger think that there is an inverted U-shaped relationship between per capita income and environmental pollution, rather than a simple linear relationship [1]. And some people think that the increase of population density does not necessarily lead to the aggravation of air pollution, that is, the sum of positive and negative effects of population agglomeration is not necessarily negative.
2. Literature review and research hypothesis

When the population migrates to large cities, it will have both positive and negative effects. Regarding the negative impacts, Y G Tong and Y Y Wang believe that urban population agglomeration can increase air pollution from three mechanisms: population size, population structure, and spatial distribution [2]. Firstly, in terms of population size, the increase of population will inevitably lead to the increase of production and life activities, the consumption of more energy and resources to produce more pollutants. Secondly, household miniaturization increases the demand for housing and motor vehicles, resulting in more pollutants. Thirdly, in terms of the spatial distribution, unreasonable urban planning makes the separation of working and residence very common, resulting in the increase of commuting distance and the prolongation of traffic jam time, resulting in more pollutants.

Regarding the positive impacts, Y L Zheng and M Lu believe that urban population agglomeration can improve the quality of urban environment from three channels: industrial structure transformation, technological innovation, and citizen quality [3]. Firstly, with the agglomeration of urban population, the secondary industry, which is seriously polluted by industrial economy, gradually gives way to the environmentally friendly tertiary industry, which is dominated by service economy, thus reducing air pollution. Secondly, in terms of technological innovation, population agglomeration is conducive to promoting the innovation and use of production technology and emission reduction technology to reduce air pollution by reducing the total amount of emissions and reducing the cost of emissions. Thirdly, in the quality of citizens, population agglomeration will expand the peer effect to improve the individual awareness of environmental protection of urban residents to reduce pollution. In addition, Dinda also believes that high-income people have a higher preference for environmental quality, that is, they are less tolerant of the negative effect of economic development on environment [4]. And he thinks that when the heavily polluted industrial economy turns to a clean service economy, air pollution will decline, that is, economic growth has a positive impact on air quality through. Arrow et al points out that the environmental carrying capacity is not immutable, but will change with the change of technology, production, and consumption structure [5].

In summary, most studies agree that population agglomeration will have a significant impact on air pollution. Due to many reasons, most research in China uses provincial or prefecture-level city data and PM2.5 as a dependent variable. Among them, the sample selection is difficult to reflect the impact of population agglomeration on air pollution in big cities. And a single pollutant cannot reflect the comprehensive impact of air pollution, so it is necessary to further study the impact of population agglomeration on air pollution in large cities. The tertiary industry may be an important mediating variable for population agglomeration to affect air pollution, and there is little literature on the impact of industrial structure on air pollution with the tertiary industry as a mediating variable. For testing whether population agglomeration will improve the air quality of large cities and the existence of tertiary industry as a mediating variable, this paper puts forward the following two hypotheses:

H1. An increase in population density will improve air quality.
H2. Tertiary industry is a significant mediator of the impact that population density has on air pollution.

3. Data and model

3.1. Data source

As the political and economic centre of each province, provincial capital cities have a dense population and developed tertiary industry. So, this paper chooses provincial capital cities as the representative of big cities. Due to the lack of data, four cities are miss out, which is Hong Kong, Macau, Taipei and Lhasa. AQI (Air quality Index) is a dimensionless index developed by the Ministry of Environmental Protection that is used to quantitatively describe air pollution. Its calculation formula is as follows:

$$AQI = \max \{IAQI_1, \ldots, IAQI_n\}$$
Among them, IAQI (Individual Air Quality Index) represents the pollution degree of a single pollutant. And $n$ represents the six pollutants of PM2.5, PM10, SO2, NO2, CO and O3, respectively. This paper chooses population density to represent population agglomeration and chooses the proportion of tertiary industry in GDP as the mediating variable to represent the degree of industrial structure optimization. At the same time, this paper chooses the per capita GDP, foreign direct investment, total natural gas supply and the number of cars as control variables. The selection and definition of variables are shown in Table 1.

| Variable abbreviation | Variable name         | Variable definition                                      |
|-----------------------|-----------------------|----------------------------------------------------------|
| Hday                  | healthy days          | Days when AQI ≤ 100                                       |
| Industry              | tertiary industry GDP  | GDP of tertiary industry / GDP                            |
| PD                    | population density    | population density                                       |
| PGDP                  | economy               | per capita GDP                                            |
| FDI                   | foreign direct investment | amount of foreign capital actually utilized            |
| NG                    | clean energy          | total natural gas supply                                  |
| CAR                   | number of cars        | number of buses, trolley buses and taxis                 |

The AQI and six pollutant data from 2013 to 2017 are from the “China Environment Statistical Yearbook” from 2014 to 2018. The socioeconomic data from 2013 to 2017 are all from the “China City Statistical Yearbook” from 2014 to 2018. It should be noted that the statistical yearbook does not give the annual AQI value, so this paper uses the number of healthy days (i.e., when AQI ≤ 100) to replace AQI.

3.2. Econometric model
Z L Wen and B J Ye proposed a new procedure to analyze mediating effects based on Baron and Kenny’s causal steps approach [6-7]. According to their research results, this paper divides a causal steps approach into three steps:

\[
\ln(Hday)_{it} = \alpha + C \cdot \ln(PD)_{it} + \beta_k \cdot control_{it} + \mu_i + \varepsilon_{it} \tag{1}
\]

\[
\ln(Industry)_{it} = \alpha + a \cdot \ln(PD)_{it} + \beta_k \cdot control_{it} + \mu_i + \varepsilon_{it} \tag{2}
\]

\[
\ln(Hday)_{it} = \alpha + c \cdot \ln(PD)_{it} + b \cdot \ln(Industry)_{it} + \beta_k \cdot control_{it} + \mu_i + \varepsilon_{it} \tag{3}
\]

where subscript $i$ represents cities, $t$ represents the time in years, $\mu_i$ represents the fixed effect, $\alpha$ is the constant and $\varepsilon$ is the error term. $a$, $b$, $c$, $C$, and $\beta_k$ are coefficients to be estimated. The first step tests whether the coefficient $C$ is significant in Eq. (1). The second step tests whether the coefficient $a$ is significant in Eq. (2). The third step tests whether the coefficient $c$ and $b$ are significant in Eq. (3). If $a$, $b$, and $C$ are all significant, yet $c$ is not significant, Industry is a significant mediator. The Eq. (1) is constructed to test Hypothesis 1. The Eqs. (2) and (3) are constructed to test Hypothesis 2.

4. Results
4.1 Description analysis
Descriptive statistics of each variable are shown in Table 2. This paper provides descriptive evidence for the hypotheses in Figs. 1-3.
Table 2. Describes statistics.

|     | N  | Mean  | SD   | Min  | Max  |
|-----|----|-------|------|------|------|
| Hday | 150 | 241.45 | 64.23 | 49   | 362  |
| Industry | 150 | 0.55  | 0.10 | 0.39 | 0.81 |
| PD   | 150 | 702.65 | 565.66 | 136.13 | 3816 |
| PGDP | 150 | 104078 | 84708.82 | 37691.18 | 984676.8 |
| FDI  | 150 | 438007.6 | 535828.4 | 577 | 3082563 |
| NG   | 150 | 176739.1 | 270768.8 | 6783 | 1641696 |
| CAR  | 150 | 21360.51 | 18033.3 | 2393 | 94108 |

In Fig. 1, (a) plots the pooled data and (b) plots the residuals after controlling the city fixed effect. From Fig. 1(a), there is a negative correlation between population density and the number of healthy days. However, after controlling the fixed effect at the city level, the influence of population density on the number of healthy days changed from negative to positive. That is to say, the increase of population density is conducive to reduce air pollution.

![Figure 1. Healthy days and population density.](image)

![Figure 2. Tertiary industry and population density.](image)
As can be seen from Fig.2, the increase in population density is conducive to the development of the tertiary industry. As can be seen from Fig.3, the increase in the proportion of the tertiary industry is conducive to improve air quality. After controlling the fixed effect at the city level, the positive correlation remains the same. Combined with Fig.2 and Fig.3, tertiary industry may be a channel of population density affecting air pollution.

4.2 Regression results

According to column (1) in Table 3, the research Hypothesis 1 holds. According to column (2) and (3) in Table 3, the research Hypothesis 2 holds. The specific analysis results are as follows. The column (1) is to verify whether the regression coefficient $C$ of population density affecting air quality is significant. The column (2) is to verify whether the regression coefficient $a$ of population density affecting the development of tertiary industry is significant. The column (3) is to verify whether the regression coefficient $b$ and $c$ are significant. The results showed that $a$, $b$, and $C$ are all significant, yet $c$ is not significant, so Industry is a significant mediator.

|             | (1)       | (2)       | (3)       |
|-------------|-----------|-----------|-----------|
|             | LnHday    | LnIndustry| LnHday    |
| LnPD        | 0.101**   | 0.055**   | 0.023     |
|             | (0.048)   | (0.024)   | (0.035)   |
| LnIndustry  |           | 1.416***  |           |
|             |           | (0.153)   |           |
| LnPGDP      | 0.158     | 0.049     | 0.089***  |
|             | (0.117)   | (0.080)   | (0.023)   |
| LnFDI       | 0.026     | -0.001    | 0.028     |
|             | (0.022)   | (0.012)   | (0.018)   |
| LnNG        | 0.303***  | 0.085***  | 0.183*    |
|             | (0.105)   | (0.029)   | (0.102)   |
| LnCAR       | -0.345**  | -0.118**  | -0.178    |
|             | (0.162)   | (0.055)   | (0.141)   |
| Constant    | 2.579     | -1.327    | 4.457***  |
|             | (1.654)   | (0.956)   | (0.658)   |
| Observations| 150       | 150       | 150       |
| R-squared   | 0.301     | 0.217     | 0.496     |

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
As can be seen from Table 3, both $a$ and $b$ are significant, but $c$ is not significant. The column (1) indicates that, with an increase of population density, there was also an increase in the number of healthy days, passing the first step of the mediating effect. The column (2) indicates that, with an increase of population density, there was also an increase in the proportion of tertiary industry in GDP, passing the second step of the mediating effect. The column (3) indicates that, with an increase of tertiary industry, there was also an increase in the number of healthy days, passing the third step of the mediating effect.

To sum up, $H1$ and $H2$ hold. The percentages of the direct effect and the mediating effect can be calculated by the effect value, in which the direct effect accounts for 22.772% and the mediating effect accounts for 77.228%. The impact of population density on air pollution is mainly through the tertiary industry as a mediating channel.

5. Conclusion and recommendation
To sum up, after controlling the city fixed effect and other control variables, the increase of population density will not increase the air pollution but will reduce air pollution. From the above empirical results, it can be found that population density would reduce air pollution in large cities, so limiting the population size of large cities may not necessarily solve air pollution problems. Therefore, other measures are needed to reduce air pollution.

Combined with relevant literature, this article puts forward the following three policy recommendations to reduce air pollution. Firstly, solutions to air pollution should be sought in terms of technology and management. Secondly, related managers should reasonably plan the spatial layout of big cities, promote population concentration, and give full play to the agglomeration effect. Thirdly, the government appropriately relax the population restrictions in big cities, encourage migrant people to settle down and provide them with equal public services to increase the proportion of tertiary industry.

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