The Evaluation of Innovative Ability of Capital Cities in China Introducing Air Pollution Indexes

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Abstract. With the regression analysis of data of 31 provincial capitals in China from 2010 to 2015, it is proved that air pollution has an impact on urban innovation. Then, based on this conclusion, the evaluation system of urban innovation ability is constructed by using factor analysis, resulting in the evaluation formula of Chinese urban innovative ability. Finally, the formula is applying to the evaluation of capital cities’ innovation ability, of which the conclusion is compared with “China Urban Innovation report 2015”. Through this comparison, Chengdu, Zheng Zhou, Ji Nan, Wu Han etc. reveal the increasing innovation ability these years.

1. Instruction
The research on urban innovative ability in foreign countries began in 1990s, and its direction is gradually systematic and mature after the 21st century; while the research on urban innovative ability in China is limited by the level of economy, science and technology, so it starts late. After analysis of the literatures on the construction of elements system towards urban innovative ability, it is surprising that the evaluation system of urban innovative ability is almost based on social and economic indicators and few people pay attention to ecological indicators. However, air pollution has become a leading problem in many cities in recent years, especially in China. According to relevant information, air pollution is closely related to the introduction of innovative talents and the improvement of urban innovative ability. Therefore, we assume that air pollution has an impact on urban innovative ability and take this as the center to our research. In order to prove this hypothesis, we will take the data of 31 provincial capitals of China from 2010 to 2015 as the research object to verify the influence of air pollution on the urban innovative ability. On the basis of the hypothesis verification, we will reconstruct the index system of urban innovative ability for a more scientific evaluation of urban innovative ability.

2. Literature Review on Urban Innovative Ability

2.1. Literature Review on foreign research about Urban Innovative Ability
The research on innovative ability of foreign cities began to develop rapidly in 21th century. Charles Landley (2000) put forward a seven-factor model of urban innovative capability and constructed a matrix of "urban innovative resource composition evaluation" and "urban innovative vitality evaluation", which evaluated urban innovative ability from two levels: current situation and potential. The European Union Scoreboard (2001) was issued to evaluate innovation performance in other countries with the United States and Japan as benchmarks. It has become one of the most mature national innovative
evaluation systems in the world. James Simier (2001) published *Innovative Cities*, which compares the levels of urban innovative ability in Amsterdam, London, Milan, Paris and Stuttgart, explaining why these five cities are leading innovative cities in Europe, also claiming that the key driving force of modern economy is innovation.

Ashheim (2011) divided innovative knowledge into analytical basic field, comprehensive basic field and symbolic basic field. Tommy Inkinen (2015) developed Ashheim’s theory and developed these three basic areas of knowledge into an urban innovative ability evaluation system with the quantitative analysis of Helsinki, Ruoholahti, Alabia and Otaniem. Uliya Georgiana (2017), by analyzing the path to the transformation of the innovative city in Yekaterinburg, proposed eight innovative urban constructions and transformation strategies, then predicting the development of population, economy and human resources of the city.

2.2. Literature Review on Chinese Research about Urban Innovative Ability

The inception of research on urban innovative ability in China is relatively late. Since the National Science and Technology Congress was held in 2006 and the *National Medium and Long-Term Science and Technology Development Program (2006-2020)* was promulgated, the research on urban innovative ability has developed gradually.

When Jianxin You (2011) studied the mode of urban innovative ability, he proposed that "a complete urban innovative system should include two aspects: innovative development strategy and innovative driving factors, which constitute the internal driving force of urban innovative. Jinhang Zhang, Bing Su (2012) defined the scientific innovative city. Considering the input-output ratio, they constructed a 4-dimensional factors evaluation system of this kind of innovative city, which includes scientific talented person resources, scientific innovative environment, scientific innovative input and scientific innovative output, then selecting Beijing, Shanghai and Tianjin to evaluate their innovative ability. Guangchun Gao (2013) highlighted the fiscal and financial support, constructing a model of 4-dimensional elements, namely fiscal support, financial support, economic base and innovative environment. The model showed that the weight of fiscal and financial factors for urban innovation is close to 60%. Wenguang Zhang, Wei Li (2017) constructed CCR and BCC models with synthetic evaluation of innovative economic output, scientific output and social environment benefit. According to the results of the innovative efficiency, the paper puts forward some policy suggestions to improve the innovative ability.

3. Relationship between Air Pollution and Urban Innovative Ability

In order to explore the relationship between air pollution and urban innovative ability, we select four air pollution indexes: PM10, PM2.5, SO2, NO2 and four urban innovative output indicators which is among the most representative indicators for urban innovation: GDP, tertiary industry output value, patent application numbers and patent authorization number of 31 Chinese provincial capitals in 2015. Then in IBM SPSS Statistics 19, the air pollution indexes are taken as the independent variables and the innovative output indexes of every provincial capital are regarded as the dependent variables, carrying out 4 multiple regression analyses. Through the results below, it is proved that air pollution indexes have influence on urban innovative output indexes. That is, air pollution is related to urban innovative ability. The following are the specific results of the four regression analyses in IBM SPSS Statistics 19:

| Model  | Sum of Squares | df | Mean Square | F     | Sig.  |
|--------|----------------|----|-------------|-------|-------|
| 1 Regression | 5.977E8        | 4  | 1.494E8     | 6.481 | .001a |
| 2 Regression | 2.620E8        | 4  | 6.5493E7    | 5.365 | .003a |
| 3 Regression | 1.747E10       | 4  | 4.368E9     | 5.011 | .005a |
| 4 Regression | 6.384E9        | 4  | 1.596E9     | 6.323 | .001a |

1 Regression model significance test of air pollution indexes to GDP regression model
a. Predictors: (Constant), PM2.5, SO2, NO2, PM10
b. Dependent Variable: GDP
2 Regression model significance test of air pollution indexes to output value of tertiary industry
   a. Predictors: (Constant), PM2.5, SO2, NO2, PM10
   b. Dependent Variable: the output value of tertiary industry
3 Regression model significance test of air pollution indexes to patent application number
   a. Predictors: (Constant), PM2.5, SO2, NO2, PM10
   b. Dependent Variable: patent application number
4 Regression model significance test of air pollution indexes to patent authorization number
   a. Predictors: (Constant), PM2.5, SO2, NO2, PM10
   b. Dependent Variable: patent authorization number

According to the above four analyses, the significant level of regression model is lower than .05, so it can be considered that the correlation between air pollution index and urban innovative output can be described by multiple linear regression model. Namely, air pollution indexes have certain influence on urban innovative ability.

4. Construction of Indexes System of Urban Innovative Ability
In order to scientifically evaluate the ability of urban innovation, we synthesize the existing literatures and select 5 air pollution indexes (adding AQI, for it is the synthetic indicator for SO2, NO2, PM2.5, PM10) and 21 common indexes which have been proved to be effective when evaluating urban innovative ability. Using the data of 31 Chinese provincial capitals in 2010-2015, factor analyses in IBM SPSS Statistics 19 are carried out.

The factor analyses take KMO and Bartlett’s test as the tests of partial correlation and unit matrix, and take factor eigenvalue \( \geq 1 \) as the criterion of factor extraction according to principal component method. The maximum variance orthogonal rotation method is used as factor load matrix rotation method and the factor score is calculated by regression method. According to the factor analysis, the KMO value of each year data is above .60; the Bartlett’s test is < .05; and the accumulative contribution rate of common factors are above 80%, so these 26 indexes are kind of suitable for factor analysis.

Then, we compare the load matrixes after each year's rotation. The results show that the load matrix after each rotation divides the 26 indexes into three factors and the index contained by the same factor has little annual variation. Therefore, 16 indexes which belong to the same factor in each year are selected as the new index system. We carry on the factor analysis to these 16 indexes again in SPSS. The result is as follows:

1. KMO and Bartlett’s test

| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | Bartlett's Test of Sphericity |
|-----------------------------------------------|-------------------------------|
| Approx. Chi-Square                            | 633.577                      |
| df                                            | 120                           |
| Sig.                                          | .000                          |

According to the above table, the KMO is .781 and the associated probability of Bartlett's test is .000, which is suitable for factor analysis.

2. Part of factor extraction results

| Component | Initial Eigenvalues | Extraction Sums of Squared Loadings | Rotation Sums of Squared Loadings |
|-----------|---------------------|-------------------------------------|-----------------------------------|
| Total     | % of Variance       | % of Variance                       | % of Variance                     |
| 1         | 8.868               | 55.426                              | 8.868                             | 55.426                           | 55.426                           | 7.527                             | 47.041                           | 47.041                           |
| 2         | 3.596               | 22.472                              | 3.596                             | 22.472                           | 77.899                           | 3.635                             | 22.717                           | 69.758                           |
| 3         | 1.117               | 6.984                               | 1.117                             | 6.984                            | 84.883                           | 2.420                             | 15.125                           | 84.883                           |
The results show that the number of extractable common factors is 3 and the contribution rate of cumulative eigenvalue of common factors is about 85% after rotation. The result is ideal.

Then, according to the rotating load matrix, we analyze the index composition of each factor and summarize it as follows:

### Table 3. Index Composition for Factor Analysis

| Factors          | Included Indexes                                      |
|------------------|-------------------------------------------------------|
| Capacity factor  | Expenses of Science and Technology                    |
|                  | Expenses of Education                                 |
|                  | Number of Employees in Science and Technology         |
|                  | Actual Investment of Foreign Enterprises              |
|                  | Number of Employees in Tertiary Industry              |
|                  | GDP                                                   |
|                  | Output Value of Tertiary Industry                     |
|                  | Patent Application Number                             |
|                  | Patent Authorization Number                           |
| Ecology Factor   | PM10                                                  |
|                  | NO2                                                   |
|                  | SO2                                                   |
|                  | PM2.5                                                 |
|                  | Good days based on AQI                               |
| Potentiality Factor | Number of Teachers in Universities and Colleges         |
|                  | Number of Students in Universities and Colleges       |

5. Comprehensive Evaluation of Urban Innovative ability

From the factor analysis above, the contribution rate of cumulative eigenvalue of the three common factors after rotation is 85%. Therefore, comprehensive evaluation of the urban innovative ability could be constructed with the common factor eigenvalues taken as weights.

If: The eigenvalues of the common factors are $T_1, T_2, T_3$; the weight of the common factors are $W_1, W_2, W_3$; and the common factor scores are $C$ (Capacity Factor), $E$ (Ecology Factor), $P$ (Potentiality Factor). With the data of factor analysis, the common factor weights are obtained as follows, after the normalization of the common factor eigenvalues:

$$ W = \frac{T_i}{\sum_{i=1}^{k} T_i} \quad (i = 1, 2, \ldots, k) $$

$W_1=0.5542; W_2=0.2676; W_3=0.1782$

Finally, the comprehensive evaluation formula of urban innovative ability is obtained:

$$ Z = 0.5542C + 0.2676E + 0.1782P $$

6. Application of evaluation formula for urban innovative ability

According to the formula, the comprehensive score of Chinese provincial capitals are calculated and ranked. Besides, we compared the results of the research with the top 10 most innovative cities ranked by *China Urban Innovation Report (2015)*. The result is as follows:

### Table 4. Comparison of Two Urban Innovative Ability Ranking

| City       | Ranking of Evaluation Formula for Urban Innovative Ability | Ranking of *China Urban Innovation Report (2015)* | Ranking Change |
|------------|-----------------------------------------------------------|--------------------------------------------------|----------------|
| Beijing    | 1                                                         | 1                                                | No Change      |
| Shanghai   | 2                                                         | 2                                                | No Change      |
| Tianjin    | 3                                                         | 4                                                | ↑1 Place       |
| Chongqing  | 4                                                         | 6                                                | ↑2 Places      |
| Chengdu    | 5                                                         | Not in the Top 10                                | ↑≥6 Places     |
| Zhengzhou  | 6                                                         | Not in the Top 10                                | ↑≥5 Places     |
| Guangzhou  | 7                                                         | 7                                                | No Change      |
| Jinan      | 8                                                         | Not in the Top 10                                | ↑≥3 Places     |
| Wuhan      | 9                                                         | Not in the Top 10                                | ↑≥2 Places     |
| Xi'an      | 10                                                        | Not in the Top 10                                | ↑≥1 Place      |
According to the changes of ranking, Beijing, Shanghai and Guangzhou have no change in ranking; Tianjin and Chongqing rise in rank; Chengdu, Zhengzhou, Jinan, Wuhan and Xi'an rise to the list. This shows that the five provincial capitals, headed by Chengdu, have shown considerable urban innovative ability when innovative ability considered comprehensively.

7. Conclusion
In this paper, the relationship between air pollution and urban innovative ability is established. Based on this relationship, a three-dimensional evaluation system of urban innovative ability is constructed, which includes capability factor, ecology factor and potentiality factor. Finally, factor analysis helps us to set up the comprehensive formula of urban innovative ability. The research focuses on the problem of air pollution, which is becoming a hot topic in recent years and fills the gap of neglecting ecological indexes in the research of urban innovative ability. It provides a useful reference for the scientific evaluation of Chinese urban innovative ability at this stage. The deficiencies of this study are the simplicity of ecological indicators and the lack of subordinate indicators of potential factors.

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