Exploring the quantitative assessment of urban economic vitality in the Yangtze River Delta of China based on PCA

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Abstract. With the accelerating urbanization in developing countries, sustainable urban development has become a strategic goal for governments. To promote sustainable development of individual cities, it is necessary to break away from the limitations of administrative divisions and use the synergistic effect of urban clusters to solve the many difficulties facing sustainable development. The assessment of economic vitality is a critical way to evaluate the development potential of cities. This paper proposes a quantitative assessment method for urban economic vitality. Using 26 cities in the Yangtze River Delta region as the research object and local statistical yearbooks as the data source, we construct 18 urban economic vitality assessment indicators. First, we use the Principal Component Analysis (PCA) method to obtain the five major factors of city vitality assessment: manufacturing and people's life factor, service industry and government management factor, industrial economic growth rate factor, urban development potential factor and primary and secondary industry efficiency factor. Then, we use spatial hotspot analysis to classify the urban economic vitality of the Yangtze River Delta region into three categories: low, medium and high. The research results have important implications for the coordinated and sustainable development of the regional economy and the formulation of economic development strategies for low-vitality regions.

1. Introduction

With the rapid urbanization in China, cities are playing an increasingly important role in social and economic development. At the same time, problems of urban development emerge frequently, and therefore attention needs to be paid to how to keep cities in high quality and sustainable development [1], of which urban vitality is an important aspect [2]. The concept of vibrancy was introduced by Jacobs, who argued that the process of intertwining human activities and living places constitutes the diversity of urban life, and urban vitality is the expression of the diversity of urban life [3-4]. At present, based on the basic concept of vitality, people make a multi-dimensional analysis of urban vitality from the aspects of urban spatial vitality and spatiotemporal vitality characteristics. Jin et al. (2017) combined DMSP/OLS data with multi-source data to develop an evaluation of urban vitality at both national and city scales [5]. Kang C et al. (2020) used multi-source spatiotemporal data and generalized entropy function to measure the spatiotemporal diversity of cities, and found that 28 indicators such as attributes, time, and spatial diversity were positively correlated with urban vitality in Wuhan city [6].

The development of economy is the driving force for the city to move forward. Urban vitality is inseparable from people's social activities as well as their economic activities. Related research has
begun to focus on this area, and from the perspective of human spatial behaviour, launched the quantitative analysis technology of urban economic vitality and the analysis of driving factors [7-8].

In summary, most economic vitality studies take the internal space of cities as the scale of analysis, and have not yet focused on the characteristics of economic vitality of cities themselves, especially urban agglomerations. From the perspective of national macro development, the analysis of economic vitality of city clusters can provide crucial decision support for industrial layout, structural adjustment and regional development planning. This paper explores the economic vitality characteristics of Yangtze River Delta urban agglomeration, the largest urban zone in China, by collecting relevant economic statistics indicators.

2. Materials and methods

2.1. Study area and data description

This paper uses the Yangtze River Delta region of China as the study area, which is one of the most economically active and creative regions in China. The region includes 13 prefecture-level cities in Jiangsu Province, 11 prefecture-level cities in Zhejiang Province, 16 prefecture-level cities in Anhui Province, and Shanghai, for a total of 26 cities. The scope of the Yangtze River Delta urban belt is shown in Figure 1.

![Figure 1. Scope of the Yangtze River Delta Urban Belt.](image-url)

The data used in this study were mainly obtained from the Statistical Yearbook 2019 (2018 data) [9] and the 2018 National Economic and Social Development Statistical Bulletin [10] published by...
To ensure the standardization and uniformity of data for all indicators, all per capita indicators in the text use the resident population, and those involving U.S. dollars are converted using the 2018 average exchange rate of US $1 = RMB 6.6174.

2.2. Urban economic vitality evaluation indicators
Taking into account the availability, consistency and coherence of statistical data of all local cities, this paper makes a comprehensive assessment of the economic development of cities in eight aspects: economic strength, economic vitality of primary industry, economic vitality of secondary industry, economic vitality of tertiary industry, openness, talent and technology level, quality of life of residents, and government management. The article uses these indicators as the evaluation index system of urban economic vitality, and the connotation and calculation methods of each indicator are shown in Table 1.

Table 1. Evaluation indicators and calculation methods of urban economic vitality.

| Dimensions                        | Indicators                                                                 | Calculation method                                                                                                                                 |
|-----------------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Comprehensive economic strength   | Gross regional product per capita (yuan/person)                              | $X_1 = \frac{\text{Gross Regional Product}}{\text{Total population of the region}} $ \text{Current year regional GDP} - \text{Previous year regional GDP}$ |
|                                   | Gross regional product growth rate (%)                                      | $X_2 = \frac{\text{Current year regional GDP}}{\text{Previous year regional GDP}}$                                                                 |
| Primary industry economic vitality| Primary industry gross regional product growth rate (%)                     | $X_3 = \frac{\text{Current year GDP of the primary sector}}{\text{Previous year GDP of the primary sector}}$                                      |
|                                   | Grain crop yield per unit area (kg/ha)                                      | $X_4 = \frac{\text{Total food crop production}}{\text{Area sown to food crops}}$                                                                   |
|                                   | Per capita ownership of agricultural machinery power (kW/person)            | $X_5 = \frac{\text{Total power of agricultural machinery}}{\text{Total population of the region}}$                                                  |
| Secondary industry economic vitality| Secondary industry gross regional product growth rate (%)                | $X_6 = \frac{\text{Current year secondary sector GDP}}{\text{Previous year secondary sector GDP}}$                                              |
|                                   | Percentage of social workers in the secondary industry (%)                  | $X_7 = \frac{\text{Number of social workers in the secondary industry}}{\text{Total number of social workers}}$                                   |
|                                   | Sales profit rate of industrial enterprises above the scale (%)             | $X_8 = \frac{\text{The main business income of industrial enterprises above the scale}}{\text{The main business income of industrial enterprises above the scale}}$ |
| Tertiary sector economic vitality | Tertiary sector gross regional product growth rate (%)                      | $X_9 = \frac{\text{Current year tertiary sector GDP}}{\text{Previous year tertiary sector GDP}}$                                              |
|                                   | Percentage of social workers in the tertiary sector (%)                     | $X_{10} = \frac{\text{Number of social workers in the tertiary sector}}{\text{Total number of social workers}}$                                 |
|                                   | The proportion of added value of tertiary industry to regional GDP (%)      | $X_{11} = \frac{\text{Value added of tertiary industry}}{\text{Gross Regional Product}}$                                                             |
| Degree of openness                | Foreign trade dependence (%)                                               | $X_{12} = \frac{\text{Total regional import and export}}{\text{Gross Regional Product}}$                                                         |
|                                   | Actual amount of foreign capital utilized                                  | $X_{13} = \frac{\text{Actual use of foreign capital in the region}}{\text{Total population of the region}}$                                     |
2.3. Principal Component Analysis of urban economic vitality
Principal component analysis (PCA) is a statistical method for dimensionality reduction. Principal component analysis creates as few uncorrelated \( p \) new variables as possible with the help of an orthogonal transformation. These new variables are able to fully represent the characteristics of the original data. PCA is geometrically expressed as a transformation of the original coordinate system into a new orthogonal coordinate system with the axes pointing to the \( p \) orthogonal directions where the sample points are most widely scattered. It can be expressed in the formula:

\[
F_1 = a_{11} * Zx_1 + a_{21} * Zx_2 + a_{31} * Zx_3 + \cdots + a_{n1} * Zx_n \\
F_2 = a_{12} * Zx_1 + a_{22} * Zx_2 + a_{32} * Zx_3 + \cdots + a_{n2} * Zx_n \\
\vdots \\
F_p = a_{1p} * Zx_1 + a_{2p} * Zx_2 + a_{3p} * Zx_3 + \cdots + a_{np} * Zx_n
\]  

(1)

\( F_p \) represents the newly obtained \( p \) principal components after dimensionality reduction. \( (a_{ij})_{p \times n} \) is the factor score coefficient matrix, and \( Zx_k \) is the \( n \) indicator variables normalized by \( Z \).

In the assessment of economic vitality, a factor score coefficient matrix is used to determine the weight of each indicator for each principal component, and then calculate the factor score for each city. Then, the weight of each principal component to the composite score is determined by the factor variance contribution ratio, and then the composite score of each city is obtained, and the formula is shown in (2). Finally, the size of a city's composite score is used as a measure of the urban economic vitality.

\[
score = \sum_{i=1}^{n} F_i * W_i = \frac{\sum_{i=1}^{n} F_i * \lambda_i}{\sum_{k=1}^{n} \lambda_k} = \frac{\sum_{i=1}^{n} F_i * \lambda_i}{\sum_{k=1}^{n} \lambda_k}
\]  

(2)

\( F_i \) denotes the five principal components, \( W_i \) is the weight of the principal component in the composite score, and \( \lambda_i \) is the percentage of variance of \( F_i \) after rotation in the total variance explained table.

2.4. Hotspot analysis of urban economic vitality
Hotspot analysis identifies "hotspots" (clusters of high values) and "coldspots" (clusters of low values) in the study area. This paper uses the Getis-Ord Gi* method to explore the spatial pattern of urban
economic vitality in the Yangtze River Delta region. The principle is to determine the distribution of "hot spots" or "cold spots" by testing the spatial autocorrelation of aggregated spatial units with respect to the whole using the statistical significance test. The calculation formula is.

\[ G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S} \left[ \frac{n \sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2}{n - 1} \right] \]

where \( x_j \) is the attribute value of element \( j \), \( w_{i,j} \) are the spatial weights between elements \( i \) and \( j \), \( n \) is the total number of elements, and

\[ \bar{X} = \frac{\sum_{j=1}^{n} w_{j} x_j}{n}, \]

\[ S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left( \bar{X} \right)^2} \]

3. Results and analysis

3.1. Five principal components of urban economic vitality

In this paper, five principal components (denoted as F1 to F5) are selected to assess the economic vitality of cities based on the following two criteria:

- The first few components with a cumulative variance contribution of 80% or more of the principal components can be selected as the final principal component.
- When the characteristic root of a component is less than 1, it is no longer selected as a principal component.

Experimentally, the cumulative variance contribution of the five components after rotation was obtained to 81.202%, proving that their interpretation of the original data as a whole satisfies the requirements of our selection. In this paper, the variance of the common factor extracted by PCA analysis was more significant than 0.7 for most of the variables, indicating less loss of the original information. The component matrix obtained by PCA analysis is shown in Table 2.

| Table 2. Urban Economic Vitality Component Matrix |
|-----------------------------------------------|
| Name of variable                              | Ingredients |
|                                              | F1  | F2  | F3  | F4  | F5  |
| Gross regional product per capita (yuan/person)| 0.822 | 0.353 | -0.171 | 0.185 | 0.111 |
| Gross regional product growth rate (%)        | 0.001 | 0.032 | 0.984 | 0.086 | 0.031 |
| Primary industry gross regional product growth rate (%) | -0.546 | -0.419 | 0.287 | -0.027 | -0.343 |
| Grain crop yield per unit area (kg/ha)        | 0.452 | 0.270 | -0.350 | -0.135 | 0.588 |
| Per capita ownership of agricultural machinery power (kW/person) | -0.778 | -0.326 | 0.065 | -0.009 | 0.055 |
| Secondary industry gross regional product growth rate (%) | -0.057 | -0.257 | 0.868 | 0.039 | -0.134 |
| Percentage of social workers in the secondary industry (%) | 0.913 | -0.160 | -0.081 | -0.146 | 0.022 |
| Sales profit rate of industrial enterprises above the scale (%) | -0.203 | -0.157 | 0.247 | 0.021 | 0.775 |
| Tertiary sector gross regional product growth rate (%) | -0.172 | 0.154 | 0.748 | -0.039 | 0.258 |
According to Table 2, it can be seen that each principal component has different loading coefficients on different indicators, indicating that they reflect other aspects of the urban economic vitality. Therefore, according to the magnitude of explanatory degrees, we summarize the principal components as "manufacturing and people's life factor (F1)", "service industry and government management factor (F2)", "industrial economic growth rate factor (F3)", "urban development potential factor (F4)" and "primary and secondary industry efficiency factor (F5)".

3.2. Comprehensive Score and Ranking of Economic Vitality in Yangtze River Delta Region

In PCA analysis, the weight of each indicator for each principal component can be determined by the factor score coefficient matrix. The principal components are expressed as a linear function of the indicators to obtain each factor score for each city. According to the method in 2.3, the factor scores of each principal component and the factor variance contribution rate of each city were combined to calculate the composite score of each city. The magnitude of the composite score was used to quantify the economic vitality of the city, and the results are shown in Table 3.

Table 3. Comprehensive score and ranking of industrial economic vitality of cities in the Yangtze River Delta region

| Urban       | Overall Score | Overall Ranking | Urban       | Overall Score | Overall Ranking |
|-------------|---------------|-----------------|-------------|---------------|-----------------|
| Shanghai    | 1.180         | 1               | Yangzhou    | 0.101         | 16              |
| Nanjing     | 0.944         | 2               | Taizhou     | -0.001        | 17              |
| Suzhou      | 0.889         | 3               | Zhoushan    | -0.013        | 18              |
| Wuxi        | 0.685         | 4               | Chuzhou     | -0.110        | 19              |
| Hangzhou    | 0.676         | 5               | Xuancheng   | -0.115        | 20              |
| Ningbo      | 0.575         | 6               | Jinhua      | -0.116        | 21              |
| Jiaxing     | 0.499         | 7               | Zhenjiang   | -0.183        | 22              |
| Changzhou   | 0.491         | 8               | Anqing      | -0.358        | 23              |
| Huzhou      | 0.402         | 9               | Yancheng    | -0.401        | 24              |
| Hefei       | 0.377         | 10              | Chizhou     | -0.501        | 25              |
| Shaoxing    | 0.328         | 11              | Tongling    | -0.842        | 26              |
| Ma Anshan   | 0.322         | 12              |             |               |                 |
| Wuhu        | 0.277         | 13              |             |               |                 |
| Nantong     | 0.180         | 14              |             |               |                 |
3.3. Spatial pattern of urban economic vitality

In this paper, the spatial distribution pattern of urban economic vitality in the Yangtze River Delta region is shown in Figure 2 using the map space visualization method and the hot spot analysis (Getis-Ord Gi*) method. As can be seen from the figure, cities in the Yangtze River Delta region with high economic vitality are mainly located in southern Jiangsu Province (Nanjing, Changzhou, Wuxi, Suzhou), northern Zhejiang Province (Hangzhou, Huzhou, Jiaxing, Shaoxing, Ningbo), eastern Anhui Province (Hefei, Maanshan, Wuhu) and Shanghai. These cities are adjacent to each other, reflecting a spatial aggregation characteristic of the economic vitality. According to the right panel of Figure 2, the southern part of Jiangsu Province, the northern part of Zhejiang Province, the southeastern part of Anhui Province and Shanghai Municipality form the hotspots where the economic vitality of high-city industries gather. North-central Anhui Province and northern Jiangsu Province, on the other hand, collectively form the cold spot area where the economic vitality of low urban industries gather. In central Jiangsu Province, southern Anhui Province and southern Zhejiang Province, there is no significant agglomeration of urban economic dynamism.

Figure 2. Urban economic vitality composite score and hotspot distribution.

4. Conclusions

This paper examines the characteristics of economic vitality in the Yangtze River Delta economic belt under the perspective of regionalization. The research results show that the economic development of the Yangtze River Delta region has certain internal unevenness, and strengthening industrial cooperation and complementary advantageous resources among cities in the region is a favorable way to promote its sustainable development. Specific findings include:

1. Eighteen indicators involving eight aspects are constructed, including comprehensive economic strength, economic vitality of primary, secondary and tertiary industry, degree of openness, talent and technology level, etc.
2. Five principal components of urban economic vitality were obtained; they are manufacturing industry and people's life factor, service industry and government management factor, industrial economic growth rate factor, urban development potential factor and primary and secondary industry efficiency factor.

3. By using the spatial hot spot analysis method, the hot spots of industrial economic vitality of cities in the Yangtze River Delta region are southern Jiangsu Province, northern Zhejiang Province, southeastern Anhui Province and Shanghai City; the cold spots are north-central Anhui Province and northern Jiangsu Province.

Limited by the data and method constraints, this paper selects prefecture-level cities as the unit to carry out the research on economic vitality. In the future, the sub-belt differences of urban economic vitality and the differences of countries at different development stages can be explored through the analysis of different economic belts in China and abroad. In addition, the assessment of vitality can be extended from the economic dimension to social, cultural, aspects based on this research idea, fully expanding the connotation and extension of urban vitality.

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