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Evaluation of the provincial competitiveness of the Chinese high-tech industry using an improved TOPSIS method

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ABSTRACT

Evaluation of the competitiveness of high-tech industry is a technical decision-making issue involving multiple criteria. It is also a practical path to promote a country's competitiveness. However, the competitiveness indicators in high-tech industry often act and react upon one another. Moreover, different dimensions and indicator weights also affect the evaluation results. In this paper, the Mahalanobis distance is used to improve the traditional technique for order preference by similarity to ideal solution (TOPSIS). The improved TOPSIS method has the following properties: (1) an improved relative closeness which is invariant after non-singular linear transformation, and (2) the weighted Mahalanobis distance is the same as the weighted Euclidean distance when the indicators are uncorrelated. The new method is applied to evaluate the competitiveness of the Chinese high-tech industry using data from 2011. Consideration of the correlation between indicators improves the evaluation results (in terms of sorting and closeness) to a certain extent compared to the traditional TOPSIS method. The top five provinces are: Guangdong, Jiangsu, Shanghai, Beijing, and Shandong. This finding reflects the practical linkage among provinces and softens the closeness value, consistent with reality.

1. Introduction

High-tech industries, which are based on intellectually-intensive technologies and integrate multidisciplinary technological achievements, are the strategic leading industries of the Chinese national economy. The statistical range of the Chinese high-tech industry includes five categories: aerospace manufacture, electronics and communications equipment manufacture, computer and office equipment manufacture, pharmaceuticals and medical equipment manufacture, as well as instrument and meter manufacture. High-tech industries are important because they drive the world's economic layout, political affairs, and military competition. Development of high-tech industry has become a concrete expression of the strength of a nation or region (Lu & Yu, 2010). Since the implementation of 'Torch Plan' (the national high-tech industrial development plan), the Chinese high-tech industry has made remarkable achievements. The evaluation of the competitiveness of provincial high-tech industry has become the basis for decision-making for the national high-tech industrial layout. Moreover, such an evaluation broadens our understanding of the geographical distribution and development status of the Chinese high-tech industries and provides rational suggestions for the promotion and planning of them.

Liang (2011) proposed that high-tech industries with high investment, high growth, high yield, and high risk should have the following general characteristics. They have (1) a high degree of uncertainty, (2) high-value with regard to human resources, and (3) a highly correlated value of intangible assets. Studies on the evaluation of the competitiveness of Chinese provincial high-tech industries have attracted the attention of many researchers. Chen and Sun (2011) used factor and cluster analyses to evaluate the competitiveness of Chinese provincial high-tech industry. They also provided a classification system while establishing evaluation indicators that included the level of human capital investment, the level of project organization investment, the level of capital investment, the level of industrial output, and the level of efficiency.

Wu and Li (2008) introduced the technique now traditionally used to evaluate the competitiveness of high-tech industry called the technique for order preference by similarity to ideal solution (TOPSIS) method. They applied it to 31 Chinese provincial administrative regions and built up the concepts of core competitiveness *within* the industry (industrial core technical capabilities, industrial core production capacity, and industrial core market power) and core competitiveness *outside* the industry (industrial policy environment, industry technical support environment, and industry incubator environment). They sorted the top six regions

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as follows: Beijing, Guangdong, Shanghai, Zhejiang, Shandong, and Jiangsu. Later, Zheng, Shi, and He (2010) made a comprehensive competitiveness evaluation of the high-tech industry in Fujian Province. The proposed evaluation indicators included technological innovation competitiveness, economic development competitiveness, financial benefit competitiveness, industrial cluster competitiveness, and energy saving and environmental protection competitiveness. Chen (2010) considered the use of data mining methods (specifically k-means clustering) to evaluate the competitiveness of Chinese high-tech industries. Based on this method, the top six regions in terms of high-tech industry competitiveness were found to be: Guangdong, Jiangsu, Beijing, Shanghai, Tianjin, and Liaoning.

Numerous studies on the evaluation of Chinese provincial high-tech industrial competitiveness have been conducted, but two issues remain unclear: (1) From the perspective of evaluation object characteristics, the differences among the provinces in economy, geography, etc. have made the development of high-tech industries unbalanced. However, the inter-provincial economic circle drives the linkage between the high-tech industries in different provinces, which is a prominent feature of provincial high-tech industry. Most studies on the competitiveness of Chinese high-tech industry have been aware of this unbalanced status quo. For example, Wang and Yu (2004) used principal component analysis to conclude that the competitiveness of Chinese high-tech industry in western regions is weaker than in the eastern regions and that the gap is gradually increasing. Wang (2007), Liang, Li, Tang, and Zhao (2007) and Sun, Xiong, and Zheng (2010) introduced empirical methods and also obtained the result that the development in high-tech industry is very unbalanced among different regions. They also found that the size of the imbalance is increasing. Although this imbalance problem is recognized, it is merely at the phenomenon level at present. Also, the majority of existing evaluation methods assume that the samples are independent and identically distributed. An imperative issue is how to take the index linkage problem into consideration through method design and thus to improve the scientific basis of the decision-making. (2) From the perspective of evaluation method, consensus has not been reached on the true evaluation of the competitiveness results for Chinese provincial high-tech industry. The differences in evaluation index systems may partly explain this situation, but more differences are found in terms of the evaluation method itself. Although the existing evaluation methods are based on the characteristics of the collected data, they all have advantages and disadvantages. TOPSIS and fuzzy methods do not consider the correlation between evaluation indicators, which often results in information overlap. Secondly, factor analysis all too easily makes the economic significance of the main components ambiguous when the factor loadings of the core variables are small. In addition, analytic hierarchy processes (AHPs) can hardly avoid deviation in subjective factors.

As a typical, uncertain multiple-criteria decision-making (MCDM) problem, evaluation of the competitiveness of the Chinese high-tech industry includes mutual interference among evaluation indicators. Developing a set of evaluation tools suitable for this kind of problem has considerable theoretical and practical significance. The TOPSIS method is an important MCDM tool. It is simple but comprehensive when applied to the evaluation of a MCDM problem. Also, the target weight is reflected in the integrated program (Boran, Genc, Kurt, & Akay, 2009; Deng, Yeh, & Willis, 2000). However, the traditional TOPSIS method, which is based on the Euclidean measure of distance to make decisions, takes the indicators as independent and do not perturb each other. This approach suffers information overlap and either overestimates or underestimates the indicators which take slack information. Considering the correlation between the competitiveness evaluation indices for the Chinese high-tech industry, we propose here an improved TOPSIS method. The method uses the concept of Mahalanobis distance to determine the distance to the ideal solution and the negative solution. The Mahalanobis distance is based on the sample covariance matrix and can solve the problem of the relevance among indicators as appropriate. This paper also provides proofs of the properties of the improved TOPSIS method and discusses its applicability through evaluation of results pertinent to the Chinese high-tech industry.

The remainder of this paper is organized as follows. Section 2 introduces the classic TOPSIS method. Section 3 uses the Mahalanobis distance to modify the traditional TOPSIS method according to the characteristics of the decision making process. It also derives the properties of the improved method. Section 4 applies the improved method to evaluate the competitiveness of the Chinese high-tech industry and analyze the evaluation effect according to the actual situation. Finally, conclusions and future work are given in the Section 5.

2. The traditional TOPSIS method

TOPSIS is an uncertain MCDM technology first proposed by Hwang and Yoon (1981). TOPSIS orders the criteria according to the distances from the object to the ideal and the negative solutions. The TOPSIS method can be summarized as follows.

Suppose there are m alternatives $A_1, A_2, \ldots, A_m$ and n decision criteria/attributes $C_1, C_2, \ldots, C_n$. Let x_{ij} denote the criteria/attribute value of A_i on C_j ($i = 1,2,\ldots,m; j = 1,2,\ldots,n$). All the values together form a decision matrix $\mathbf{X} = (x_{ij})_{m\times n}$. The decision matrix can be standardized in the form

$$R = (r_{ij})_{m\times n}, \tag{1}$$

where $r_{ij} = x_{ij}\left(\sum_{i=1}^{m} x_{ij}\right)^{-1/2}$.

The ideal solution $\mathbf{S}^+$ and the negative ideal solution $\mathbf{S}^-$ (also called the 'anti-ideal solution') are then determined:

$$\mathbf{S}^+ = \{s_1^+, s_2^+, \ldots, s_n^+\}, \quad \mathbf{S}^- = \{s_1^-, s_2^-, \ldots, s_n^-\}. \tag{2}$$

For the benefit index C_j:

$$s_j^+ = \max\{r_{ij} | 1 \leqslant i \leqslant m\}, \quad s_j^- = \min\{r_{ij} | 1 \leqslant i \leqslant m\};$$

and for the cost index C_j:

$$s_j^+ = \min\{r_{ij} | 1 \leqslant i \leqslant m\}, \quad s_j^- = \max\{r_{ij} | 1 \leqslant i \leqslant m\}.$$

We calculate the Euclidean distances of each alternative to the positive ideal and negative ideal solutions. The distance between alternative A_i and the positive ideal solution is:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (s_j^+ - r_{ij})^2}, \quad i = 1,2,\ldots,m. \tag{3}$$

The distance between alternative A_i and the negative ideal solution is:

$$d_i^- = \sqrt{\sum_{j=1}^{n} (s_j^- - r_{ij})^2}, \quad i = 1,2,\ldots,m. \tag{4}$$

Finally, we calculate the relative closeness of each alternative to the ideal solution:

$$c_i = \frac{d_j^-}{d_j^- + d_j^+}, \quad i = 1,2,\ldots,m. \tag{5}$$

The alternatives are ranked based on their relative closeness. A higher c_i value indicates that A_i is a better alternative, and *vice versa*.

TOPSIS simultaneously considers information about the positive and negative ideal solutions. Moreover, the calculation is simple,