

A Multi-model Based Approach for Measuring Operational Efficiency in Smes: Theory Construction and Empirical Analysis

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Abstract: Small and medium-sized enterprises (SMEs) play a pivotal role in China's economy, but the issue of their operational efficiency has attracted much attention. This study aims to construct a method to measure the operational efficiency of SMEs based on DEA-PCA model. Through theoretical elaboration, model construction, indicator selection, empirical analysis, and result discussion, it reveals the characteristics and influencing factors of SMEs' operational efficiency, and provides theoretical basis and practical guidance for enterprises to improve their operational efficiency. The study shows that this method can effectively overcome the subjectivity of the traditional DEA method in the selection of indicators, and provide strong support for the accurate assessment of the operational efficiency of SMEs.

Keywords: SMEs (Small and Medium-sized Enterprises), Operational Efficiency, DEA-PCA Model, Indicator System, Efficiency Improvement.

1. Introduction

1.1. Background

As an important part of China's economy, SMEs play an irreplaceable role in promoting economic growth, employment and innovation [1]. However, in the process of rapid development, SMEs are faced with many challenges, such as fierce market competition, limited resources, and uneven management levels, etc., which have led to large differences in their operational performance, and the problem of operational efficiency has gradually become a key factor restricting the sustainable development of SMEs [2].

1.2. Status and Purpose

At present, there are relatively few studies on SME efficiency evaluation at home and abroad, and the traditional DEA method, when applied to the measurement of SME operational efficiency, has the problem of strong subjectivity in the construction of the index system, which makes the accuracy and reliability of the results questionable [3]. This study aims to fill this research gap by constructing a DEA-PCA model, combining data envelopment analysis and principal component analysis, and proposing a more scientific and objective method to measure the operational efficiency of SMEs, with a view to accurately evaluating the operational efficiency of SMEs, revealing its influencing factors, and providing targeted suggestions for enterprises to improve their efficiency.

2. Theoretical Foundation and Model Construction

2.1. Data Envelopment Analysis (DEA) Theory

Data Envelopment Analysis (DEA) is a nonparametric efficiency evaluation method based on linear programming, which determines the relative efficiency of multiple Decision Making Units (DMUs) by constructing a production frontier that compares their inputs and outputs to determine the relative efficiency of each DMU [4]. The DEA model

assumes that each DMU is pursuing the maximization of efficiency, and evaluates the efficiency of DMUs by comparing the gap between the actual output and the maximum possible output Level [5].

The DEA model used in this study is as follows:

$$\left\{ \begin{array}{ll} \max & z \\ \text{s.t.} & \sum_{j=1}^n \lambda_j x_j \leq x_0 \\ & \sum_{j=1}^n \lambda_j y_j \geq zy_0 \\ & \lambda_j \geq 0, j = 1, 2, \dots, n \end{array} \right.$$

Where j_x and j_y are the input and output variables of the j th DMU, respectively, while x_0 and y_0 are the input and output variables of the target DMU, respectively. The optimal value of this linear programming problem is not less than 1, which indicates the proportion of target DMUs whose outputs can be further expanded given the inputs, and its reciprocal is the value of the output efficiency index of the target DMU.

2.2. Principal Component Analysis (PCA) Theory

Principal Component Analysis (PCA) is a multivariate statistical analysis method, the core idea of which is to transform multiple correlated variables into a small number of uncorrelated composite variables, i.e., principal components, by linear transformation of the original data. PCA aims to reduce the dimensionality of the data and simplify the structure of the data while retaining most of the information of the original data, so that it is easier to analyze and interpret the data [6].

To the subjectivity of the traditional DEA method in constructing the efficiency indicator system, this study introduces PCA to downsize all possible indicator systems. Through PCA, the principal components reflecting the main information of the original indicators can be extracted, avoiding the deviation of the efficiency evaluation results due to the subjectivity of the indicator selection, thus improving

the accuracy and reliability of the efficiency evaluation [7].

2.3. Construction of the DEA-PCA Model

In this study, the DEA-PCA model was constructed by combining DEA and PCA. First, the DEA model is utilized to calculate the efficiency value of each DMU to obtain multiple efficiency indicators. Then, PCA is applied to downsize these efficiency indicators, and the first few principal components whose cumulative contribution rate reaches a certain level (e.g., in this study, the cumulative contribution rate is greater than 94% and the eigenvalue is greater than 1) are selected, through which the information of all the efficiency indicators is comprehensively reflected. Finally, based on the results of principal component analysis, the comprehensive efficiency value of each DMU is calculated, so as to realize a comprehensive and objective assessment of the operational efficiency of SMEs.

3. Construction of the Indicator System

In order to accurately assess the operational efficiency of SMEs, this study takes into account the operational characteristics of SMEs and the availability of data, and selects the company's operating revenue, independent visitors, number of employees, operating expenses, and total assets as alternative indicators. Operating revenue is a direct reflection of the company's operating results, reflecting the profitability of the company; independent visitors as a measure of the company's market influence and potential customer scale of the indicators, for the Internet-related industry SMEs is particularly important; the number of employees and the total assets is an important aspect of the company's inputs, which represents the investment of human and material resources, respectively; operating expenses cover the costs of the company's day-to-day operations. Operating expenses cover the costs of daily operation of the enterprise, and can partially replace the unavailable data such as R&D expenses.

Table 1. Input and output parameters

Coding	Attribute	Name (Unit)
A	Input	Operating expenses (100 million)
B	Input	Total assets (100 million)
C	Input	Number of employees (10,000)
1	Output	Unique visitors (10,000)
2	Output	Operating revenue (100 million)

According to the main types of business of SMEs, the sample enterprises are categorized into three types, including online commerce, media portals and social networks. Through analyzing the data of the sample enterprises, it is found that there are significant differences in the indicators of different types of enterprises, which reflects the diversity of SMEs in terms of resource allocation and operation modes. The categorization of the sample firms helps to study the operational efficiency characteristics of different types of firms in depth, and provides the basis for targeted efficiency improvement strategies.

4. Empirical Analysis

4.1. Empirical Analysis

Focusing on the above five indicators of SMEs, the different permutations and combinations between the input and output indicators form 21 scenarios, corresponding to 21

CCR output-oriented efficiency models, thus generating 21 DEA efficiency indicators. According to the composition of the output indicators in the CCR models, all DEA models are divided into three categories: the first category of models contains both independent visitors and business revenue output indicators, which can comprehensively measure the market influence and profitability of the enterprise; the second category of models contains only independent visitors indicators, which focuses on evaluating the market-oriented efficiency of the enterprise; and the third category of models contains only business revenue indicators, which is mainly used to measure the revenue-oriented efficiency of the enterprise. The third type of model contains only operating income indicator, which is mainly used to measure the revenue-oriented efficiency of enterprises.

Table 2. 21 CCR output-oriented efficiency models

Type	I	II	III	IV	V	VI	VII
One	A1	B1	C1	AB1	AC1	BC1	ABC1
Two	A2	B2	C2	AB2	AC2	BC2	ABC2
Three	A1	B1	C1	AB1	AC1	BC1	ABC1
	2	2	2	2	2	2	2

In terms of inputs, all 21 models can be divided into 7 categories, each of which possesses the same inputs.

The differentiation of efficiency indicators obtained by solving different models varies. The comprehensive utilization of all efficiency models can reflect the relative strengths and weaknesses of enterprises in different aspects more comprehensively and avoid the one-sidedness of single model assessment. Categorizing the 21 models from the input perspective, with each type of model having the same combination of input variables, helps to further analyze the impact of input elements on enterprise efficiency.

4.2. Principal component Analysis of DEA Efficiency

The 21 DEA efficiency indicators were subjected to principal component analysis, and the first three principal components (PC1, PC2, PC3) were selected to represent the information of all the efficiency indicators according to the criteria that the cumulative contribution rate is greater than 94% and the eigenvalue is greater than 1. These three principal components realize the effective dimensionality reduction of high-dimensional data while retaining the original data information.

Based on the results of principal component analysis, the principal component value of each SME is calculated, and the eigenvalues are used to weight the principal component values to obtain the comprehensive efficiency value of each enterprise. This comprehensive efficiency value integrates the information of multiple efficiency indicators, which can more accurately reflect the operational efficiency level of the enterprise and provide a unified standard for the efficiency comparison between enterprises.

4.3. Analysis of the Ways in Which the Efficiency of Smes is Realized

Combining the principal components of the DEA efficiency indicators, the operation types of the sample SMEs are classified. By analyzing the correlation between the principal components and the output indicators, it is found that PC1 mainly reflects the efficiency in terms of

independent visitors, which reflects the market influence of the enterprise; PC2 mainly reflects the efficiency in terms of operating income, which represents the income-generating capacity of the enterprise; and PC3 focuses on characterizing the coordinating ability of the enterprise in dealing with the relationship between market influence and income-generating capacity. Based on their scores on the three principal components, SMEs are categorized into different types, with significant differences in their main business and operational focus.

The study finds that media portal enterprises are outstanding in terms of market influence, with high PC1 scores; online business enterprises have an advantage in terms of revenue-generating capacity, with high PC2 scores; and social and other types of enterprises pay more attention to the coordination of market influence and revenue-generating capacity, with relatively high PC3 scores. This indicates that different types of SMEs have their own characteristics in terms of efficiency realization, and should formulate corresponding development strategies and efficiency improvement measures according to their own characteristics.

5. Results and Recommendations

The DEA-PCA model constructed in this study shows significant advantages in the operational efficiency measurement of SMEs. By combining DEA and PCA, it effectively solves the problem of subjectivity in the construction of the indicator system of traditional DEA method and improves the accuracy and reliability of efficiency evaluation. The empirical analysis results show that different types of SMEs have differences in operational efficiency and efficiency realization methods, which provides a basis for enterprises to accurately locate their own problems and formulate personalized development strategies.

SMEs should rationally allocate human, material and financial resources according to their own business types and operational characteristics. For example, media portals can invest more in content creation and marketing to further enhance their market influence; online commerce enterprises should focus on optimizing supply chain management and customer service to improve their revenue-generating capacity; and social and other types of enterprises need to balance the relationship between market expansion and profitable growth and improve the efficiency of resource utilization.

Strengthen the internal management of enterprises and improve operational efficiency. Establish a scientific

decision-making mechanism and rationally plan enterprise development strategies. At the same time, focusing on data analysis and mining, using the measurement methods proposed in this study to regularly assess the operational efficiency of enterprises, identify problems in a timely manner and take targeted measures to improve them.

Although this study has achieved some results, there are still some limitations. For example, the number of sample enterprises may be limited and cannot fully represent the whole group of SMEs; although the indicator system has been carefully selected, there may still be some influencing factors that have not been taken into account. Future research can further expand the sample size to cover SMEs in more industries and regions, and at the same time continuously improve the indicator system by introducing more indicators reflecting the innovation ability and social responsibility of enterprises, so as to assess the operational efficiency of SMEs in a more comprehensive way.

In summary, the SME operational efficiency measurement method based on DEA-PCA model proposed in this study provides a new idea and tool for SME operational management, which has important theoretical and practical significance.

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