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Investigation on the Impact of the Development of Digital Economy on the Innovation Efficiency of Chinese Small and Medium-sized Board Listed Enterprises

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Abstract: With the development of the Digital Economy (abbreviated as DE for convenience), research on the impact of Innovation Efficiency (abbreviated as IE for convenience) on Chinese Small and Medium-sized Board Listed Enterprises (abbreviated as SMBLE for convenience) is constantly improving. The design of IE impact models for Chinese SMBLE based on DEA (Data Envelopment Analysis) is becoming increasingly important. In the entire research on the impact of IE, how to construct key indicators of IE for listed companies is currently a key issue that needs to be urgently addressed. Through the research on DE and Small and Medium-sized Board Enterprises (abbreviated as SMBE for convenience) innovation, as well as the analysis of IE index system of listed enterprises, with the help of the application of DEA and the definition of basic concepts, combined with simulation and questionnaire experiments, the following conclusions were drawn based on the data results: On the basis of the development of the DE, among the six selected factors influencing IE, the enterprise IE after adjusting the development level of the DE had the most significant improvement effect, increasing by 18.2%. The IE improvement effect after the adjustment of technical efficiency and scale efficiency was good, with an increase of 14.7% and 13.8%, respectively. In the questionnaire survey, adjusting the internal governance structure of enterprises could help improve the IE of Small and Medium-sized Enterprises (SME), indicating that the development level of the DE, technological efficiency, scale efficiency, and internal governance structure of enterprises had a certain impact on IE.

1. Introduction

The development of the DE and the progress of innovative technology are constantly accelerating, and people's research and discussion on it has entered a new stage. The main objective of this paper is to design the index system of IE of listed enterprises, and the application of DEA and the definition of basic concepts. Therefore, it is very important to study the impact of DE development on IE of China's SMBLE.

There are many research theories on the influencing factors of different IE. Based on the increasing requirements of SMBLE for technological and management innovation, Shoulin L hoped to find the reasons and solutions for the low IE of listed enterprises using DEA method. The results indicated that for enterprises that were not at the forefront of production, it was necessary to improve IE from three aspects: government, industry associations, and enterprises [1]. Fang M used DEA-Malmquist model to study the efficiency and changes of the overall technological innovation activities of SME in Hubei Province in the last decade, and found that the development of the DE slightly reduced total factor productivity, and the efficiency of the overall technological innovation activities was low. In addition, based on dozens of listed companies in Hubei Province as samples, the PSM (Propensity Score Matching) model was used to investigate the impact of government support on enterprise IE, and the results showed no significant positive impact [2]. Wang Y M established an innovation performance evaluation index system for energy-saving and environmental protection listed companies, and used a three-stage DEA model to evaluate the IE of all energy-saving and environmental protection listed companies in a certain region. The results showed that after stripping off environmental variables and statistical noise, the technical efficiency and scale efficiency of most energy-saving and environmental protection listed companies improved, while the pure technical efficiency decreased slightly. The return on scale of most listed companies was increasing, and environmental variables constrained the IE of listed companies [3]. Against the backdrop of changes in economic development caused by immigration reform in the United States, GGD A used the DEA model to analyze the factors influencing innovation led by technical talents in listed companies, inferring that enterprise innovation might bring spillover effects to non-technical sectors. The issue of wage gap had an important relationship with technology research and development investment departments, thus having a significant impact on the efficiency of technology innovation [4]. Atta Mills EFE attempted to evaluate the impact of IE and its micro level drivers in the context of a globalized DE. He first considered the two growth stages of innovation related activities experienced by 138 listed SMBE in China, and then proposed a predictive difference analysis model. In addition, panel regression method was used to study the influencing factors of IE. The results indicated that listed companies were generally inefficient in innovation [5].

The combination of China's DE and the development of SMBLE has prompted the corporate sector to re study the factors influencing IE [6]. The above uses various research theories and methods to effectively discuss the impact of enterprise innovation on the technology sector, but lacks some empirical validation analysis.

The analysis of research related to the DE and innovation of SME in China is a major focus of this paper. In this article, based on the discussion and research on the IE indicator system of listed enterprises, and combined with simulation and questionnaire survey experimental analysis, a DEA based IE impact model for Chinese SMBLE was constructed. The final results showed that the degree of DE development, technological efficiency, scale efficiency, and internal governance structure of enterprises had a certain impact on IE.

2. System Function Evaluation

2.1 Investigation on the Relationship between DE and Innovation of SMBE

The new generation of information technology promotes the vigorous development and industrial transformation of China's DE industry. This guides the new development of digital industrialization and new forms of industrial digitization, achieving a new economic form of productivity development [7-8]. SME are a special cluster of SME set up by Shenzhen Stock Exchange to encourage independent innovation. Companies in the sector generally have the

characteristics of rapid income growth, strong profitability and active innovation performance [9-10]. According to the relevant theoretical achievements of innovation influencing factors, the existing research on the DE and innovation of SMBE is shown in Table 1:

Table 1: Research results on DE and enterprise innovation

Author	Research Results
Han X F	The development of digital communication technologies can effectively bridge the innovation gap between regions
Huang Q H	It can promote innovation efficiency of firms by reducing their transaction costs
Guo J T, Luo P L	Internet technology development in China is found to be conducive to technological total factor productivity improvement
Li E	Based on A-share listed companies show that the digital economy promotes the digital transformation of enterprises to improve their innovation efficiency
Jiang D C , Pan X W	The study points out that the development of digital economy drives the improvement of corporate innovation performance

The improvement of IE of listed enterprises and the development of technology all factor production can be achieved mainly by reducing enterprise transaction costs, developing digital communication technology and promoting digital transformation of enterprises [11-12]. The essential meaning of enterprise IE is the ratio of enterprise innovation input to enterprise innovation output. Therefore, the improvement of IE of listed enterprises can be divided into two situations: One is that the enterprise innovation input is lower under the given innovation output, and the other is that the enterprise innovation output is more under the given innovation input [13-14].

2.2 Index System for IE of Listed Enterprises

Due to the existing literature on the relationship between the DE and corporate innovation mainly focusing on the micro and macro perspectives of industry innovation and regional innovation in the development of the DE, the IE indicator system for SMBLE has also been established using the two perspectives of industry innovation and regional innovation [15-16]. Industry innovation is based on regional innovation, so the analysis of the IE indicator system for listed companies is completed according to the concept of digital leading industry innovation, as shown in Figure 1:

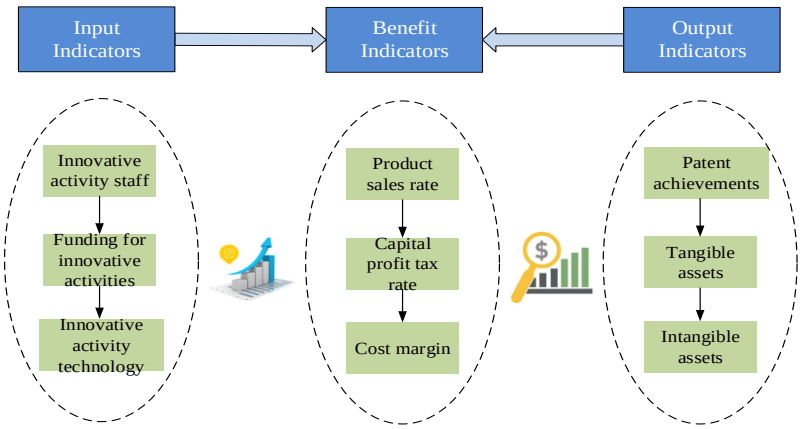

Figure 1: Index system for IE of listed enterprises

In summary, the IE indicator system of listed enterprises mainly consists of three major links: input indicators, output indicators, and benefit indicators. Among them, benefit indicators are economic indicators that comprehensively reflect the economic benefits of enterprises on the basis of innovation input and output [17-18]. The input indicators include innovation activity personnel, funds, and technology related elements, while the output indicators consist of professional achievements, tangible assets, and intangible assets. Based on SMBLE, optimizing the IE indicator system is of great significance [19-20].

3. Overall System Design

3.1 Data Envelopment Evaluation

DEA is generally used to measure the production efficiency of enterprise decision-making departments. The main goal is to establish a linear programming model, which is expressed as the ratio of output to input. The traditional Linear programming model is composed of multiple input indicators and one output indicator, but many practical problems are composed of multiple input indicators and multiple output indicators. DEA can fully meet these requirements. Some basic concepts of DEA are shown in Table 2:

Table 2: The basic concept and content of data envelopment method

Basic Concepts	Note
Technical efficiency	Refers to the ratio of actual output to ideal output while keeping the inputs of the decision unit constant
Payoffs for scale	If the factor of production is doubled, and if the output is also doubled, it is called a constant payoff to scale
DEA strongly efficient	The quantity of any one input cannot be reduced unless the quantity of output is reduced
DEA weakly efficient	The quantity of each input cannot be reduced in equal proportion unless the quantity of output is reduced

In addition, the production frontier is also an important part of DEA modeling, which means that for a given production factor and output price, the enterprise selects the optimal combination of factor inputs and output, that is, the combination with the minimum input cost and the maximum output benefit.

3.2 Construction of Enterprise Innovation Model Based on DEA

According to the relevant research and analysis on DE and innovation of SMBE in China, and combined with the design of IE indicator system of listed enterprises and the application and basic concept definition of DEA, the enterprise innovation model based on DEA is divided into indicator system module, BCC (Business Cloud Customer) module, similar SFA (Stochastic Frontier Approach) analysis module and data adjustment module. Therefore, the construction of the IE impact model for Chinese SMBLE based on DEA is shown in Figure 2:

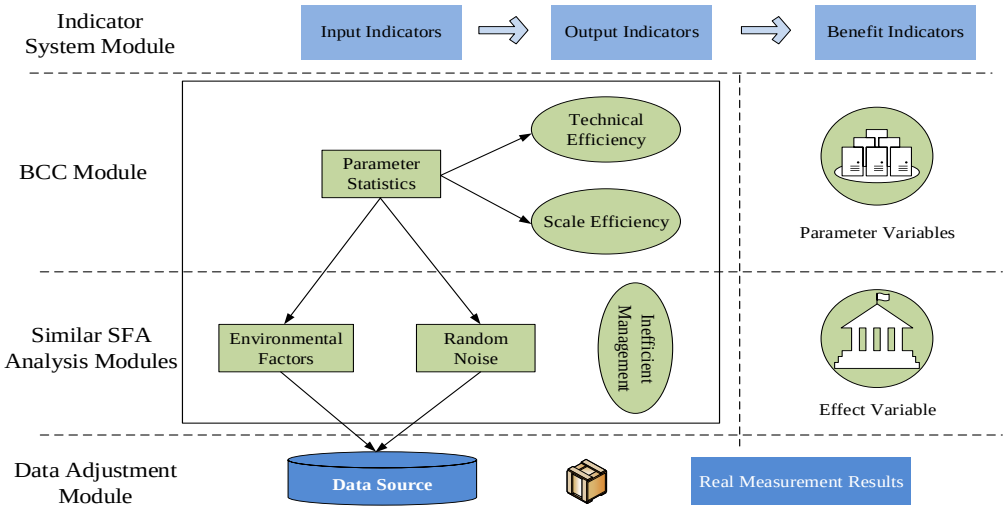

Figure 2: Enterprise innovation model based on DEA

When analyzing the impact of DE development on the IE of Chinese SMBLE, the establishment and calculation of the financial option valuation CRR (Cox Ross Rubinstein) model is an important step in verifying the impact of enterprise IE. Assuming there are m input indicators and n output indicators, the CRR model calculation is shown in Formula 1:

$$MinZ_{kD} = \alpha \tag{1}$$

$$s.t.\begin{cases} M\lambda + S = \alpha M_k \\ N\lambda - S = N_k \end{cases} \tag{2}$$

Among them, α and λ represent decision variables; S represents the relaxation variable; M and N represent the $m \times n$ matrix of input and output indicators; the subscript k represents the k-th input or output indicator.

4. Experimental Results and Evaluation

After completing the design of the IE impact model for Chinese SMBLE based on DEA, in order to test the actual effectiveness of the model applied to specific SMBLE, experiments were conducted through simulation experiments and questionnaire surveys.

This experiment selected six sample parameters that might have an impact on the IE of enterprises, named DE development level A, internal governance structure B, technical efficiency C, scale efficiency D, cost constraint E, and government support F. These parameters were used as the dataset for training and testing. The Monte Carlo method was used to test and analyze the data for 400 rounds in a certain period of time, and the changes in the IE of enterprises before and after the adjustment of these variables were obtained. The IE results after adjusting the innovation model of Chinese SMBLE based on DEA are shown in Figure 3:

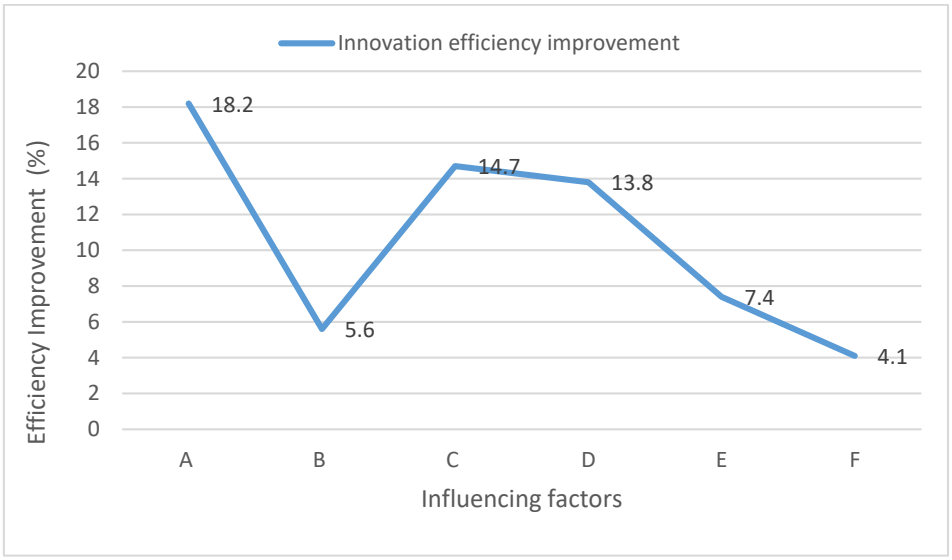

Figure 3: Improvement results of IE after adjusting the enterprise innovation model

Among them, the blue line represents the improved IE of Chinese SMBLE after adjusting the innovation model based on DEA. It could be seen that after adjusting the development level of the DE (A), the improvement effect of enterprise IE was the most significant, increasing by 18.2%. The improvement effect of IE after adjusting for technical efficiency (C) and scale efficiency (D) was good, with an increase of 14.7% and 13.8%, respectively. The improvement effect of the internal governance structure (B), cost constraints (E), and government support (F) of enterprises was all below 8%, which could be considered almost unrelated. This indicated that the development level of the DE, technological efficiency, and scale efficiency were the influencing factors of IE.

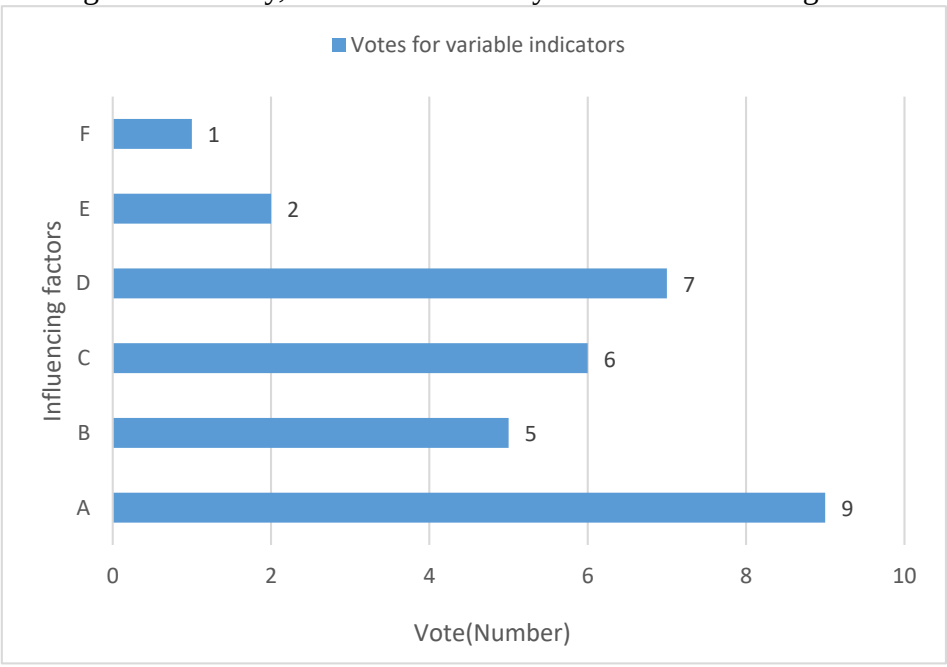

Figure 4: Voting results of variables obtained after questionnaire survey

After discussing the above impact results, the questionnaire survey experiment was continued. Ten technical department heads of SMBLE were selected, and their evaluation of the importance of these six influencing factors was investigated. The three indicator variables that had the greatest impact on the IE of the enterprise were selected, and the vote status of each variable was finally

counted. The survey results after investigation are shown in Figure 4.

Among them, the blue column represents the vote results of the impact indicators of the innovation model of Chinese SMBLE based on DEA. It could be seen that the heads of the technology department unanimously believed that the degree of development of the DE (with a vote of 9) was a factor affecting the IE of enterprises, and technological efficiency (with a vote of 6) and scale efficiency (with a vote of 7) were also related. In empirical research, adjusting the internal governance structure of enterprises (with a vote of 5) could help improve the IE of SME. This indicated that the development level of the DE, technological efficiency, scale efficiency, and internal governance structure of enterprises were the influencing factors of IE.

5. Conclusions

In the context of the increasingly rapid development of the DE, a DEA based innovation model for Chinese SMBLE can be widely applied to analyze the factors affecting IE of various enterprises. Based on the research on DE and innovation of SMBE, this article constructed an innovation model of Chinese SMBLE based on DEA through the IE index system of listed enterprises, and conducted simulation experiments and questionnaire surveys on it. It was concluded that the development level of the DE, technological efficiency, scale efficiency, and internal governance structure of enterprises had a certain impact on IE. This article aimed to provide China with an innovation model design for SMBLE based on DEA through theoretical and empirical research. The selected variables affecting IE were few, and the application of DEA and the definition of basic concepts were not perfect. The discussion on the impact of DE development on IE of China's SMBLE in this paper still had many defects and deficiencies, which would be further improved in the future research.

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