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TR Equipment Manufacturing Enterprise Technology Innovation Performance Evaluation

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Abstract: The correct evaluation of enterprise technological innovation performance is the premise and foundation to improve the efficiency of enterprise innovation. This paper first puts forward the index system of enterprise technological innovation performance evaluation, then establishes the model of technological innovation performance evaluation, explores the quantitative evaluation of enterprise innovation performance by using the DEA method, and finally makes an empirical study on the technological innovation performance of the TR enterprise.

Keywords: Equipment manufacturing industry; Innovation performance; Data envelopment analysis

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1. Introduction

Innovation-driven industrial upgrading is an essential path for the development of the equipment manufacturing industry. As one of the traditional pillar industries in China, the equipment manufacturing sector plays a significant role in enhancing the country's independent innovation capabilities, securing a competitive edge in traditional industries, and addressing environmental and resource challenges. The development of the equipment manufacturing industry is influenced by numerous factors. For enterprises to make scientifically sound decisions regarding technological innovation, it is crucial to establish a proper evaluation system for technological innovation performance. As a direct tool for enterprises to anticipate future technological trends, technological innovation performance evaluation can assist companies in planning related decisions more scientifically. TR Enterprise, as a subsidiary of a state-owned enterprise, still faces issues in technological innovation management that need improvement. Currently, technological innovation performance plays a vital role in enterprises, making it necessary to establish a scientific and reasonable technological innovation evaluation system to promote the rational allocation of innovation resources within the company.

This paper takes the TR enterprise as the research object, takes the DEA method as the theoretical basis, and examines its technological innovation performance from the vertical dynamic evolution. Based on the characteristics of the equipment manufacturing industry, a multi-level technological innovation performance evaluation system is constructed. Based on the data envelopment analysis (DEA) model, the static and dynamic evaluation of the technological innovation performance of TR enterprises is carried out in combination with the time series span. It reveals the characteristics of "excellent technology and weak scale" of TR enterprise's technological innovation performance and clarifies the core bottleneck of insufficient scale efficiency. It is necessary to release technological potential through strategies such as capacity integration and supply chain optimization to lay an empirical foundation for the subsequent improvement path.

2. Related literature review

2.1. Research on enterprise technology innovation performance evaluation system

The equipment manufacturing industry is a unique concept under China's economic system. The term "equipment manufacturing enterprise" does not appear in foreign literature. They all focus on the performance evaluation of the manufacturing industry. The research on the performance evaluation system of the manufacturing industry in foreign countries is earlier than that in China, and the research results obtained are also more comprehensive and systematic. Hong *et al*. think that the evaluation of technological innovation ability should be based on the enterprise's investment ability, the ability to earn profits, the ability to resist risks and the ability of government support, and use the analytic hierarchy process to measure the technological innovation level of listed companies [1]. Sun establishes the evaluation index system of regional scientific and technological innovation ability by using the social network analysis method and software centrality analysis. The system includes four first-level indicators of scientific and technological innovation foundation, scientific and technological innovation input, scientific and technological innovation output, and scientific and technological innovation efficiency, 10 second-level indicators such as scientific and technological awareness and human input, and 32 related third-level indicators [2]. Sun focuses on the field of green technology innovation. Based on the positive and negative factors that can affect the green technology innovation of enterprises, the scholar constructs the corresponding index system [3]. The research object of Sun is the equipment manufacturing enterprises in Liaoning Province. From the perspective of technological innovation catalysis, the scholar divides it into three parts: Innovation catalytic investment, innovation catalytic operation, and innovation catalytic effect to formulate relevant innovation indicators, to provide theoretical basis and practical guidance for manufacturing industry to improve innovation ability in this field [4]. From the perspective of technology digitization, Zhang *et al*. constructs the evaluation index system of traditional enterprise digitization from four dimensions: Strategy, organization, business, and technology [5].

2.2. Research on the performance evaluation method of enterprise technological innovation

There are abundant research results on the construction of enterprise technological innovation performance evaluation indicators and the selection of evaluation methods in China. The selection of indicators is generally a multi-dimensional and multi-index synthesis. The evaluation methods are mainly studied from subjective and objective perspectives. In the research topic of technology sterilization, Li *et al*. involve the coupling innovation of technology management. For the innovation of this kind of management mode, scholars have adopted the evaluation method of constructing a grey language evaluation model, combining grey correlation analysis and using GLWAA for comprehensive calculation [6]. Through the combination of subjective and objective empowerment, Zhang Xiang studied the innovation and development of the equipment manufacturing industry through the analytic hierarchy process and the Delphi method [7]. Yang Chao and Li Lan have systematically sorted out the performance evaluation methods of technological innovation, and the analysis methods covered are more comprehensive. The qualitative method includes the peer review method and the Delphi method, and the quantitative analysis method includes the data envelopment method, statistical analysis method, and BP neural network method.

3. The content of index system of evaluation system

Different enterprises will set the performance evaluation indicators according to their industries. By sorting out the CNKI, Wanfang, Duxiu, and other databases, there are search results on 'equipment manufacturing enterprises,' 'data envelopment analysis,' 'innovation performance evaluation,' and 'financial performance evaluation.' It is found that domestic and foreign scholars usually use corporate assets and costs as input indicators and income and profits as output indicators. Combined with the characteristics of equipment manufacturing enterprises, the impact of indicators on performance should be fully considered when selecting indicators. At present, since China has not yet formed a standard for innovation performance evaluation system, this paper considers the frequency and availability of indicators and constructs an evaluation system that conforms to the characteristics of TR's technological innovation under the system design principles and objectives. Finally, three input indicators and two output indicators were selected. The technology research and development of enterprises is generally measured from the perspective of manpower and capital investment. Referring to the research results of relevant literature, in terms of manpower investment, this paper selects the index of R&D personnel; in terms of capital investment, R&D expenses and patent application indicators are selected. The output index of technological innovation selects the number of patent authorizations and the sales revenue of new products.

The above indicators can reflect the level of technological innovation performance of equipment manufacturing enterprises. Therefore, the input and output indicators of technological innovation performance evaluation of TR enterprises are shown in **Table 1** below:

Table 1. Statistical description

	Index	Observed value	Mean value	Standard deviation	Minimum value	Maximum value
Input	Number of technical personnel	300	808.86	377.81	336	1321
	Research and development Expenditure	300	197.46	171.90	25.06	533.99
	Patent application number	300	324.53	192.47	110	729
Output	Patent grants	300	152.86	102.81	42	369
	New product sales	300	3716.15	1516.44	1984.59	6057.37

4. Evaluation system construction

DEA is one of the commonly used methods in the field of performance evaluation. It evaluates the performance of similar decision-making units by comparing their relative efficiency. Specifically, DEA weights the input and output indicators of each DMU to find the optimal weight combination so that the efficiency value of each DMU is maximized. In the DEA model, the efficiency value is equal to the sum of the weighted output divided by the sum of the weighted input. When the efficiency value is equal to 1, it means that the DMU is at the optimal efficiency boundary; when the efficiency value is less than 1, the efficiency of DMU is lower than the optimal level.

(1) The CCR model is the basic model of the DEA method. It is a non-parametric method based on linear programming to evaluate the relative efficiency of production decision-making units. The CCR model assumes that the production process has a constant return to scale; that is, the proportional relationship between input and output is constant.

In the CCR model, the comprehensive efficiency (total efficiency) includes two parts: Technical efficiency and scale efficiency. Technical efficiency reflects the ability of a decision-making unit to achieve maximum output under a given input. Scale efficiency reflects the production efficiency of a decision-making unit at its current scale. When the comprehensive efficiency of a decision-making unit is equal to 1, it shows that the decision-making unit is efficient in the production process. When the comprehensive efficiency is less than 1, it means that the decision-making unit has efficiency loss in the production process.

$$h_i = \frac{u^t y_i}{v^t x_i} = \frac{\sum_{s=1}^{k} u_s y_{si}}{\sum_{t=1}^{m} v_t x_{ti}}, i = 1,2,\cdots,n \tag{1}$$

$$s.t.\begin{cases} min\theta \\ \sum_{i=1}^{n} \lambda_i x_i - s^- = \theta_{x0} \\ \sum_{i=1}^{n} \lambda_i x_i - s^+ = y_0 \\ \lambda_i \geq 0, s^- \geq 0, s^+ \geq 0, j = 1,\cdots,m; i = 1,\cdots,n \end{cases} \tag{2}$$

(2) The BCC model is an extended model of the DEA method. Different from the CCR model, the BCC model assumes that the production process has variable returns to scale. The proportional relationship between input and output is variable. Under this assumption, the BCC model is mainly used to calculate the pure technical efficiency of the decision-making unit and exclude the impact of scale efficiency on the overall efficiency.

Pure technical efficiency reflects the ability of a decision-making unit to achieve maximum output under a given input, regardless of production scale. When the pure technical efficiency of a decision-making unit is equal to 1, it means that the decision-making unit is efficient in the production process. When the pure technical efficiency is less than 1, it means that the decision-making unit has a loss of technical efficiency in the production process.

The mathematical expression of the BCC model is similar to that of the CCR model. The difference is that the BCC model adds a constraint condition: $\sum_{i=1}^{n} \lambda_i = 1$.

The BCC model is widely used in many fields. For example, by evaluating the pure technical efficiency of different enterprises in the same industry, inefficient enterprises can be found and improved to improve the technical level of the whole industry. In a large enterprise, the BCC model can be used to evaluate the pure technical performance of different departments to find out which departments need to be improved to improve the technical efficiency of the whole enterprise. Moreover, the BCC model can be used to evaluate the pure technical efficiency of public service institutions, such as schools and hospitals, to determine which institutions have room for improvement at the technical level. By comparing the pure technical efficiency of different banks, we can find inefficient banks and improve them to improve the technical level of the whole banking industry.

5. Selection of evaluation model

This paper analyzes the technological innovation performance of TR equipment manufacturing enterprises vertically and horizontally and analyzes the financial data of a total of 15 years from 2008 to 2022 vertically.

The data is sorted out and output as a notepad file: TR.txt, using DEAP calculation software, the relevant parameters are set as follows:

tr.txt	data file name
tr-out.txt	output file name
15	number of firms
1	number of time periods
2	number of outputs
4	number of inputs
0	0 = input and 1 = output orientated

1 0 = crs and 1 = vrs

0 0 = DEA(multi-stage), 1 = cost-DEA, 2 = malmquist-DEA, 3 = DEA(1-stage), 4 = DEA(2-stage)

Run the DEA 2.1 program, use the BCC model for calculation, and the output calculation result is TRout. txt. After further collation by Microsoft Excel, the 15-year innovation performance measurement results of TR enterprises are as follows **Table 2.** shown:

Table 2. TR 2008–2022 BCC model calculation results

DMU	Comprehensive technical efficiency	Pure technical efficiency	Scale efficiency	Returns to scale
2008	1.000	1.000	1.000	-
2009	1.000	1.000	1.000	-
2010	1.000	1.000	1.000	-
2011	1.000	1.000	1.000	-
2012	1.000	1.000	1.000	-
2013	0.787	1.000	0.828	irs
2014	0.700	0.951	0.754	irs
2015	0.817	0.928	0.882	irs
2016	0.914	0.926	0.957	irs
2017	1.000	0.956	1.000	-
2018	1.000	1.000	1.000	-
2019	1.000	1.000	1.000	-
2020	0.927	1.000	0.927	irs
2021	1.000	0.970	0.955	-
2022	1.000	1.000	1.000	-

(1) Comprehensive efficiency analysis

Based on the BCC model, the performance evaluation results of TR equipment manufacturing enterprises from 2008 to 2022 show that the allocation structure of technological innovation resources of TR enterprises from the initial stage of listing to 12 years is reasonable, and the performance is relatively excellent. In the selected 15 sets of data, the comprehensive efficiency, technical efficiency, and scale efficiency of 2008–2012 for five consecutive years are 1 at the same time. It shows that the enterprise is in a state of complete efficiency in the five years, the technology management is mature, there is no waste of resources, the production scale matches the market demand, and it is in the stage of constant returns to scale. It shows that the proportion of input and output is fully coordinated at this stage, and there is no need to adjust the scale. In 2013–2016, TR enterprises entered a recession period, the comprehensive efficiency decreased from 0.787 in 2013 to 0.700 in 2014, and then slowly recovered to 0.914 in 2016. It shows that TR equipment manufacturing enterprises made full use of the existing internal resources in 2013, and the technology application has reached the optimal level. It may be due to changes in market demand or lagging adjustment of internal resources, resulting in a decline in scale efficiency.

In 2014, the rapid expansion of scale led to insufficient technical management capabilities, such as process chaos and waste of resources. In 2016, although the scale efficiency rebounded, the technical efficiency has not yet recovered, forming a ‘scale dependence’ path. The inefficiency of this stage shows that there is an imbalance between input and output in the data of TR equipment manufacturing enterprises based on innovation activities.

In the four years after the introduction of technology, the effect of gradually increasing input is not as good as before. There may be non-financial problems in management efficiency, which indirectly leads to the waste of resources, thus failing to achieve Pareto optimality. Although the innovation investment of TR enterprises is high, the emphasis on R&D is not low, the output effect is not as expected, and some adjustments need to be made. In addition to the external shocks such as the pandemic in 2020, in the following years, TR enterprises offset the technology gap through scale expansion, the comprehensive efficiency reached 1 again, the technology and scale efficiency were double excellent, and the golden period state was restored.

The comprehensive efficiency of TR enterprises is equal to 1 in 10 years of 15 years, indicating that the technical management foundation of TR equipment manufacturing enterprises is relatively stable. The rapid recovery of scale efficiency in 2017 and 2022 shows that TR enterprises have strong scale adjustment ability, but scale expansion and technical management are prone to alternating fluctuations, such as in 2013–2016. Therefore, TR equipment manufacturing enterprises need to establish a collaborative optimization mechanism to cope with market fluctuations with scale elasticity, consolidate the cornerstone of efficiency with technical standardization, and achieve long-term steady growth.

(2) Pure technical efficiency analysis

From **Table 2**, it can be seen that in 2008–2012, the pure technical efficiency of TR equipment manufacturing enterprises was one for five consecutive years, there was no shortage in technical management, and the resource utilization efficiency was the best. It reflects the mature standardized production process, stable R&D investment and technological innovation, efficient management team, and low resource waste rate of TR enterprises at this stage. In 2013, the pure technical efficiency of TR equipment manufacturing enterprises showed the first inflection point of decline, and the trend of change changed inversely with the growth of input, and it did not rebound until 2017. The failure of technical efficiency leads to a downward trend in the efficiency of the enterprise's comprehensive level. Specifically, in 2013, the pure technical efficiency remained 1.000, but the scale efficiency decreased to 0.828, indicating that the technical management at this stage was not affected by the scale adjustment. However, after 2013, the TR equipment manufacturing enterprises expanded rapidly, resulting in increased management complexity, and the original technical process could not adapt to the new scale. In 2014, the pure technical efficiency fell below one for the first time to 0.951. The reason behind it may be that the resources are not fully utilized, and part of the investment does not produce technological transformation and become a profitable product. Enterprises need to improve their innovation ability from the aspects of technology introduction, enterprise cooperation, and employee ability training, so that the input and output can be matched properly. At the same time, the "explosive" expansion of scale has destroyed the rational division of labor within the R&D center, and the increase in innovation projects has increased the difficulty of coordinating production relations, thus reducing efficiency. As the project increases, the management class emerges. At the same time as the consumption of human resources, employee compensation will also increase (the proportion of employee compensation in the R&D department is more than 70%). Managers usually have low production capacity but high salaries. In this way, if there is chaos within each manager, it will bring about a reduction in production efficiency. In 2015–2016, due to the continuous decline in the proportion of R&D expenses, the dispersion of R&D investment, the tilt of resources to scale expansion, and the crowding out of the technology upgrading budget, the pure technical efficiency of the two years continued to be low. In addition to the above reasons, the weak demand from the macro market, the reduction of the competitive advantage of the original production line, and the lag of the benefits of new products have all tested the management of TR enterprises.

In addition to the temporary resource mismatch caused by supply chain disruption in 2021, which led to a slight decrease in the pure technical efficiency of TR enterprises to 0.970, the pure technical efficiency of TR equipment manufacturing enterprises will return to 1.000 in 2018–2022. The key to the success of TR equipment manufacturing enterprises lies in the reconstruction of technical standardization, the introduction of a lean production system, and the reduction of resource waste; at the same time, resources are concentrated on core processes, such as a 30% increase in the number of patents in 2017.

(3) Scale efficiency analysis

From **Table 2**, the returns to scale of TR are not in a stable state. In the calculation of the 15 periods, there are 10 periods to achieve the best scale. In 2008–2012 for five consecutive years, the scale efficiency is equal to 1, in a state of constant returns to scale, production capacity and market demand perfect match. It reflects the stable market demand and accurate capacity planning of TR equipment manufacturing enterprises, and the efficient and coordinated operation of the supply chain while allocating resources. Later, due to capacity expansion lagging behind demand growth, the scale efficiency fell to 0.828 for the first time in 2013. In the face of short-term demand surges, TR equipment manufacturing enterprises lack long-term planning. When the order volume increases by 20%, the capacity can only increase by 10%. In 2014, the scale efficiency continued to fall to 0.754. Due to excessive expansion, resources were dispersed, the utilization rate of new factories was less than half, and the coordination ability of the supply chain and production was insufficient. In 2015–2016, the capacity optimization was started, the inefficient capacity was gradually contracted, and two redundant factories were closed, so that the scale efficiency rose to 0.957. After 2017, except that the epidemic led to the disruption of the supply chain from 2020 to 2021, the shortage of key components, and the slight decline in scale efficiency, the scale efficiency returned to 1.000 in other years, which means that TR equipment manufacturing enterprises achieved the best allocation of technological innovation resources at this stage. The level of capital utilization is also good, and the return to scale is constant. If the input is increased, the output will not increase accordingly, and the output efficiency is already the best efficiency value under the corresponding input. The key to the recovery of scale efficiency is that TR equipment manufacturing enterprises adopt asset-light mode-outsourcing and cooperative production to reduce the risk of fixed investment. Based on the market demand forecast, the production capacity is dynamically adjusted, the scale efficiency is fully restored through resource integration and accurate production capacity, and the production capacity elasticity is enhanced.

Disclosure statement

The author declares no conflict of interest.

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