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Research Article

Research on Technical Innovation Efficiency of Listed Company in Food Industry

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Abstract: By means of establishing the input-output indicator system of technical innovation of listed companies in food industry, in this study authors apply the DEA model to assess the technical innovation efficiencies of 26 listed companies in China food industry from 2012 to 2014. Results show generally lower technical innovation efficiencies in listed companies in food industry. The average of overall efficiencies is only 0.707, where there is a greater space for growth. Among the 26 listed companies, only five have reached the relatively higher technical innovation efficiency, accounting for a percentage of 19.2%. In addition, the technical innovation efficiencies significantly differ from each other among listed companies in various food industries. For dairy companies and large food companies, the technical innovation efficiency is relatively higher. Results also indicate that scale efficiency is the main factor affecting the overall technical innovation efficiency of food companies. A majority of food companies are at the stage of increasing returns to scale, where they are confronted with the problem of insufficient investment in technical innovation.

Keywords: Data envelopment analysis, efficiency, listed company, technical innovation

INTRODUCTION

In recent years, the internal and external environment of food companies has undergone dramatic changes. The traditional survival and development mode faces serious challenges. In the food industry, the R and D and technical innovation cycles are significantly shortened. Most products tend to be excessive, indicating the emergence of a buyer's market. The customer demands are more diversified and individualized so that food companies are facing a growing gap. Food companies can merely survive or achieve a slow growth through enhancing marketing, reducing costs, improving productivity and other traditional practices. Technical innovation is becoming a key factor in each of food business obtaining excess profits, maintaining sustainable growth and improving competitiveness. It is the innovation efficiency that determines the effect of enterprises' technical innovation activity. In a sense, technical innovation efficiency is the most critical indicator assessing enterprises' technical innovation capabilities, as well as the most important factor affecting enterprises' scientific and technical output and economic output, which can ultimately impact the competitiveness of enterprises. This research was conducted to evaluate the technical innovation efficiencies of listed companies in China food industry.

THEORETICAL AND LITERATURE REVIEW

Efficiency evaluation was originally developed by Farrell (1957). Based on Debreu (1951) research, Farrell (1957) defined the concept of corporate efficiency evaluation by taking multiple inputs into consideration. Farrell (1957) divided efficiency into technical efficiency and scale efficiency. The former reflects enterprise's capability of obtaining maximum output through utilizing the existing technologies, given the fixed inputs. The later is the ratio of enterprise's minimum costs to actual costs, under the circumstance of fixed outputs and effective technologies, which reflects enterprise's capability of optimizing input resources, given the fixed input prices. The two measurements above constitute the overall efficiency.

Technical innovation efficiency refers to the ratio of enterprise's technical innovation output to innovation input during certain period, i.e., the input-output conversion efficiency of elements during the process of technical innovation, which reflects the contribution of enterprise's technical innovation capabilities and technical innovation resources to the profits during certain period. As for the measurement of technical innovation efficiency, currently the most popular method is non-parameter analysis. As a representative of this method, DEA (Data Envelopment Analysis) is

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capable of measuring the multi-input and multi-output innovation efficiency. The DEA method does not need to set a specific production frontier function, avoiding the potential errors caused by incorrect setup of function. In the current literature, few of them focus on applying the DEA to study technical innovation efficiency. Fan and Li (2009) uses the DEA to assess the relative efficiency of input and output in science and technology from 1987 to 2007 in Guangdong province. Che and Zhang (2010) conduct a R and D input-output analysis based on DEA and assess the production-study-research cooperative innovation efficiencies of 13 manufacturing industries in Shanghai. Yu *et al*. (2013) adopt the DEA to assess the relative efficiency of scientific and technological input and output of ten strategic emerging industries in Jiangxi province in 2010. Besides, some scholars also conduct researches on large and medium-sized enterprises. For instance, Yang (2007) uses the C2R model and C2GS2 model to evaluate the overall efficiency and technical efficiency of large and medium-sized industrial enterprises' technological resources allocation in Shanghai. Luo and Sun (2010) assess the technical innovation efficiency of cross-provincial large and medium-sized industrial enterprises between 1996 and 2008 in China through the DEA method. Duan and Wang (2010) apply the DEA method to analyze the difference degree of technical innovation efficiencies among China's large and medium-sized industrial enterprises and build a regression model for innovation efficiency and influencing factors. Li *et al*. (2011) conduct a research on the large and medium-sized industrial enterprises' technical innovation efficiency in Xinjiang in 2009. Hua *et al*. (2011) apply the updated DEA model to measure the technical innovation efficiency of large and medium-sized enterprises in 30 regions of China based on data from 2000 to 2007 and analyze the utilization efficiency of innovation inputs, resulting in the regional classification on the basis of DEA. Jiang (2012) uses non-parameter Malmquist index to conduct an empirical analysis of the dynamic changes of large and medium-sized enterprises' technical innovation efficiencies from 2001 to 2008 in China and study the differences of technical innovation efficiencies and relevant causes. Based on different perspectives, scholars implement various methods to evaluate enterprises' technical innovation efficiency. Due to diversified opinions on the key factors of technical innovation efficiency, scholars may choose different indicators in their researches. Currently, there is not any unified evaluation indicator system in use.

These researches prove to be useful references for us in this study. On the basis of previous studies, in this study we employ the DEA method, following the principle of availability, scalability, relevance and comprehensiveness and select the appropriate input and output indicators, targeting at the listed companies in food industry of China. Then, we measure these companies' technical innovation efficiencies from 2012 to 2014 and make comparisons, in the hope of providing valuable references for scientific evaluation on food enterprises' technical innovation efficiency and better promoting technical innovation.

METHODOLOGY

Data Envelopment Analysis (DEA) was originally proposed by the famous American operation expert Charnes *et al*. (1979), based on the concept of "relative efficiency evaluation". DEA, as a decision-making method, means to compare relative efficiencies of similar multi-input and multi-output Decision Making Units (DMU). Its fundamental idea is to take each evaluation object as a DMU and establish the effective production frontier through overall analysis of input-output ratio of each DMU and the calculation taking weighs of input and output indicators of each DMU as variables (Banker *et al*., 1989). According to the distance between each DMU and the effective production frontier, we can determine whether a DMU is DEA effective or not.

Suppose there are n decision making unit (DMU_j, j = 1, …, n) and each DMU has m input and s output. Then, for the DMU_j, the input is $X_j = (x_{1j}, x_{2j}, \ldots, x_{mj})^T$ and the output $Y_j = (y_{1j}, y_{2j}, \ldots, y_{sj})^T$. Set v as the weighting coefficient vector of input vector x and u the weighting coefficient vector of output vector Y and h_i the efficiency rating index of DMU_j. Conduct the efficiency evaluation of DMU_0 and the original DEA model is as follow:

$$\left.\begin{array}{l} \max h_0 = \dfrac{u^T Y_0}{v^T X_0} \\ s.t \dfrac{u^T Y_j}{v^T X_j} \le 1 \quad j = 1,2,\cdots,N \end{array}\right\} \begin{array}{l} v = (v_1, v_2, \cdots, v_m)^T \ge 0 \\ u = (u_1, u_2, \cdots, u_s)^T \ge 0 \end{array} \quad (1)$$

To facilitate the calculation, introduce the slack variables s- and s+. Then the formula (1) can be converted into the following multiple linear programming model:

$$\left.\begin{array}{c} \min \theta \\ \text{s.t.} \quad \sum_{j=1}^{N} \lambda_j x_j + s^- = \theta x_0 \\ \sum_{j=1}^{N} \lambda_j y_j - s^+ = y_0 \\ \lambda_j \ge 0, \; j = 1,2,\cdots,N \\ s^+ \ge 0, s^- \ge 0 \end{array}\right\} \quad (2)$$

Get the solution of formula (2) and set θ^*, S^*, S^{+*}as the optimal solutions. Explanations for results follow this principle.

Table 1: Indicator system for technical innovation efficiency evaluation of food enterprises

First-level indicator	Second-level indicator	Third-level indicator
Input	Capital input	R and D expense (10,000Yuan, x_1)
		Proportion of R and D expenses to sales revenue (%, x_2)
	Personnel input	Sum of technicians (person, x_3)
		Proportion of total technicians to total employees (%, x_4)
Output	R&D output	Authorized inventions and patents (number, y_1)
		New products (number, y_2)
	Economic output	new products Sales (100,000,000Yuan, y_3)
		Sales rate of new products (%, y_4)

When $\theta^* = 1$ and $s^{-*} = 0$, $s^{+*} = 0$, it means this DMU is DEA effective. In an economic sense, the resource allocation state of this DMU is relatively the most reasonable decision. At the current input level, the output is optimal.

When $\theta^* = 1$ and $s^{-*} \neq 0$ or $s^{+*} \neq 0$, it means this DMU is poorly DEA effective. In an economic sense, this DMU is close to the optimal state of resource allocation. But there is still space for further improvement: maintain constant output but reduce s^{-*} input of certain resources, or increase s^{+*} output but maintain current input level.

When $\theta^* < 1$, it means this DMU is non-DEA effective. In an economic sense, the DMU is far from the optimal state of resource allocation. Then, in order to maintain the same output level, we can reduce the inputs of all resources by the percentage of θ^*.

SELECTION OF INDICATORS AND DATA SOURCES

Selection of indicator system: To apply the DEA method, we must establish the input and output indicator system. As for the technical innovation of food companies, the essential idea is to achieve the maximum output of technical innovation as well as minimum input of technical resources in food enterprises' technical innovation activities, which is in accordance with the requirements of DEA method for input and output indicators. Therefore, by taking references to some input and output indicators in domestic and foreign corporate technical innovation efficiency evaluation and considering the availability of data, we establish the indicator system for technical innovation efficiency evaluation of food enterprises as follow in Table 1.

Input indicators: Variables for DEA efficiency evaluation depend on input indicators and output indicators. Considering the features of listed companies' annual financial reports and the data availability, we divide the food enterprises' technical innovation input into capital input and human input. The capital input can be reflected by two indicators, namely the R and D expenses and the proportion of R and D expenses to sales revenue. Here, the R and D expenses include costs of internal research and development projects. It is an absolute indicator reflecting enterprises' capital input in technical innovation. The proportion of R and D expenses to sales revenue is a relative indicator reflecting enterprises' capital input in technical innovation. The human input can be embodied by the two indicators, namely the sum of technicians and the proportion of total technicians to total employees. Here, the sum of technicians serves as an absolute indicator reflecting enterprises' human input in technical innovation, while the proportion of total technicians to total employees as a relative indicator reflecting enterprises' human input in technical innovation.

Output indicators: Food enterprises' technical innovation may exert effects on all sectors of enterprises, such as the number of patents, the number of new products, the increase of sales, sales revenue from new products, improvement of labor productivity and corporate profits, etc. Considering the data availability, in this study we choose the number of authorized patents, new products sales ratio and new products sales revenue to comprehensively reflect the output efficiency of innovation.

Data sources: Because of the technical innovation cycle in food enterprises and the time lag between input and output, firstly we calculate the annual average of technical innovation input and output of the targeted 26 listed companies in food industry between 2012 and 2014 and then assess their technical innovation efficiencies respectively during these years. Data comes from listed companies' annual reports 2012-2014.

RESULTS AND DISCUSSION

Input the data of relevant indicators of 26 listed companies in food industry into the Deap 2.1, software of DEA calculation and get the solutions, including the overall technical efficiencies, pure technical efficiencies and scale efficiencies of the 26 listed companies from 2012 to 2014. The results are shown in the Table 2.

The frontier analysis of listed companies' technical innovation in food industry: Table 2 shows that listed companies in food industry have general lower technical innovation efficiencies. The average of overall efficiency is only 0.707 and there are more 29.3% of spaces for further improvement. Among the 26 listed companies, five of them (accounting for 19.2% of the total), namely Yili Industrial Group, Bright Dairy, By-Health, Huangshi Group and Quantum High-tech, stay at the frontier of production and the overall efficiency of technical innovation in these five companies reaches 1. It means that in these five companies the technical innovation input-output proportion is appropriate and in a DEA effective state, achieving the technical effective

and the scale effective. In other words, at this level of input, the output has reached the maximum, without input redundancy or shortage of output.

The overall efficiency of technical innovation is lower than 1 in 21 companies (accounting for 80.8% of the total), which means that the technical innovation input-output efficiency is relatively ineffective. Therefore, these non-frontier companies are confronted with serious problems in their innovation resources input and the supporting system for innovation. It is urgent to make significant improvement: adjust the innovation resources' input allocation and proportion, reform companies' organization system and management pattern to coordinate with technical innovation activities. Accordingly, realize the transition of technical innovation efficiency from the ineffective state to the effective state.

The differences of technical innovation efficiencies among different types of listed food companies: Judging from the different sub-sectors of food industry, we notice that the dairy companies possess the highest overall efficiency of technical innovation, with an average of 0.905. And four of the five frontier companies belong to the dairy sector. Other dairy companies, if not at the frontier group, are not far from the frontier. In contrast, the flavor and yeast food enterprises have relatively lower technical innovation efficiency, with an average of 0.519. For instance, Lotus Aginomoto, Jiajia Food and Meihua Bio-tech are far from the frontier. The reason is the more intensive market competition in front of dairy companies in recent years. These dairy companies have increased R and D investment, updated production equipments, developed new products, strengthened technical innovation management and ultimately achieved higher technical innovation efficiency.

In perspective of the size of companies, 14 companies of the 26 samples are large-sized companies and 12 small and medium-sized companies. Large food companies have relatively higher technical innovation efficiencies, with an average overall technical efficiency of 0.893. In contrast, the small and medium-sized food enterprises have lower technical innovation efficiencies, with an average of 0.491. In addition, among the five companies at the production frontier, four companies are large-sized and only Quantum High-tech is small and medium-sized. It means that the technical innovation efficiency is relatively lower in small and medium-sized enterprises among these listed companies in food industry. Therefore, they should invest more in innovation and improve management level in order to increase enterprises' technical innovation efficiency.

The technical efficiency and scale efficiency of food enterprises' technical innovation: Scale efficiency is the dominant factor affecting enterprises' overall technical innovation efficiency. In most of enterprises, the pure technical efficiency is higher than scale efficiency. In Table 2 to 5, the average of pure technical efficiencies of all sample enterprises is 0.967 and the pure technical efficiency is effective in 16 enterprises, accounting for 61.54% of the total samples. 21 enterprises have the pure technical efficiency higher than 0.9, accounting for 80.77% of the total samples. In contrast, the average of scale efficiencies in sample enterprises is 0.731. The scale efficiency is effective in

Table 2: Results of technical innovation efficiency evaluation of listed companies between 2012 to 2014

No.	Company	Overall efficiency	Technical efficiency	Scale efficiency	Returns to scale
1	Yili Industrial Group Co., Ltd.	1	1	1	Unchanged
2	Bright Dairy and Food Co., Ltd.	1	1	1	Unchanged
3	By-Health Co., Ltd.	1	1	1	Increasing
4	Huangshi Group Co., Ltd.	1	1	1	Increasing
5	Quantum High-tech Biological Co., Ltd.	1	1	1	Increasing
6	Angel Yeast Co., Ltd.	0.986	1	0.986	Increasing
7	Tianrun Dairy Co., Ltd.	0.977	1	0.977	Increasing
8	Kingdomway Group Co., Ltd.	0.914	1	0.914	Increasing
9	Hengshun Vinegar-Industry Co., Ltd.	0.894	1	0.894	Increasing
10	Shuangta Food Co., Ltd.	0.877	1	0.877	Increasing
11	Haitian Food Co., Ltd.	0.871	1	0.871	Increasing
12	Keming Noodle Manufacturing Co., Ltd.	0.825	1	0.825	Increasing
13	Southern Food Co., Ltd.	0.793	1	0.793	Unchanged
14	Jialong Food Co., Ltd.	0.784	1	0.784	Increasing
15	Sanyuan Group Co., Ltd.	0.756	1	0.756	Increasing
16	VTR Bio-Tech Co., Ltd.	0.717	0.946	0.758	Increasing
17	Zhongju High-tech Co., Ltd.	0.705	0.952	0.741	Decreasing
18	Beingmate Group Co., Ltd.	0.697	0.883	0.789	Decreasing
19	Shanghai Maling Aquarius Co., Ltd.	0.495	0.981	0.505	Increasing
20	Sanquan Food Co., Ltd.	0.417	0.873	0.478	Decreasing
21	Fuling Mustard Group Co., Ltd.	0.396	0.954	0.415	Increasing
22	Meihua Bio-tech Group Co., Ltd.	0.383	0.956	0.401	Increasing
23	Lotus Aginomoto Co., Ltd.	0.339	0.841	0.403	Increasing
24	Maiquer Group Co., Ltd.	0.205	0.861	0.238	Increasing
25	Jiajia Food Co., Ltd.	0.204	1	0.204	Unchanged
26	Star Lake Bio-Science Co., INC.	0.157	0.882	0.178	Increasing
Average		0.707	0.967	0.731	

Table 3: The difference of technical innovation efficiencies of listed companies based on sub-sector of food industry

Sub-sector of food industry	Quantity	Average of overall efficiencies	Sum of DEA-effective companies
Dairy food manufacturing	6	0.905	4
Fast food manufacturing	6	0.599	0
Flavor and yeast food manufacturing	7	0.519	0
Other food manufacturing	7	0.819	1
Total	26		5

Table 4: Difference of technical innovation efficiencies in different sized food enterprises

Size of enterprise	Quantity	Average of overall efficiencies	Sum of DEA-effective companies
Large enterprise	14	0.893	4
Small and medium-sized enterprise	12	0.491	1
Total	26		5

Table 5: Statistics of pure technical efficiency and scale efficiency of food enterprises

Pure technical efficiency	Quantity	Percentage	Scale efficiency	Quantity	Percentage
1	16	61.54%	1	5	19.23%
[0.9, 1)	5	19.23%	[0.9, 1)	2	7.69%
(-∞, 0.9)	5	19.23%	(-∞, 0.9)	19	73.08%
Total	26	100%	Total	26	100%

Table 6: Statistics of returns to scale of food enterprises

Returns to scale	Quantity	Percentage
Unchanged	5	19.23%
Increasing	18	69.23%
Decreasing	3	11.54%
Total	26	100%

five enterprises, accounting for 19.23% of the total samples. Seven enterprises have the scale efficiency higher than 0.9, accounting for 26.92% of the total samples. Higher pure technical efficiency indicates that the input in technical innovation activities is relatively efficient. Lower scale efficiency, especially the annually increasing returns to scale, means that there are more spaces for the growth of scale efficiency. Therefore, enterprises can enlarge the scale of technical innovation appropriately and increase input in innovations in order to realize the scale economy and improve the innovation outputs and efficiency.

Technical innovation's returns to scale in food enterprises: Returns to scale refers to changes of output along with changes of internal production factors by the same proportion, under the circumstance of unchanged other elements. Increasing returns to scale is such a condition that the output increases greater than the increased input. In contrast, decreasing returns to scale is such a condition that the output increases lower than the increased input. According to the Table 6, among the 26 sample enterprises, the technical innovation efficiencies in five enterprises have resulted in unchanged returns to scale, accounting for 19.23% of the total samples. There are 18 enterprises realizing the increasing returns to scale, accounting for 69.23% of the total samples and three enterprises decreasing returns to scale, accounting for 11.54% of the total samples. Apparently, most food enterprises are at the stage of increasing returns to scale, indicating that these enterprises have not reached the optimal scale of technical innovation. With the increase of investment in technical innovation, the ratio of increased output is greater than that of increased input. It also proves the shortage of enterprises' input in the process of technical innovation.

CONCLUSION

Based on the empirical analysis of technical innovation efficiency of listed food companies between 2012 and 2014 and the discussions on the data analysis results, we propose the following suggestions for food enterprises' technical innovation:

- Food enterprises should establish the technical innovation efficiency evaluation and monitoring system and arrange reasonable investment in technical innovation. Technical innovation efficiency is not proportional to the quantity of inputs. In order to achieve the maximum output with limited inputs, enterprises should conduct continuous evaluation and monitor on technical innovation efficiency so that they can identify problems immediately and make correction.
- Food enterprises' technical innovation efficiency needs to be investigated comprehensively based on pure technical efficiency and scale efficiency. Effective technical efficiency means that both pure technical efficiency and scale efficiency are effective. Ineffective technical efficiency may be caused by one or two factors. Technical innovation must emphasize on efficiency. However, high output and high input does not necessarily means high innovation efficiency. The pattern of seeking for high output regardless of increasing costs will be discarded with the lack of resources. Improving technical innovation efficiency is the key for maintaining sustainable development.
- There is sharp difference of technical innovation efficiencies among different sub-sectors of food industry. The dairy food enterprises have relatively higher technical innovation efficiencies because of the more intensive market competition in this sub-

sector, while the flavor and yeast food enterprises have relatively lower technical innovation efficiencies. Currently, the driving force of technical innovation in food enterprises is mostly from external competition instead of internal needs for development. Therefore, food enterprises should further improve the initiatives for technical innovation and seek for long-term sustainable development.

- For different sized food enterprises, the technical innovation efficiencies are significantly different. Large food enterprises apparently possess higher technical innovation efficiencies than that of small and medium-sized enterprises. Therefore, large enterprises should keep in maintaining their advantages and achieve a stable increase of technical innovation efficiency. Small and medium-sized enterprises should make full use of the late advantages of technology selection. By means of purchasing, imitating and learning from large food enterprises' advanced technologies and management experiences, small and medium-sized enterprises can further improve their technical innovation efficiencies so that they can finally catch up with or even exceed the large food enterprises in this field.

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