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The Research of Technology Innovation Efficiency of High - tech Industry in Shandong Province Based on SBM - DEA Model

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***Abstract*—In this paper, the SBM-DEA model of data envelopment analysis is used to study the technical efficiency, pure technical efficiency, scale efficiency and scale of technological innovation research and development and transformation process of high-tech industry in Shandong province. The aim is to promote the rational and efficient development of high-tech industry in Shandong province. The results show that the technical efficiency of two stages of technological innovation in Shandong Province has improved year by year, but the scale efficiency has weakened year by year, and the technical efficiency hasn't improved obviously. The study also found that the technical R & D phase of technological innovation in high-tech industry in Shandong Province is now in a state of diminishing returns to scale. After 2009, the four major industries are all in this state.**

Keywords—high-tech industry; technological innovation efficiency; two stages of technological innovation; SBM-DEA model

I. INTRODUCTION

High-tech industry as the current economic production activities in the most innovative industries, has effectively promoted the Chinese economic model to change and upgrade from extensive to intensive. Shandong Province as the third largest economy in China, it's rapid economic take-off can not be separated from the rapid development of high-tech industry. China is currently in a critical period of industrial transformation. In this context, Shandong Province is bound to take the road of independent innovation and develop high-tech industries vigorously. Therefore, it is of great significance to analyze the historical performance of Shandong high-tech industry and help enterprises to allocate resources more rationally.

So far, the research on the efficiency of technological innovation in high-tech industry based on DEA model has made some achievements at home [1]. However, most scholars use the traditional radial DEA model that does not consider the relaxation of input-output variables relaxation problem and easily lead to the efficiency of technological innovation too high; the same time, the main research focused on the national level but lack of regional analysis on Shandong Province. Based on this, this paper will use SBM-DEA model on the basis of decomposing technological innovation of high-tech industry in the two stages analyze technology innovation efficiency of high-tech industry in Shandong Province.

II. MODEL ANALYSIS

Tone Kaoru (2001) proposed the SBM model (Slack Based Measure, SBM) [2]. Suppose there are m kinds of input and output indicators of technological innovation and n decision units, (Xij,Yrj)(i=1,2,3,⋯,m;r=1,2,3,⋯,s ; j=1,2,3,⋯,n) is the sorted index data, the non-oriented SBM model is planned as:

$$\min TE = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{v_{r0}}}$$

$$s.t.\quad x_{i0} = \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- \quad i = 1,2,...,m \qquad (1)$$

$$y_{i0} = \sum_{j=1}^{n}\lambda_j y_{rj} - s_i^+ \quad i = 1,2,...,s$$

$$\lambda_j \geq 0, s_i^- \geq 0, s_r^+ \geq 0$$

There is no restriction that $\sum_{j=1}^{n}\lambda_j = 1$ in model (1), so the optimal solution of the model is the technical efficiency under the constant scale pay, that is, the SBM model under CRS.When TE * = 1, there is no weak problem in non-radial model, DMUO is strong and effective. In the radial model, the inefficiency is proportional to all inputs or outputs; in the SBM model, inefficiency is measured by the average ratio of inputs or outputs that can be varied The radial model does not contain the problem of the slack variable, so the SBM model can measure the efficiency more efficiently.

$$\min TE = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1+\frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{v_{r0}}}$$

$$s.t. \quad x_{i0} = \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- \quad i = 1,2,...,m \qquad (2)$$

$$y_{i0} = \sum_{j=1}^{n} \lambda_j y_{rj} - s_i^+ \quad i = 1,2,...,s$$

$$\lambda_j \geq 0, s_i^- \geq 0, s_r^+ \geq 0, \sum_{j=1}^{n} \lambda_j = 1$$

If model (1) constrains $\sum_{j=1}^{n} \lambda_j = 1$, model (2) is obtained. Considering the impact of industrial scale, it is a measure of the efficiency of industrial technology efficiency under variable scale pay. The optimal solution is to consider the pure technical efficiency under the influence of enterprise scale. Compared with model (1), model (2) can use panel data to obtain industry scale efficiency.

III. INDICATOR SETTING AND DATA SELECTION

A. Indicator Setting

High-tech industry is different from other general production industries. According to Zheng Jian and Ding Yunlong (2007) [3], the output can be divided into technical knowledge, economic and social benefits. As the output of human and capital investment, technical knowledge is the middle of the process of technological innovation. It is the ultimate goal of business pursuit through the transformation of technical knowledge to be transformed into the intrinsic value of new products and achieve economic efficiency. In view of the two-stages of the technological innovation process of high-tech industry, this paper divides the innovation of high-tech industry into technical R & D and technological transformation two stages to study it's efficiency of technological innovation [4].Specific classification can be seen form Table I&Table II.

TABLE I INPUT AND OUTPUT INDICATORS IN TECHNICAL R & D STAGE

	Level 1 indicators	Level 2 indicators
Input indicators	Manpower input	R & D staff is equivalent to full time number
	Capital investment	R & D internal expenses
		Expenditure on new product development
Output indicators	Technology R & D achievements	Number of patent applications

TABLE II INPUT AND OUTPUT INDICATORS IN TECHNICAL ACHIEVEMENT TRANSFORM STAGE

	Level 1 indicators	Level 2 indicators
Input indicators	Technical input	Number of patent applications
	Manpower input	Annual average number of employees in the industry
	Capital investment	Expenditure on technological transformation
		New fixed capital
Output indicators	New product revenue	Sales revenue of new products

B. Data Setting

According to the China High Technology Industry Statistical Yearbook, China's high-tech industry is divided into five major industries: pharmaceutical manufacturing industry(MPPI), aerospace manufacturing industry(AAMI),electronic and communications equipment manufacturing industry(ECEI),electronic computer and equipment manufacturing industry(ECOEI) and medical equipment and instrumentation manufacturing industry(MTIMI), this classification standard also applies to the division of high-tech industry in Shandong Province.

Due to the small size of the aerospace manufacturing industry in Shandong Province and the imperfect development of the industry and to ensure the accuracy of the efficiency measure, sample data selected in the high-tech industry in Shandong Province from 2004 to 2014 in the four major industries: MPPI,ECEI,ECOEI and MTIMI.

TABLE III STATISTICAL DESCRIPTION OF INPUT AND OUTPUT INDICATORS OF FOUR MAJOR INDUSTRIES IN SHANDONG PROVINCE FROM 2004 TO 2014

Indicators	Maximum value	Minimum value	Average value	Standard deviation	Observed value
R & D staff is equivalent to full time number(people/year)	16969.60	347.87	5299.10	4662.48	44.00
R & D internal expenses(million yuan)	681393.60	3666.30	194347.98	182423.99	44.00
Expenditure on new product development(million yuan)	654897.70	3797.90	208355.46	188206.64	44.00
Annual average number of employees in the industry	332096.00	21729.00	128949.16	76115.11	44.00
Expenditure on technological transformation(million yuan)	235041.00	3915.60	51421.41	52661.88	44.00
New fixed capital(billion yuan)	393.69	0.77	85.78	101.02	44.00
Number of patent applications	3860.00	43.00	981.57	942.69	44.00
Sales revenue of new products(million yuan)	7776704.60	408352.10	2719803.69	2425643.48	44.00

Source: 2005 - 2015 China High Technology Industry Statistical Yearbook.

IV. EMPIRICAL ANALYSIS

A. Technical R&D stage efficiency analysis

According to TableIV, it can be concluded that the MPPI has reached active state of technical efficiency in 2004, then its technical efficiency has been greatly reduced and has been maintained at around 0.2 from 2007 to 2014; the technology

efficiency mean value of MTIMI was significantly higher than the other three industries, and achieved technical efficiency effective state in 2006 and this number of other years fluctuated around the mean 0.61; ECEI has not been achieved without technical efficiency effective state in 11 years, its technical efficiency value was low, but overall in upward trend;ECPMI has the lowest technical efficiency mean value of 0.28, but the industry has the largest increase in technical efficiency, the difference was 0.49.

TABLE IV TE, PTE, SE AND RTS OF 4 INDUSTRIES IN TECHNICAL R & D STAGE FROM 2004 TO 2014

MPPI					MTIM				
	TE	PTE	SE	RTS		TE	PTE	SE	RTS
2004	1.00	1.00	1.00	C	2004	0.55	0.55	0.99	I
2005	0.53	0.61	0.86	D	2005	0.47	0.47	1.00	I
2006	0.37	0.37	1.00	C	2006	1.00	1.00	1.00	C
2007	0.18	0.18	1.00	C	2007	0.51	0.51	1.00	C
2008	0.23	0.29	0.78	D	2008	0.42	0.42	1.00	C
2009	0.19	0.25	0.73	D	2009	0.58	0.79	0.73	D
2010	0.20	0.26	0.76	D	2010	0.71	0.79	0.90	D
2011	0.16	0.24	0.68	D	2011	0.63	1.00	0.63	D
2012	0.19	0.29	0.66	D	2012	0.62	0.92	0.67	D
2013	0.21	0.33	0.63	D	2013	0.65	1.00	0.65	D
2014	0.21	0.34	0.61	D	2014	0.57	0.90	0.64	D
Aver-age value	0.31	0.38	0.79		Aver-age value	0.61	0.76	0.84	
ECEI					**ECOEI**				
	TE	PTE	SE	RTS		TE	PTE	SE	RTS
2004	0.23	0.31	0.73	D	2004	0.10	0.10	1.00	C
2005	0.20	0.37	0.53	D	2005	0.07	0.07	1.00	C
2006	0.21	0.36	0.58	D	2006	0.07	0.07	1.00	C
2007	0.22	0.44	0.50	D	2007	0.16	0.16	1.00	C
2008	0.25	0.45	0.56	D	2008	0.24	0.28	0.87	D
2009	0.32	0.59	0.54	D	2009	0.49	0.67	0.72	D
2010	0.33	0.61	0.54	D	2010	0.56	0.78	0.72	D
2011	0.59	1.00	0.59	D	2011	0.27	0.40	0.67	D
2012	0.48	1.00	0.48	D	2012	0.27	0.41	0.66	D
2013	0.40	0.84	0.48	D	2013	0.30	0.47	0.64	D
2014	0.44	1.00	0.44	D	2014	0.51	1.00	0.51	D
Aver-age value	0.33	0.63	0.54		Aver-age value	0.28	0.40	0.80	

[a] TE refers to technical efficiency, PTE refers to pure technical efficiency, SE refers to scale efficiency, RTS refers to scale state, I refers to increment of the scale pay, C refers to constant scale pay, D refers to decreasing returns to the scale. The next table is same to this one.

[b] The data in this table is calculated using MaxDEA.

From the view of pure technical efficiency, MPPI achieved an effective state of pure technical efficiency in 2004,followed by a significant reduction of pure technical efficiency and increased slightly year after year after the lowest point in 2007; pure technical efficiency of MTIMI achieved an effective state in 2006, 2013 and 2013,the industry's pure technical efficiency is relatively high and the average is 0.76; ECEI achieved an effective state of pure technical efficiency in 2011,2012 and 2014, the industry's pure technical efficiency had basically entered the growth trend since 2004,and maintain a higher level of efficiency after 2011; ECOEI achieved an effective state of pure technical efficiency in 2014 and had the largest growth rate of pure technology efficiency ,the range of pure technical efficiency is 0.93.

B. Technical achievement transformation stage efficiency analysis

According to TableV, it can be concluded that the technical efficiency of MPPI, MTIMI is low, the mean value is only 0.19, 0.10, but the value of the two industries is on the rise; the technical efficiency of the ECEI increased firstly, then reduced, and reached the highest value in 2010 and 2011.ECOEI achieved an effective state of technical efficiency in 2004,2005,2006,2007 and 2011, in the rest years the technical efficiency around 0.45 fluctuations. In a word, the technological transformation of high-tech industry in Shandong Province, the transformation of technological efficiency is low, only ECOEI achieved an effective state of pure technical efficiency in five years.

TABLE V TE, PTE, SE AND RTS OF 4 INDUSTRIES IN TECHNICAL ACHIEVEMENT TRANSFORM STAGE FROM 2004 TO 2014

MPPI					MTIMI				
	TE	PTE	SE	RTS		TE	PTE	SE	RTS
2004	0.07	0.07	1.00	C	2004	0.08	0.08	0.98	I
2005	0.06	0.06	1.00	C	2005	0.04	0.05	0.98	I
2006	0.10	0.10	1.00	C	2006	0.04	0.04	1.00	C
2007	0.11	0.11	1.00	C	2007	0.07	0.07	1.00	C
2008	0.13	0.14	0.94	D	2008	0.07	0.07	1.00	C
2009	0.18	0.23	0.75	D	2009	0.08	0.08	1.00	C
2010	0.25	0.36	0.69	D	2010	0.07	0.07	1.00	C
2011	0.27	0.37	0.71	D	2011	0.12	0.12	1.00	C
2012	0.30	0.46	0.65	D	2012	0.15	0.15	1.00	C
2013	0.27	0.53	0.52	D	2013	0.15	0.15	1.00	C
2014	0.34	1.00	0.34	D	2014	0.21	0.21	1.00	C
Aver-age value	0.19	0.31	0.78		Aver-age value	0.10	0.10	1.00	
ECEI					**ECOEI**				
	TE	PTE	SE	RTS		TE	PTE	SE	RTS
2004	0.40	1.00	0.40	D	2004	1.00	1.00	1.00	C
2005	0.37	0.48	0.77	D	2005	1.00	1.00	1.00	C
2006	0.37	0.48	0.76	D	2006	1.00	1.00	1.00	C
2007	0.43	1.00	0.43	D	2007	1.00	1.00	1.00	C
2008	0.57	1.00	0.57	D	2008	0.48	0.53	0.91	D
2009	0.54	0.89	0.61	D	2009	0.38	0.51	0.74	D
2010	0.62	1.00	0.62	D	2010	0.35	0.40	0.87	D
2011	0.62	1.00	0.62	D	2011	1.00	1.00	1.00	C
2012	0.33	0.90	0.37	D	2012	0.56	0.71	0.78	D
2013	0.36	1.00	0.36	D	2013	0.43	0.52	0.82	D
2014	0.31	0.85	0.37	D	2014	0.44	0.50	0.89	D
Aver-age value	0.45	0.87	0.54		Aver-age value	0.69	0.74	0.91	

[a] The data in this table is calculated using MaxDEA.

In the perspective of pure technical efficiency, this value of MPPI & MTIMI is relatively low. Only MPPI achieved pure technical efficiency in 2014.This value of ECEI and ECOEI is relatively high, the mean value are 0.87 and 0. 74.In

short, pure technical efficiency of high-tech industry in Shandong Province have a huge gap between different industries in the stage of technological innovation achievements transformation, the gap may be related to the product update cycle.

C. Two-stage comprehensive analysis

According to the different performance of four industries technology development and transformation in Shandong province, we use SBM model under VRS to calculate average efficiency value and take 0.6 as the critical value, four industries can divide the into four types.

TABLE VI INVESTMENT AND OUTPUT INDICATORS OF FOUR HIGH - TECH INDUSTRIES IN SHANDONG PROVINCE IN 2014

Indicators	MPPI	MTIMI	ECEI	ECOEI
R & D staff is equivalent to full time number(people/year)	16970	5115	14258	12519
R & D internal expenses(million yuan)	613194	169699	633165	262595
Expenditure on new product development(million yuan)	654898	202776	642192	200463
Annual average number of employees in the industry	234180	79994	332096	75753
Expenditure on technological transformation(million yuan)	228449	15421	88976	40414
New fixed capital(billion yuan)	394	154	320	27
Number of patent applications	2030	1598	3860	2241
Sales revenue of new products(million yuan)	7776705	1220842	7126607	3118341

[a.] Source: 2015 China High Technology Industry Statistical Yearbook.

MPPI belongs to low-R & D and low-conversion industry, from Table VI we can find that this industry put a lot of manpower and capital in both R & D stage and technical achievement transformation stage and a huge investment in research and innovation activities but not pay attention to efficiency in technical R & D stage, and does not pay attention to the realization of the market value in technological achievement transformation stage, and belongs to extensive and low level R & D innovation. MTIMI belongs to high-R & D and low-conversion industry. Most of the industry's high-end technology are in the hands of developed countries, Shandong Province and even China's medical equipment and instrumentation use the means and methods of digest innovation and innovation of imitation. Most patent applications are appearance of patents and practical patents, so the more patent applications, technical R & D efficiency is higher. But the technical achievements can't bring excess economic benefits of new products. ECEI belongs to high-R & D and high-conversion industry. The industry is the "traditional" high-tech industry in Shandong Province, which has a good foundation in the industrial system and technical R & D. The marketing demand for products and the prospect in this industry are both broad, that all promote the innovative efficiency of the industry. ECOEI belongs to low-R & D and high-conversion industry. But according to the evaluation of Feng Zhijun&Chen Wei (2014) [5], the industry should belong to high-R & D and high-conversion industry at the national level.

V. CONCLUSIONS AND POLICY ANALYSIS

A. Conclusion

In this paper, the non - radial - non - directional SBM - DEA model is used to analyze the technical efficiency, pure technical efficiency and scale efficiency of technological innovation in the four major industries of Shandong high - tech industry from 2004 to 2014. The results show:

1) Shandong Province high-tech industry technology innovation R & D stage technical efficiency is low and basically maintain the trend of shock. The efficiency of pure technology is relatively low but the trend is rising. The scale efficiency is high, but the scale efficiency caused by the decreasing returns of the four major industries has been affected year by year. The improvement of pure technical efficiency can not be reflected in the technical efficiency.

2) The technological efficiency is significantly different from that of sub-sectors in the stage of transformation of technological achievements. In this stage, the scale efficiency is generally high, and the low efficiency of technology limits the improvement of technical efficiency.

3) In the four major industries of high-tech industry in Shandong province, the R & D of the MPPI is seriously redundant and the efficiency of technological transformation is weak [6].There is a low-added value of technological achievements in MTIMI due to the lack of high-end technology, making a low efficiency of technological transformation. The efficiency of ECEI is relatively high. There is a partial gap between ECEI and the national level, conversion rate in research and development stage is low.

B. Policy analysis

According to the above conclusions, this paper puts forward the following suggestions in order to effectively improve the efficiency of high-tech industry in Shandong Province.

1) To build high-tech industry management system. China's high-tech industry need to build high-tech industry management system in the future, to further strengthen the market management and improve the scale of the state.

2) To actively participate in domestic and international competition, and improve the core cutting-edge technology independent research and development level. Actively promoting high-tech industry to participate in market competition and increasing high-tech industry R & D

investment, improving the industrialization and commercialization of patents.

3) To perfect innovation model and set up a system that enterprises, scientific research institutions, institutions of higher learning can promote and develop with each other. To strengthen the management of technology imitation and digestion and re-innovation, to avoid blind or repeated introduction, to commit to develop independent intellectual property rights with the first innovation, and to vigorously support the promotion of tripartite cooperation of enterprises, research institutions and institutions of higher learning to form innovation chain.

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