Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2013, 5(11):195-199

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

R & D efficiency appraisal of pharmaceutical industry based on DEA-Malmquist

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ABSTRACT

This paper analyzes R&D efficiency changes of pharmaceutical industry by DEA-Malmquist on the basis of the selected panel data from 2002 to 2011. The paper indicates: In terms of time, TFP(total factor productivity) of entire pharmaceutical industry shows an increasing trend with year and overall average annual growth rate reach up to 5.7%, TFP and TC (technological progress index)curves are highly similar; technological progress is the main source to promote the growth of TFP; In terms of industry, TFP and TC values in different industries are all greater than 1 for the recent 10 years, the technical efficiency and TC play different role in TFP growth for different industries.

Key words: Pharmaceutical Industry; Biological and Biochemical Manufacturing Industry; Medicine Manufacturing Industry; Total Factor Production; DEA-Malmquist Index

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INTRODUCTION

Till 2011, China has become the third largest pharmaceutical market of the world, second only to the United States and Japan in market size and by 2020, China’s pharmaceutical market will exceed Japan to become the world's second largest pharmaceutical market, then pharmaceutical industry will become the mainstay industry in high-tech areas and national economy. However, the report from Commerce Department “Industrial Safety Assessment on Pharmaceutical Industry 2009-2010 in China” showed: So far, without any kind of drug has been recognized internationally, and the total sales revenue of Chinese pharmaceutical enterprises is less than one-third of that in the United States， which indicates low level of R & D and weak profitability in pharmaceutical corporate. This is the key that restricts sustained and rapid development of China's pharmaceutical industry. As one of the five high-tech industries, pharmaceutical industry is divided into three sub-sectors: chemical manufacturing, medicine manufacturing, biological and biochemical products manufacturing. It is an extremely important strategic industry with the characteristics of high-input, high-yield, high-risk, and long payback period. As a typical research-driven industry, research and innovation are the basis for its survival and development. In general, the high-tech industries are those which the ratio of R & D expenditure to total output value is much higher than that of other industries, therefore it becomes important to study the R & D efficiency on pharmaceutical industry. It is a good way to evaluate the efficiency on technological resource. It is important to improve use of resources and output efficiency in R&D.

Many scholars have conducted studies on the pharmaceutical industry. From the aspect of research content, they primarily focused on efficiency of technology and innovation, for example, CaoYang, Xiang Ying, Mao Ning-Ying (2013) conducted a comprehensive analysis on innovation efficiency of Pharmaceutical Industry based on the sample of 23 provinces in China during 2000~2010； Luo Ya-Fei, Jiao Yu-Can (2007) analyzed about the technology innovation efficiency in the whole; Zheng Jie, Yang Chang-Hui, Xu Sheng's studies (2008) have shown that in recent years, technology innovation efficiency showed overall upward trend, but the efficiency is relatively low; Taken the listed companies from 2006 to 2009,Qiao Yun-Zhi (2011) investigated the impact of R&D investment on business performance in pharmaceutical manufacturing; WANG Miao (2008) analyzed the key factors influencing the technology growth of enterprise in different sizes. From the aspect of research methods, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are the most important methods. Generally speaking, in measuring TFP, SFA required only one output，so this paper believes that the DEA-Malmquist index method based on non-parametric is more suitable for the pharmaceutical industry. Based on this, selects the latest panel data, the paper tries to measure the static and dynamic R & D efficiency for pharmaceutical manufacturing with the DEA-Malmquist model, to give some countermeasures to improve R & D efficiency.

EXPERIMENTAL SECTION

2.1 Introduction of DEA

Data Envelopment Analysis (DEA) is becoming an increasingly popular management tool, put forward by Charles, Cooper, and Rhodes in1978.It can handle multiple input and output models, and does not require an assumption of a function between inputs and outputs. With those characteristics, DEA is commonly used to evaluate the relative efficiency of a number of peers. , DEA is an extreme point method and compares each unit with only the "best" unit. As the earlier list of applications suggests, DEA can be a powerful tool when used wisely.

DEA model includes input-oriented and output-oriented model. Input-oriented model is defined as how to reduce the proportion of investment to make minimum investment, in the condition of keeping output unchanged. CCR model estimates the production frontier with linear programming method, DMU falling on the boundary is regarded as the most efficient decision making unit, its efficiency equal to 1; others outside the boundary are invalid DMU, their efficiency values range between 0-1.

2.2 Malmquist Index

DEA model is used to analyze resource allocation efficiency with sectional data or time series model, to panel data analysis, we need to introduce Malmquist index method to make up for the lack of DEA , assuring to draw reliable conclusions.

Nearly 50 years ago, Shephard (1953) introduced the input distance function in the context of production analysis. At the same time Malmquist (1953) introduced the input distance function in the context of consumption analysis. However, Malmquist went a step further than Shephard, by developing a standard of living index as the ratio of a pair of input distance functions. In the context of production analysis, his standard of living index becomes an input quantity index. There is an analogous output quantity index based on output distance functions introduced by Shephard (1970).

Nowadays, Total factor productivity based on the distance function to define the Malmquist index, has become an important tool to analyze the sources of national economic growth and is widely used in productivity measurement. The formula is

$$M_0(x_{t+1},y_{t+1},x_t,y_t)=[\frac{d_0^t(x_{t+1},y_{t+1})}{d_0^t(x_t,y_t)}\times\frac{d_0^{t+1}(x_{t+1},y_{t+1})}{d_0^{t+1}(x_t,y_t)}]^{1/2}=\frac{d_0^{t+1}(x_{t+1},y_{t+1})}{d_0^t(x_t,y_t)}\times[\frac{d_0^t(x_{t+1},y_{t+1})}{d_0^{t+1}(x_{t+1},y_{t+1})}\times\frac{d_0^t(x_t,y_t)}{d_0^{t+1}(x_t,y_t)}]^{\frac{1}{2}} = \text{EC}\times\text{TC} = \text{PEC}\times\text{SEC}\times\text{TC}$$

By constructing the TFP index M (x_{t+1}, y_{t+1}, x_t, y_t) from T to T+1, the TFP (total factor productivity) can be divided into technical efficiency change (EC) and technological progress (TC). Technical efficiency change (EC)can be further decomposes into pure technical efficiency (PEC)and scale efficiency change(SEC).TC represents technological progress, EC = 1 means that the two adjacent technical efficiency does not change and EC<1 indicates decreased technical efficiency. Technical efficiency and technological progress are two key factors to improve efficiency. Changes in efficiency value of Malmquist index greater than 1, indicates its positive role in promoting the growth of TFP.

Empirical analysis

3.1 Data Sources and the Index System

The paper selects the data from《China Statistics Yearbook On High-tech Industry》，National Statistics Database| and《China Statistics Yearbook》

According to the classification of high-tech industry, the article takes those industries as samples: pharmaceutical manufacturing, chemical manufacturing, medicine manufacturing, biological and biochemical manufacturing, time span of 2002 ~ 2011.

Selecting appropriate input and output indicators are the key issues to apply DEA rightly to efficiency evaluation. Combining evaluation methods with R&D features in pharmaceutical industry, the input and output indicators are selected properly. Input indicator x_1 ,x_2, x_3 respectively represents full-time equivalent staff in R&D, R&D expenditure and R&D funding on new product; output indicators include output value of new product (y_1) and the number of patent applications (y_2). Selection of input and output indicators is critical in DEA; the basic requirement is to put a positive correlation between input and output indicators. Correlation analysis shows that the selected indicators meet the basic requirements of the DEA on positive correlation. According to Paul Romer and Robert Lucas's basic point of view in "new growth theory", more precisely, it is R & D capital stock not the current R&D investment that affects output. Here adopt the internationally accepted perpetual inventory method to check R&D capital stock in pharmaceutical manufacturing.

3.2 Efficiency Measurement

Select R&D input and output data from 2002 to 2011 in pharmaceutical manufacturing, the paper uses DEAP software for analysis, the results shown in Table 1.

Table 1 shows that overall efficiency of R&D resources allocation is higher; means of technical efficiency and scale efficiency has reached above 0.9. Among those, three DMU—2005,2010 and 2011 are effective unit and the returns to scale are unchanged; meanwhile, because of invalid in scale, 2002,2003 and 2006 DMU are non-effective; finally, the remaining invalid unit are non-effective in both technical efficiency and scale efficiency. All non-effective units are increasing in returns to scale.

Table 1 R&D resources allocation efficiency in pharmaceutical manufacturing

DMU	CRS	VRS	Scale	Returns to Scale	DMU	CRS	VRS	Scale	Returns to Scale
2002	0.767	1	0.767	Irs	2008	0.872	0.890	0.980	Irs
2003	0.983	1	0.983	Irs	2009	0.918	0.927	0.991	Irs
2004	0.953	0.979	0.973	Irs	2010	1	1	1	-
2005	1	1	1	-	2011	1	1	1	-
2006	0.998	1	0.998	Irs	Means	0.937	0.970	0.966	
2007	0.878	0.906	0.968	Irs					

3.3 Dynamic Analysis on Total Factor Productivity

3.3.1Changes of TFP in different years

In recent years, growth rate of TFP and technological progress in China's pharmaceutical industry have shown fluctuating trend， as shown in Table 2.

Table 2 Malmquist index values and composition in pharmaceutical industry

Year	EC	TC	PEC	SEC	TFP	Year	EC	TC	PEC	SEC	TFP
2002~2003	0.730	1.362	0.767	0.952	0.994	2007~2008	0.928	1.085	1.000	0.928	1.006
2003~2004	0.972	0.905	1.039	0.936	0.880	2008~2009	1.078	0.870	1.000	1.078	0.938
2004~2005	1.497	1.668	1.273	1.177	2.498	2009~2010	1.000	1.103	1.000	1.000	1.103
2005~2006	0.872	0.961	1.000	0.872	0.838	2010~2011	0.905	1.138	0.974	0.929	1.030
2006~2007	1.246	0.673	1.000	1.246	0.839	Means	1.005	1.052	0.999	1.006	1.057

（EC represents technical efficiency index; TC means technological progress index; PEC represents pure technical efficiency index; SEC for scale efficiency index; TFP for the Malmquist productivity index）

Take the year 2007 as cut-off point, TFP before 2007 is remained at 0.8~0.9 without increasing trend (except in 2004) and TC showed a downward trend; TFP and TC indexes after2007 are all greater than 1, showing the wave growth (except for 2008, the global financial crisis in 2008 may be a major factor leading to decrease in TC index).Among those, the technological advances in 2009-2010 and 2010-2011 is up to 10.3% and 13.8% respectively.

During the decade, pure technical efficiency value is higher, while the scale efficiency in more than half are less than 1, such as 2002 ~ 2003 and 2010 ~ 2011 ,their pure technical efficiency growth was -4.8%, -7.1% .Although technological progress index in those years are much higher than means, the overall TFP value is below the desired level, which indicates that technical efficiency hinders the growth of TFP , and it is technological progress that promotes the growth of TFP in China's pharmaceutical industry in recent years.

3.3.2 Malmquist index in different industries

Suppose 1-4 represents the pharmaceutical manufacturing, chemical manufacturing, medicine manufacturing, biological and biochemical products manufacturing respectively, the TFP trends from 2002 to 2011 show in Table 3:

Table 3 Malmquist index value in R&D efficiency

Industry	EC	TC	PEC	SEC	TFP
1	0.995	1.057	1	0.995	1.052
2	0.987	1.038	0.994	0.993	1.025
3	1	1.057	1	1	1.057
4	1.038	1.055	1	1.038	1.095
Means	1.005	1.052	0.999	1.006	1.057

First, to the pharmaceutical industry and the three sub-sectors, the average annual TFP, TC, EC index shows an increasing trend. Average growth of TFP equal to 5.7% and technological progress is a major contributing factor(an average annual increase of 5.2%), while technical efficiency play a small role(average annual growth of 0.5%);the means of pure technical efficiency index is less than 1 (0.999), indicating an obstacle to efficiency. In the long run, the means of technological progress efficiency index and total factor productivity index were greater than 1, pharmaceutical manufacturing and three sub-sectors all have achieved technological progress.

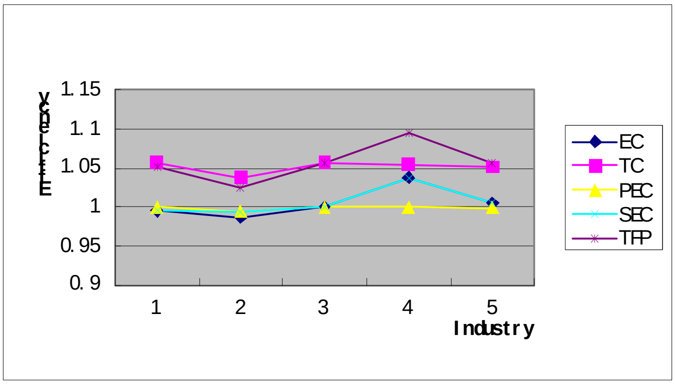

Fig.1: Line chart of TFP in different industries

Second, from the different industry point of view, TFP growth rate in biological and biochemical products industry is up to 9.5%,of which both technological progress and technical efficiency have contributed to TFP growth, and technological progress(growth rate up to 5.5 percent) gives a greater contribution to TFP ; TFP growth in medicine manufacturing is also more prominent as 1.057 and its growth only stems from technological progress, technical efficiency is unchanged; TFP growth in chemicals manufacturing is the smallest ,2.5%, and the technical efficiency is less than 1,so technological progress compensate for decreased technical efficiency.

In conclusion, the average TFP growth in the pharmaceutical industry and sub-industry is 5.7%. Technological progress exponential curve is highly similar with that of TFP, which indicates that technological progress is the main factor to TFP growth in recent years; it is consistent with the conclusions drawn from other relevant scholars. Particularly, from Table 3 and Figure 1, we can see the largest increase in TFP happens in biological and biochemical manufacturing, the technical efficiency of this industry has increased significantly, both technological progress and technical efficiency promote the increasing of TFP.

CONCLUSION

The paper analyzes the TFP index changes in pharmaceutical industry and three sub-sectors by DEA-Malmquist method. TO eliminate the problem of time delay between input and output, adopt capital stock of R&D expenditure instead of the R & D expenditures. The study indicates: TFP in pharmaceutical industry and its affiliated three sub-sectors—chemical manufacturing, medicine manufacturing, biological and biochemical products manufacturing, shows upward trend and the growth in different industries are quite different. Biological and biochemical manufacturing industry is the only one to achieve progress on both technical efficiency and technological progress, TFP growth in other sub-sectors mainly due to technological progress rather than technical efficiency.

Therefore, how to improve the technical efficiency is what we need to consider first and most. First, the Government and enterprises should strengthen intellectual property protection, knowledge innovation to promote further technological progress in the pharmaceutical manufacturing industry, especially for medicine industry; Secondly, Optimizes the scale of R&D investment and improves the level of management in various industries, to improve technical efficiency and scale efficiency. In addition, the Government should build a favorable policy environment and provide appropriate tax incentives to promote the healthy development of pharmaceutical industry.

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