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# Evaluation Research of Innovation Efficiency of the Equipment Manufacturing Industry Based On Super Efficiency DEA and Malmquist Index

Xiaowei Xu[1,a], Liangqun Qi[1,b] and Yuanyuancai[1,c]

*1. School of management, Harbin University of science and technology, Harbin, 150080, China*
*[a]4994129@qq.com, [b]xxw2921@163.com, c4502921@163.com*

***Abstract***

*In order to promote the overall innovation efficiency and running effect of the equipment manufacturing industry effectively which we focus on cultivating and developing strategic in China, overall innovation efficiency and running effect of sampling data is completely evaluated and analyzed by establishing the data analysis of the DEA model and using the Malmquist index analysis method based on the representative data samples of some equipment manufacturing industries in Heilongjiang province in China in 2003-2012.Analysis result shows the overall innovation efficiency characteristics of the equipment manufacturing industry in Heilongjiang province, illustrates the related factors which influence the improvement of the innovation ability and incensement of its growth rate of the equipment manufacturing industry in Heilongjiang province. The study provides the necessary theoretical basis for clarifying the development state of equipment manufacturing industry in Heilongjiang province, points out the strategic development of the development of equipment manufacturing industry and the development direction of overall innovation.*

***Keywords:*** *equipment manufacturing industry; innovation efficiency; Super efficiency DEA; Malmquist index*

## 1. Introduction

As one of the national important old industrial base, Heilongjiang province has a good base for the development of the equipment manufacturing industry. It has advantage in large power transmission and transformation equipment production, heavy machinery manufacturing, petrochemical and CNC machine tool production and other fields so far. So, exploring the efficiency of enterprise independent innovation in view of the uniqueness of the development of equipment manufacturing industry in Heilongjiang province has important strategic meaning and practical value in promoting regional equipment manufacturing industry innovation ability.

Studies on the innovation efficiency mainly use the data envelopment analysis and stochastic frontier analysis at home and abroad. The former is data envelopment analysis (DEA) method proposed by Charnes, referred to as "the super efficiency DEA method", the latter is stochastic frontier analysis method put forward by Aigner, such as SFA methods for short. Scholars compared the DEA method with SFA method according to the actual research situation, concluded that, first, the DEA method has more credibility than SFA method by contrast. Second, two kinds of methods have consistent conclusion, but the efficiency value of the super efficiency DEA method slightly higher than that of the SFA method. Overall, the super efficiency DEA method and SFA method measuring principle is different, the applicable specific situation also is different, must undertake choosing according to the actual situation.

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Most scholars research efficiency measure using super efficiency DEA method from the related research on the efficiency of the equipment manufacturing industry by domestic scholars. Pengfei Yan measured technical efficiency of various provinces, autonomous regions in China using super efficiency DEA methods; He thought the technical efficiency has the absolute influence to production efficiency [2]. Fang Wei and Yulin Zhao evaluate the innovation efficiency of China's high-tech enterprises using the CCR model in super efficiency DEA method, and analyzed the R&D efficiency and the reasons for differences between industries [3]. Xiaohong Song made a comprehensive evaluation of the independent innovation ability for the equipment manufacturing industry in China by using super efficiency DEA method. He carried on the attempt in the enterprise independent innovation evaluation theory through building the two stages appraisal model of independent innovation [4]. Peng Wang and Liangjian Wang studied manufacturing innovation efficiency of Hunan province with super efficiency DEA method, the result showed that the vast majority of manufacturing industries innovation was in a non DEA efficient in Hunan province, it provided reform train of for improving the efficiency of manufacturing innovation through the variance analysis [5]. Also, some scholars measure technical efficiency with SFA method. Youwei Zhu and others analyzed the R&D efficiency of high and new technology enterprise in China by using SFA method, and puts forward the path of narrowing the difference of regional development efficiency through the analysis of the factors that influence efficiency of research and development [6]. Yijun Yuan measured equipment manufacturing industry technological innovation efficiency with SFA method in 2000-2006 in China, and analyze the factors that influence efficiency of innovation on this basis [7].Although having some try on manufacturing innovation efficiency and innovation path simply using DEA or SFA method, but still cannot form systematically analysis for the key elements and comprehensive evaluation to leading the efficiency ascend.

From the perspective of the use of Malmquist index, studying innovation efficiency with the DEA model and Malmquist index combined is relatively rare like this article. Most scholars studied the efficiency of decision making units in a field from the perspective of Malmquist index method. For example, Junhong Bai made empirical analysis to changes in the ecological rate of innovation efficiency in China's regional using Malmquist index method [8]. Fengchao Liu and others evaluated the technological innovation efficiency by Malmquist index method in China [9]. Yong Qi evaluated its innovation resources integration in Jiangsu by using Malmquist index method [10]. Some scholars research innovation efficiency with super efficiency DEA model and Malmquist index method combined. For example Xiaoqin Xu studied the regional technological innovation efficiency in China by two methods with Chongqing as an example [11]. Jinfang Liu and others analyzed the industrial innovation efficiency of domestic enterprises using these two methods [12]. The article study the innovation efficiency of the equipment manufacturing industry in Heilongjiang province based on the super efficiency DEA model and Malmquist index method, make the dynamic analysis for the innovation efficiency of various industries, put forward the feasible policy suggestions for the future industrial development and structural adjustment of the equipment manufacturing industry in Heilongjiang province.

## 2. Research Method

### 2.1. The Super Efficiency DEA Model

DEA is put forward by three American scholars such as A•Chames. It is an evaluation method of studying relative effectiveness of multiple decision making units. The basic principle of DEA is dividing the sample data classification into input indexes and output indexes on the basis of the linear programming method. Its essence is a systematic "input - output" efficiency evaluation model. CCR and BCC both are the most basic models of DEA model. Assume that decision making units refer to the

 

equipment manufacturing industries in this article, evaluate innovation efficiency of K kind of equipment manufacturing industries. And assuming there are L kinds of investment indicator variables and M kinds of output indicators variables in efficiency evaluation index. Assume that $X_{jl}$ represents the Lth factor inputs of the Jth industry, $Y_{jm}$ represents the Mth factor output of the Jth industry. For the Pth equipment manufacturing industry (n=1, 2….k), there are DEA model:

$$min\ \theta_p$$

$$s \cdot t \sum_{j=1}^{k} x_{ji}\lambda_j + s_l^- = \theta_p x_{lp}\ l = 1,2,\ldots,L\ \ j \neq 0 \qquad \sum_{j=1}^{k} y_{jm}\lambda_j - s_m^+ = y_{mp}$$

$$m = 1,2\ \ldots, m,\ j \neq 0 \qquad \lambda_j \geq 0,\ s_l^- \geq 0,\ s_m^+ \geq 0,\ j \neq 0 \quad (1)$$

If add scale variable constraint $\sum_{j\neq 0}\lambda_j = 1$ in (1), it will turn into BBC model. The BBC is also known as pure technical efficiency (PTE). There is the following relationship between scale efficiency and pure technical efficiency. Scale efficiency $SE = TE/PTE$. $S_l^-$ and $S_m^+$ represent the slack variable, $\theta_p$ represents the efficiency value of the DEA model. In general, the closer to 1 the index of comprehensive efficiency $\theta$, the higher the efficiency of innovation of the industry. The comprehensive efficiency of the industry achieve the best state when $\theta$=1.

### 2.2. Malmquist Productivity Index Method

Assume that at random time t=1, 2…T, decision making units put into $X_t$ factor of production, transform into $Y_t$ output. If as the technology in a prescribed time for reference, then total factor productivity of Malmquist index based on output can be defined as $D^{t+1}(x^{t+1}, y^{t+1})$. The innovation efficiency production index of the equipment manufacturing industry can be applied as follow model:

$$M(x^t,y^t,x^{t+1},y^{t+1}) = \left[\frac{D^t(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \times \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t+1}(x^t,y^t)}\right]^{\frac{1}{2}} \quad (2)$$

In the formula (2), $D^t(x^t, y^t)$ and $D^t(x^t, y^t)$ represent the technical efficiency function the t phase of the data reflected, $D^t(x^t, y^t)$ and $D^{t+1}(x^{t+1}, y^{t+1})$ represent technical efficiency function the (T + 1) data reflected. Malmquist productivity index is decomposed as follow:

$$M(x^t,y^t,x^{t+1},y^{t+1}) = \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \times \left[\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})} \times \frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)}\right]^{\frac{1}{2}} \quad (3)$$

M represents the innovation efficiency index of the equipment manufacturing industry. It means innovation efficiency improved when the index greater than 1, It means innovation efficiency reduced when the index less than 1, It means innovation efficiency not changed when the index equal 1. So, Malmquist productivity index is further decomposed as follow:

$$M(x^t,y^t,x^{t+1},y^{t+1}) = effch \times techch = pech \times sech \times techch \quad (4)$$

Among them, the production index M can be decomposed into technical efficiency change (effch) and technology change (techch) two parts. And technical efficiency change can be further decomposed into pure technical efficiency change (pech) and scale efficiency change(sech).

$$effch = \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^t(x^t,y^t)} \qquad techch = \left[\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})} \times \frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)}\right]^{\frac{1}{2}}$$

$$pech=\frac{D^t(x^t,y^t)}{D^{t+1}(x^t,y^t)} \qquad sech=\frac{D^t(x^{t+1},y^{t+1})}{D^{t+1}(x^{t+1},y^{t+1})}$$

effch is relative efficiency index. It is generally used to indicate whether inputs use lacked or wasting resource use. The index shows that the extent of the chase on the production frontier pursued of all decision making units stage from t to t + 1. If effch is greater than 1, it shows that the gap of production frontiers with the optimal decision units is reducing. The organization's management level is lifting. When effch equal to 1, it means the technical efficiency between two periods did not change. When effch less than 1, it shows that the management level is falling. etchch is to measure the degree of technological changes of decision making units in the adjacent two degree. If etchch is greater than 1, the production technology is making progress. When etchch is equal to 1, the production technology has no change. When etchch is less than 1, the production technology is fall behind. When studying the overall innovation efficiency index of equipment manufacturing industry, we can analysis decomposition factors which affect overall innovation efficiency index according to the various indexes after decomposed.

### 2.3. Index Selection and Data Sources

For study, this article will instead seven industries such as fabricated metal products with $DMU_1$, $DMU_2$, $DMU_3$… $DMU_7$. In this paper, most data comes from Heilongjiang Statistical yearbook, the Yearbook of Chinese Industry and China Statistical Yearbook on Science and Technology from 2004 to 2013, and the related data of official website of Science and Technology Agency in Heilongjiang province.

According to the basic principle of DEA model and considering the availability of data, this article selects R&D funds and R&D personnel number, product sales cost and technical transformation expenditure as input indicators for evaluating innovation efficiency. The purpose of focusing on the expenditure of technical modification is analyzing how many funds used for enterprise technical transformation, rather than used for technological introduction and digestion and absorption. In most cases, when the enterprise technology introduction and digestion attract more invest of R&D, this can cause Foreign technology dependence of enterprise and low efficiency of technology research. Select output indicators such as new product sales income, total sales revenue and patent applications quantity.

**Table 1. Evaluation Index of Innovation Efficiency of the Equipment Manufacturing Industry in Heilongjiang Province**

| Category | variable | index |
|---|---|---|
| Input Indicators of Innovation Efficiency | $X_1$ | Number of R&D staff(one) |
| | $X_2$ | R&D expenditure (ten thousand Yuan) |
| | $X_3$ | Total sales cost (ten thousand Yuan) |
| | $X_4$ | technical transformation expenditure (ten thousand Yuan) |
| output indicators of Innovation Efficiency | $Y_1$ | new product sales revenue (ten thousand Yuan) |
| | $Y_2$ | patent application number(one) |
| | $Y_3$ | Total Sales Revenue (ten thousand Yuan) |

## 3. Operation Result Analysis

### 3.1. The Operation Result Analysis of DEA Model

Using DEAP2.1 software, get run results of each decision-making unit from 2003 to 2012. The table and the chart show that no mean value of comprehensive efficiency reaches 1 in seven industries. Among them, the two industries whose comprehensive efficiency most

 

close to 1 are general equipment manufacturing and transportation equipment manufacturing industry, these two industries' comprehensive efficiency reached to1 during 2006-2011. More than that, the gap of the comprehensive efficiency between all kinds of industries is obvious. The comprehensive efficiency of fabricated metal products, communications equipment computer and electronic equipment manufacturing and instrumentation and culture office supplies manufacturing are all at about 0.5.

**Table 2. The Computational Results of Innovation Efficiency of Equipment Manufacturing Industry in Heilongjiang Province in 2003-2012**

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|
| $DMU_1$ | 0.5321 | 0.6987 | 0.4562 | 0.3918 | 0.3855 | 0.5685 | 0.6185 | 0.6125 | 0.6687 | 0.6877 |
| $DMU_2$ | 0.6456 | 0.9877 | 0.9747 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $DMU_3$ | 0.8978 | 0.8774 | 0.8142 | 0.7869 | 0.7745 | 0.8965 | 0.9512 | 0.8412 | 0.8878 | 1 |
| $DMU_4$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.8812 |
| $DMU_5$ | 0.7887 | 0.8874 | 0.7425 | 0.7745 | 0.7655 | 0.7951 | 0.8421 | 0.7745 | 0.6578 | 0.9912 |
| $DMU_6$ | 0.5567 | 0.5544 | 0.4112 | 0.3256 | 0.3123 | 0.3232 | 0.4411 | 0.2254 | 0.2365 | 0.8754 |
| $DMU_7$ | 0.4261 | 0.4123 | 0.3698 | 0.3598 | 0.5264 | 0.3855 | 0.4069 | 0.3155 | 0.3887 | 0.4454 |

Now analyze the equipment manufacturing industry by dividing it into three sorts in Heilongjiang province according to the operation result of the model.

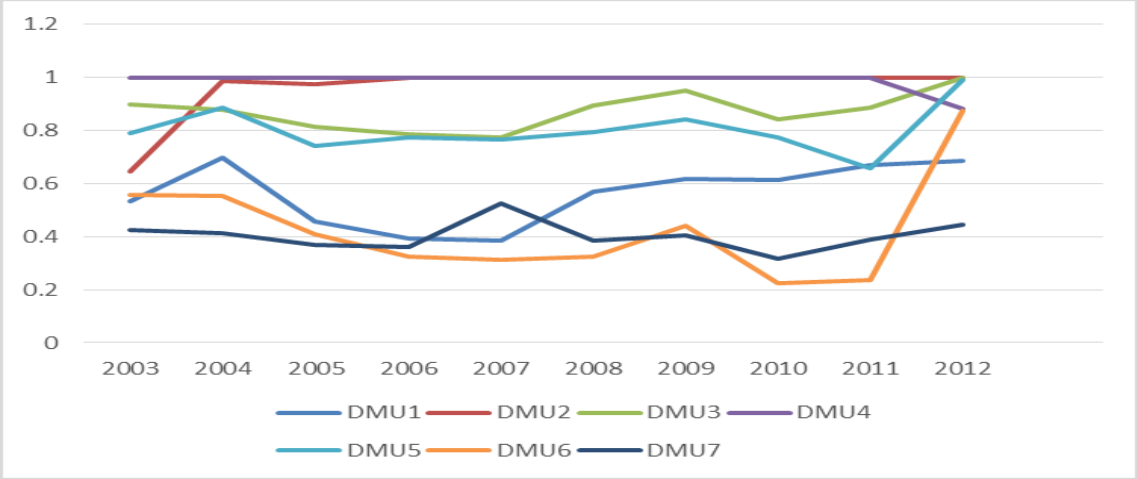


**Figure 1. The Innovation Efficiency of the each Equipment Manufacturing Industry in Heilongjiang Province in 2003-2012**

The first sort includes general equipment manufacturing and transportation equipment manufacturing industry. The comprehensive efficiency $\theta_p$ of these two industries are both close to 1, this shows that these two industries mainly achieves the DEA effective. The efficiency achieves the best condition in these decision-making units. In other words, the input and output achieve the optimal state. Need to be sure, even the comprehensive efficiency of two industries is close to 1, but that does not mean input and output efficiency of the two industries are the best. Just efficiencies of these two industries are better than other industries. As a matter of fact, equipment manufacturing and transportation equipment manufacturing industry are leading industries of the equipment manufacturing industry in whole province. Automotive industry achieved individual industrial output value accounted for 30% of the whole equipment manufacturing industry represented by Harbin Hafei Automobile Industry Group co., LTD and Harbin Dongan Automotive Engine Manufacturing co., LTD in 2012, pull the entire province equipment manufacturing industry growth of nearly 2%. Aviation manufacturing enterprises represented by Harbin Hafei Automobile

Industry Group co., LTD are 7% of the total output value of the equipment manufacturing industry in the province, pull the manufacturing economy grew by 1.3%.

The second sort includes special equipment manufacturing and electrical machinery &equipment manufacturing. The average comprehensive efficiency of these two industries is above 0.8. This suggests that the two industries are relatively DEA effective. The comprehensive efficiency of these two industries has room for improvement when considering the increasing return to scale. That is, the earnings still can increased under the situation of scientific research investment increased and the production efficiency improved. Enterprise vests in these two industries are represented by Harbin Jiuzhou Electric co., LTD and Harbin Bearing Group Corporation from collating the data. Power transmission and distribution and control equipment manufacturing represented by Harbin Jiuzhou Electric co., LTD realized total industrial output value nearly 1.8 billion Yuan in 2012, pull the entire province equipment manufacturing industry economic growth of about 0.1%. Machinery manufacturing enterprises represented by Harbin Bearing Group Corporation realized total output value 2.1 billion Yuan, has contributed 1% to the equipment manufacturing industry of province.

The third sort includes fabricated metal products, communications equipment computer and electronic equipment manufacturing and instrumentation and office supplies manufacturing. The average comprehensive efficiency of these three industries is about 0.5, it can be thought of DEA is invalid. This shows that the number of R&D staff and the R&D expenses are relatively insufficient funds. These factors are the important factor of restricting the enterprises to improve production efficiency.

### 3.2. The Operation Result Analysis of Malmquist Index

We can get the mean of total factor productivity of the seven industry of equipment manufacturing industry in Heilongjiang province from 2003 to 2012 according to the basic principle of Malmquist index, using DEAP2.1 software (Table3). According to the decomposition of Malmquist productivity index formula, we can know that technical efficiency is equal to the product of pure technical efficiency and scale efficiency. It represents the difference between actual production ability and the theory of optimal production capacity, which is production efficiency under a certain inputs.

**Table 3. The Mean of Malmquist Index of Equipment Manufacturing Industry in Heilongjiang Province（2003-2012）**

| | *effch* | *techch* | *pech* | *sech* | *M* |
|---|---|---|---|---|---|
| $DMU_1$ | 0.996 | 0.859 | 1 | 0.996 | 0.855 |
| $DMU_2$ | 1.102 | 1.002 | 0.996 | 1.106 | 1.004 |
| $DMU_3$ | 1.128 | 1.003 | 0.981 | 1.149 | 1.131 |
| $DMU_4$ | 1.119 | 0.995 | 1 | 1.119 | 1.113 |
| $DMU_5$ | 1.075 | 0.963 | 1.083 | 0.993 | 1.035 |
| $DMU_6$ | 0.830 | 0.868 | 0.956 | 0.869 | 0.720 |
| $DMU_7$ | 0.664 | 0.896 | 0.875 | 0.759 | 0.594 |

By the table 3 above shows, total factor productivity of various industries of equipment manufacturing industry in Heilongjiang province is relatively low. Only the total factor productivity of Special Equipment and General Equipment and manufacture of transport equipment and electrical machinery and equipment are gradually improved. Other all reduced with different degree. The main reason of most of the industry total factor productivity dropped is the technological progress is relatively slow by total factor productivity is equal to the product of technical efficiency and technical progress.

 

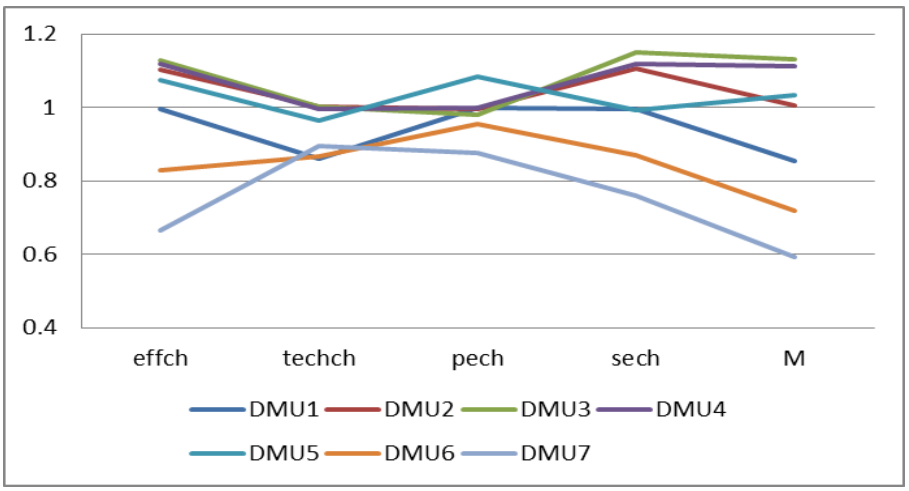


**Figure 2. The Malmquist Index of the Equipment Manufacturing Industry in Heilongjiang Province**

Form Figure 2, we can see that total factor rate of professional equipment manufacturing is growth fast, achieve 13.2%. The factor promoted the industry growth rate fastest is the improvement of technical efficiency, 12.8%. The improvement of scale efficiency is the principal factor of pulling the technical efficiency growth. Although total factor growth rate of the professional equipment manufacturing industry in Heilongjiang province is high, but it cannot explain the industry technological innovation efficiency is high. The growth rate is triggered by market demand, capital inputs, the role of science and technology innovation to improve the enterprise productivity rate is not obvious. The total factor growth rate of instrumentation and culture and office supplies manufacturing are Lowest. The affecting factors include economies of scale and technological progress. The industry belongs to the weak industry in Heilongjiang province, its competitiveness is not strong, ite development is slow. This conclusion is consistent with the DEA analysis result.

## 4. Conclusion

It analyzed and studied the overall innovation efficiency and operation effect using data of the equipment manufacturing industry in Heilongjiang province in China with DEA model and Malmquist index analysis method. We can draw the following conclusions through the study:

(1). Growth rate of the equipment manufacturing industry in Heilongjiang province are greatly influenced by technological progress. Most industry technology innovation is not obvious, the proportion to achieve effective innovation of the equipment manufacturing industry is only 28.6%. The overall innovation efficiency is low, the innovation ability of manufacturing needs to improve.

(2). Equipment manufacturing industry is highly uneven development, the scientific research strength distribution of equipment manufacturing industry is imbalance. The vast majority of scientific research and development of the equipment manufacturing industry is in the disorderly development state. Transformation effect of scientific research is not perfect. This need to increase the scientific research investment, improve the economies of scale further.

(3). The room for improvement of overall level of innovation of The equipment manufacturing industry in China is big. It can be realized by formulating the corresponding innovation policy, strengthening the judicial protection of enterprise independent intellectual property rights, attract human resource effective and create a collaborative innovation platform between enterprises and schools.

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