# A study on the Efficiency of Enterprise Science and Technology Innovation and the Influence Factors Based on the Two-stage SBM-DDF Model

Tian Tian[1], Li Li*

School of Economics and Management, Nanjing University of Science and Technology. Nanjing 210094, China

[1]1259565207@qq.com, *lily691111@126.com

**Abstract.** Dividing enterprise S&T innovation activities into stage of R&D and technology transformation(TT), uses SBM-DDF model to measure and analyze the S&T innovation efficiency of enterprises in R&D and TT stage in 30 provinces and cities in China from 2010 to 2020, and finally uses Tobit model to test the influencing factors of the efficiency of the two stages. The results show that: (1) the result conversion efficiency is higher than the R&D efficiency. (2) There are obvious efficiency differences between regions. (3) Government science and technology support and opening to the outside world have a significant positive impact on the efficiency value of the two stages.

**Keywords:** Enterprise STI efficiency; SBM-DDF; influencing factors; Tobit model

## 1 Introduction

Chinese enterprises play a vital role in scientific and technological innovation. In recent years, China's technology R&D has been hindered by Western countries. In order to break through technical barriers, scientific and technological enterprises continue to increase R&D investment, but ignore the improvement of innovation efficiency. In addition, the emissions of industrial "three wastes" are increasing day by day, making the contradiction between scientific and technological development and environmental pollution increasingly acute. Therefore, this study included the industrial three pollutants into the framework of scientific and technological innovation efficiency. With reference to the practice of Han et al.[1], the scientific and innovation activities of enterprises in provincial regulations were divided into R&D stage and technology transformation(TT) stage, and the differences and causes of the innovation efficiency of enterprises in the two stages in different provinces were explored.


V. Gaikar et al. (eds.), *Proceedings of the 2023 3rd International Conference on Financial Management and Economic Transition (FMET 2023)*, Advances in Economics, Business and Management Research 262,
https://doi.org/10.2991/978-94-6463-272-9_25

# 2 Method

## 2.1 SBM Directional Distance Function Model

The parametric method SFA can avoid measurement errors in calculation[2] and maximize the use of information from each sample, but its assumptions are extremely strict. Nonparametric DEA uses linear programming method to construct efficiency frontier [3], which can measure the relative effectiveness of multiple inputs and outputs[4], but cannot measure relaxation variables. Scholars put forward the SBM model which includes undesired output. Later, Fukuyama[5] combined this model with the directional distance function to form a SBM-DDF model that could better explain the input-output relationship under the constraints of environmental resources. Many domestic scholars use this model to measure innovation efficiency[6]. This study takes 30 provinces and cities in China as the production decision-making unit $DMU_i$ to carry out the optimal frontier structure of scientific and technological innovation. Each $DMU_i$ input N elements in R&D activities, and get M expected outputs, accompanied by K non-expected outputs. Therefore, the SBM-DDF model is constructed as follows[7]:

$$\overrightarrow{V^t}(x^{t,i'}, y^{t,i'}, u^{t,i'}, g^x, g^y, g^u) = \max_{v^x, v^y, v^u} \frac{\frac{1}{N}\sum_{n=1}^{N}\frac{V_n^x}{g_n^x} + \frac{1}{M+1}(\sum_{m=1}^{M}\frac{V_m^y}{g_m^y} + \sum_{k=1}^{k}\frac{V_k^u}{g_k^u})}{2} \tag{1}$$

$$s.t. \quad \sum_{i=1}^{I}\alpha_i^t x_{in}^t + v_n^x = x_{i'n}^t, \forall n; \sum_{i=1}^{I}\alpha_i^t y_{im}^t - v_m^y = y_{i'm}^t, \forall m; \sum_{i=1}^{I}\alpha_i^t u_{ik}^t + v_k^u = u_{i'k}^t, \forall k$$

When the direction vector $g_n^x = x_n^{max} - x_n^{min}, \forall n,\ g_m^y = y_m^{max} - y_m^{min}, \forall m$, there is $0 \le \overrightarrow{V^t} \le 1$. Therefore, the enterprise innovation efficiency index can be constructed:

$$TTE = 1 - \overrightarrow{V^t}(x^{t,i'}, y^{t,i'}, u^{t,i'}, g^x, g^y, g^u) \tag{2}$$

The input-output system of enterprise S&T innovation efficiency constructed by this research institute is shown in the following Table1:

**Table 1.** Input-output index system

| Stage | Variable | Variable name | Symbol |
|---|---|---|---|
| R&D | Inputs | R&D expenditure | $RDExpense$ |
| | | R&D staff | $RDPerson$ |
| | | R&D projects | $RDItem$ |
| | Outputs | patents granted for inventions | $Patent$ |
| | | domestic and foreign scientific and technical papers published | $Paper$ |
| | | Number of scientific and technical publications | $Literature$ |
| TT | Inputs | - | R&D outputs |
| | | Technical input | $Technology$ |
| | | Transformation funds | $Trans-funds$ |

| | | |
|---|---|---|
| Expected outputs | New product sales revenue | $Sales-revenues$ |
| | Technical contract turnover | $Tech-sele$ |
| Unexpected outputs | Industrial wastewater discharge | $Water$ |
| | Industrial waste gas emission | $Gas$ |
| | Industrial waste discharge | $Solid$ |

### 2.2 Tobit Model

Since the measured value of scientific and technological innovation efficiency is within the interval [0,1], many scholars use the Tobit model to analyze the influencing factors of innovation efficiency[8]. The Tobit model constructed in this study is as follows:

$$TTE^{*} = \alpha_1 E_{1it} + \alpha_2 E_{2it} + \alpha_3 E_{3it} + \varepsilon_{it} \tag{3}$$

The influencing factor system of enterprise S&T innovation efficiency is shown in the following Table 2:

**Table 2.** Input-output index system

| Stage | Variable | Explain | Symbol |
|---|---|---|---|
| Explained variable | R&D efficiency | - | $TTE_{it}^{(1)}$ |
| | TT efficiency | - | $TTE_{it}^{(2)}$ |
| Explaining variable | Capacity of government support | Expenditure on S&T accounted/total expenditure | $Techfund$ |
| | Level of opening up | Foreign investment | ln$FIE$ |
| | Economic development level | GDP value | ln$Localgdp$ |
| | Level of social development | Proportion of urban/Population in total | $Town$ |

## 3 Empirical analysis

### 3.1 Data collocation

This study selected the data of 30 provincial and municipal enterprises from 2009 to 2020, and the data came from China Statistical Yearbook and China Science and Technology Statistical Yearbook. Due to the time lag of R&D activities, the output data is processed with a lag of one phase. In the calculation process, the larger value is logarithmic.

### 3.2 Two-stage enterprise efficiency measurement

As can be seen in Fig. 1, from the perspective of the whole country, the conversion efficiency of the two stages showed different trends. The average R&D efficiency is 0.3751, lower than 0.9 overall, which is always lower than the TT efficiency, and the

efficiency value in 2020 has increased by 17.8% compared with 2010. The average TT efficiency is 0.6704, which is basically higher than 0.2 as a whole, maintaining a basically smooth trend from 2012 to 2016, but the conversion rate in 2020 is reduced by 0.08% compared with 2010.

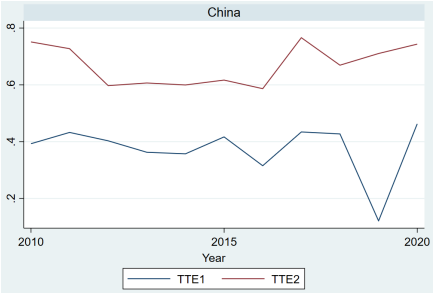


**Fig. 1.** Dynamic change chart of efficiency of two-stage enterprises in China

As can be seen in Fig. 2, from the perspective of provinces and cities, the absolute value of R&D efficiency of enterprises in 30 provinces and cities in China is between 0.1-0.9, and the absolute value of TT efficiency of enterprises is between 0.2-1.0, showing an upward and downward trend. The innovation efficiency values of eastern regions such as Beijing, Jiangsu, Shanghai, Zhejiang and Guangdong were higher than those of other provinces and cities, while the efficiency values of western provinces and cities such as Xinjiang, Yunnan, Sichuan and Shaanxi were lower. Due to the extremely low undesired output in Qinghai Province, the relative values of R & D efficiency and conversion efficiency calculated are relatively high.

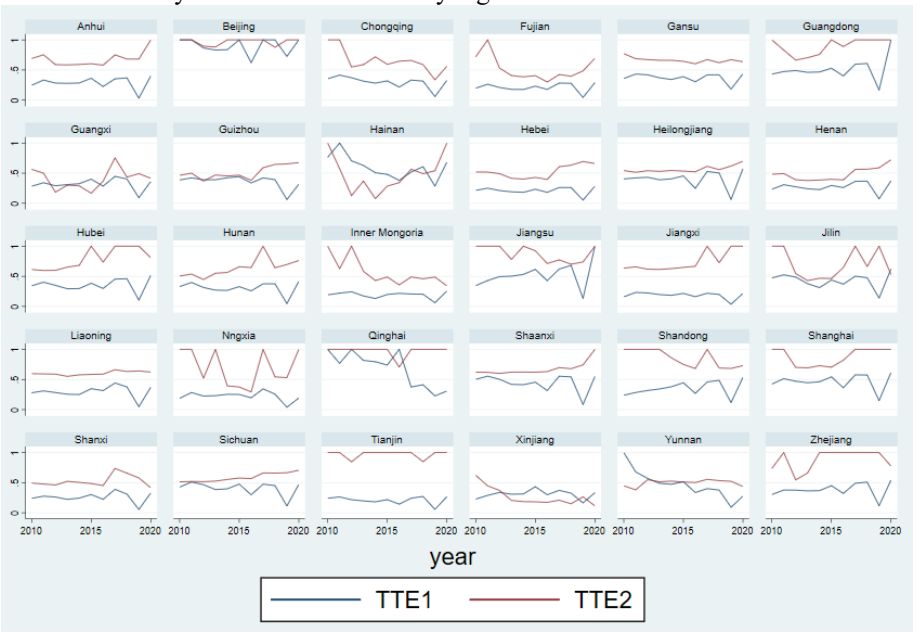


**Fig. 2.** Dynamic change chart of efficiency of two-stage enterprises in all provinces and cities

### 3.3 Tobit regression results

The Tobit model was further adopted, and the two-stage conversion efficiency was taken as the expected variable to conduct regression test on the possible influencing factors. The regression results are shown in Table 3.

**Table 3.** Regression results

| Variable name | $TTE_{it}^{(1)}$ | | | $TTE_{it}^{(2)}$ | | |
|---|---|---|---|---|---|---|
| | *Coef.* | *Std. Err.* | *p* | *Coef.* | *Std. Err.* | *p* |
| $Techfund$ | 4.509*** | 1.502 | 0.003 | 8.054*** | 1.585 | 0.000 |
| ln$FIE$ | 0.026** | 0.013 | 0.049 | 0.028** | 0.014 | 0.041 |
| ln$Localgdp$ | -0.102*** | 0.029 | 0.000 | -0.067** | 0.027 | 0.014 |
| $Town$ | -0.209 | 0.196 | 0.287 | 0.143 | 0.199 | 0.471 |
| $\_cons$ | 1.225*** | 0.219 | 0.000 | 0.890*** | 0.219 | 0.000 |

Standard errors in parentheses * $p < .10$, ** $p < .05$, *** $p < .01$

According to the regression results, all the other variables have significant effects on $TTE_{it}^{(1)}$ and $TTE_{it}^{(2)}$, except that *Town* has no significant effect on the efficiency value of the two stages. In addition, *Techfund* is significantly positive at the 1% level; ln*fie* is significantly positive at the 5% level. ln*Localgdp* has a negative impact on $TTE_{it}^{(1)}$ at 1% level and on $TTE_{it}^{(2)}$at 5% level, and the impact coefficient is close to 0. The regression results are consistent with Lai[9]. It can be concluded that rent-seeking behavior is prone to occur when the regional economic development level is high, and scientific research funds will flow to other fields.

### 3.4 Robustness testing

In this study, the robustness of Tobit model was tested by tailed regression. After the test, the significance and direction of influence of each variable on $TTE_{it}^{(1)}$ and $TTE_{it}^{(2)}$ did not change, which proved that the regression results were robust.

## 4 Conclusion and Future Research

### 4.1 Conclusion

First of all, the TT efficiency of Chinese enterprises is much higher than that of R&D, indicating that enterprises in various provinces and cities pay more attention to the transfer and application of scientific and technological achievements than R&D. Secondly, the dynamic variation diagram of efficiency values in the two stages of provinces and cities fluctuates up and down, and the efficiency values of provinces and cities in

the eastern region are higher than those in other regions. Finally, *Techfund* and ln*FIE* have a significant positive impact on R&D efficiency and conversion efficiency.

### 4.2 Implication and Limitation

Based on the empirical results, this study makes the following recommendations.

First of all, the government should rationally allocate scientific and technological resources. Secondly, local governments and enterprises should attach importance to the coordinated construction of innovative environment. Finally, local governments should continue to increase the proportion of S&T expenditures in total fiscal expenditures, increase foreign investment, and absorb and integrate foreign technologies.

The limitation of this study is that the number of influencing factor indicators is limited due to the data integrity of the statistical yearbook. Future studies can support the analysis of new influencing factor indicators through different calculation methods.

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