EVALUATION OF SCIENCE AND TECHNOLOGY FINANCE EFFICIENCY - BASED ON SUPER EFFICIENCY DEA MODEL

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ABSTRACT
Development of science and technology is closely related to financial investment and government support, thus, science and technology participants' behavior and related input-output factors are analyzed to improve government's technological effectiveness in science and technology investment. In this research, Super efficiency DEA model and Malmquist index are applied to evaluate the characteristics of science and technology finance efficiency in the perspective of space and time. Our analysis enables policy makers to identify an area's strength and weakness in science and technology, and integrate these results on special financial support.

Keywords: Super Efficiency DEA; Science and Technology Finance; Malmquist Index; Efficiency.

1. Introduction

In terms of t social development, China is one of the fastest growing economies in the world. As one of the typical production factors, technology innovation is increasingly important for sustainable economic growth and structural transformation.

At present, China's economic growth mainly relies on low-tech and energy-intensive industries, which has caused poor status of science and technology development. Therefore, transforming traditional model of extensive economic development with modern financial and technological innovation is necessary for China. In a long period, China's industry remains in a relatively low level, for not achieving powerful policy support in technology, finance and development. Thus, the government should focus on solving financing difficulties of technological innovation-based enterprises, especially the small and medium enterprises, to in line with the focus of technology and finance integration of China's Science and Technology Development Financial Report (2013). Meanwhile, the framework of National Science and Technology Financial Strategy proposed on International Science and Technology Summit Forum has pointed out the positive interaction between technology and capital as well as China's technological innovation and financial system. This meeting also emphasized the guiding role of government planning, serving and reforming, which helps to achieve the driving force of science and technology finance in process of social capital marketization.

Since innovating distribution way of national science and technology subsidy, while combining research aid, venture capital and stages equity participation have been researched to stimulate enterprises to invest in technological innovation. Vasilescu and Popa (2011) pointed out that venture capital is a small part of the larger asset class of alternative investments, it is essential for the growth of innovative firms. Meanwhile, special investment fund of the government can guide the local government to establish science and technology(S&T) innovation investment fund by allocating more social financial resource to S&T field, forming a linked S&T innovation investment system eventually. In addition, the government need to pay more attention to transformation feature of technological achievements and the principle of input-output in technology-based enterprises to target accurately the potential high-growth technology regions.

Methodology of research on S&T finance domestic and overseas mainly focuses on two methods: Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA). Griliches and Lichtenberg (1984) studied the relationship between American 193 manufacturing industries and technology R&D funding, explaining that the investment in R&D expenditure intensity is closely related to total factor productivity growth. Nasiorowski (2008) estimates whether funds are effectively used by analyzing the EU European Innovation Scoreboard data in DEA model. Similarly, the Innovation Union Scoreboard (IUS) / European Innovation Scoreboard (EIS) index are applied to measure technical innovative efficiency with which countries transform innovativeness inputs into innovativeness outputs is measured through DEA (Nasierowski and Arcelus,2010). Moreover, Fandel (2003) applies a nonparametric DEA approach to estimate technical efficiency of different size of groups of farms. Cullmann et al. (2012) applied the same method assessing the relative efficiency of knowledge production in the OECD, given the institutional and legal constraints, resources allocated to R&D are limited and therefore must be used efficiently. Domestic researches are as following, Wang *et al.* (2003) adopted AHP method to evaluate the combination efficiency of technology and finance in China from 1991 to 1999. According to 22 provinces' technology statistics in China from 2005 to 2008, Zhao (2012) estimated the relative efficiency between technological finance and technological innovation by means of DEA. The existing literature shows that the domestic research on technological finance efficiency evaluation is still at a preliminary stage. Although some scholars have adopted the method of DEA to improve the credibility of the results, reducing subjective influence to a certain degree in calculation process. The traditional DEA model cannot distinguish and rank effective units. Under this circumstance, super efficiency DEA model and Malmquist index are applied from both static and dynamic level, indicating the improved financial expenditure can boost the effectiveness of special technology fiscal investment in different regions.

2. Methodology

2.1. Indicators and data sources

The studied area covers 25 provinces and municipalities, which are then divided into three regions from east to west by the *China Statistical Yearbook*, then regarding these regions as the DUMs to assess S&T finance efficiency. Based on current research (HUA etal.,2013), the data is mainly from different levels of *China's statistical yearbooks*. The financial input indicators include R&D expenses, the percentage of local financial provision funds to total financial expenditure, high-tech industry assimilation and introduction expenditure. Among these indicators, R&D expenses reflects regional strength of S&T, serving as the basis of overall strength and competitiveness, while the percentage of local financial provision funds to total financial expenditure measures the local support intensity for S&T. High-tech industry assimilation and introduction expenditure indicates total expenditure for technical innovation and application by local enterprises.

New product sales revenue of high-tech industries, the accepted and authorized number of patents for invention, the number of technology transaction contracts are chose as the scientific output indicators. The sales revenuer explains direct results of S&T activities, which combines the financial input and scientific output. The accepted and authorized number of patents for invention reflects the non-industrialization achievement of S&T activities. The number of transaction contracts also measures the outcome of non- industrialization, which is applied to record object amount of accepted and registered technical contracts (See Table 1).

Table 1 Input and output indicators of S&T efficiency

Objective Level	Indicators
Financial Input	R&D expenses percentage of local financial provision funds to total financial expenditure High-tech industry assimilation expenditure High-tech industry introduction expenditure
S&T Output	New product sales revenue of high-tech industries Accepted number of patents for invention Authorized number of patents for invention The number of technology transaction contracts

2.2. Research Method

2.2.1. Super Efficiency DEA model

Based on classic Data Envelopment Analysis(DEA), Super Efficiency DEA is put forward to compare the efficient evaluation values. To overcome the deficiency of classic model, Andersen and Perterson (1993) modified traditional input-output assessment process by excluding the DUM_i when judging the potential assessment sets, then project DUM_i to the production frontier to make the final comparative efficiency evaluation. The model is as follows:

$$\max\left[\theta_k-\varepsilon\left(\sum_{m=1}^{t}s_m^-+\sum_{n=1}^{r}s_n^+\right)\right]=v_d\left(\varepsilon\right)$$

$$s.t.\begin{cases}\sum_{j=1,\ j\neq k}^{n}x_{jm}\lambda_j+s_m^-=x_{km} & \forall m\\ \sum_{j=1,j\neq k}^{n}y_{jn}\lambda_j+s_n^+=\theta_k y_{kn} & \forall n\\ \lambda_j\geq 0;s_m^-\geq 0;s_n^+\geq 0\\ j=1,2,\cdots,n;m=1,2,\cdots,t;n=1,2,\cdots,r\end{cases}$$

Where s_m^-、s_n^+ are slack variables of object programming model, ε is non-Archimedean infinitesimal, x_{jm} is financial input indicator m of region j, y_{jn} is the scientific output indicator n of region j, λ_j is the weight, $1/\theta_k$ is the final comparative efficiency of DUM$_k$ named S&T Finance Efficiency in this paper. In the function, $1/\theta_k$ represents the capacity to convert input elements to output results. Meanwhile, the value of $1/\theta_k$ are no longer limited within 1, illustrating that the efficient DUMs can be ranked. Furthermore, this function can forecast the increased percentage of input factors while keeping the DUM efficient.

2.2.2. Malmquist Index

Malmquist Index was first introduced by Caves etal.(1982), then developed by Färe etc(1994). On the basis of Shephard's distance function, this index is used to describe the production techniques of multiple input variables and output variables. According to the methods of Shephard and Färe, the distance function of output indicators are defined as

$D_0^t(x,y) = \inf\{\delta : (x, y/\delta) \in P(x)\} = \left(\sup\{\delta : (x, \delta y) \in P(x)\}\right)^{-1}$, where x is the input matrix and y the output matrix, δ is the efficiency index intending to export, $P(x)$ is the potential productive sets. Malmquist index are defined:

$$M(x_t, y_t, x_{t+1}, y_{t+1}) = \sqrt{\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)}}$$

$D_0^t(x_t, y_t)$、$D_0^{t+1}(x_{t+1}, y_{t+1})$ are output distance functions by comparing the production plots with same stochastic frontier analysis in different periods. $M(x_t, y_t, x_{t+1}, y_{t+1})$ is total factor productivity index named *tfpch*. When the value of *tfpch* exceeds 1, meaning production efficiency is increasing, otherwise decreasing. This index *tfpch* can be discomposed as follows:

$$M(x_t, y_t, x_{t+1}, y_{t+1}) = \frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)} \times \sqrt{\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)}}$$

$$tfpch = effch \times techch$$

$$effch = \frac{S_0^t(x_t, y_t)}{S_0^t(x_{t+1}, y_{t+1})} \times \frac{D_0^t(x_{t+1}, y_{t+1} / VRS)}{D_0^t(x_t, y_t / VRS)}$$

$$= sech \times pech$$

$\frac{D_0^{t+1}(x_{t+1}, y_{t+1})}{D_0^t(x_t, y_t)}$ is the index of technology efficiency change ($effch$), explaining observation DUMs' change compared to technology efficiency and the quality of managing decisions. If *effch*>1, it means that the DUMs' productivity is in the process of optimizing with the increased technology efficiency. As a technical change index(*techch*), $\sqrt{\frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)} \times \frac{D_0^t(x_{t+1}, y_{t+1})}{D_0^{t+1}(x_t, y_t)}}$ describes the movement of production frontier in different periods, reflecting the technology progress and the degree of innovation. When *techch*>1, it means technology progress. Similar to VRS model, *effch* can be discomposed into scale efficiency change(*sech*) and pure efficiency change(*pech*) as well.

3. Methodology and Analysis of S&T Finance Efficiency

3.1 Comprehensive Evaluation of Static Science and Technology Finance Efficiency

Super efficiency DEA model demands that the number of decision-making units are not less than twice of input and output indicators in consideration of the data availability of decision-making units (regions). The annual input and output indicators of three areas from 2005 to 2013 are collected from *China Statistical Yearbook on Science and Technology* and *China statistical Yearbook on High technology Industry* from 2006 and 2014. Then they are used in super efficiency DEA model to get static S&T finance efficiency values in three regions every year, as shown in Table 3.

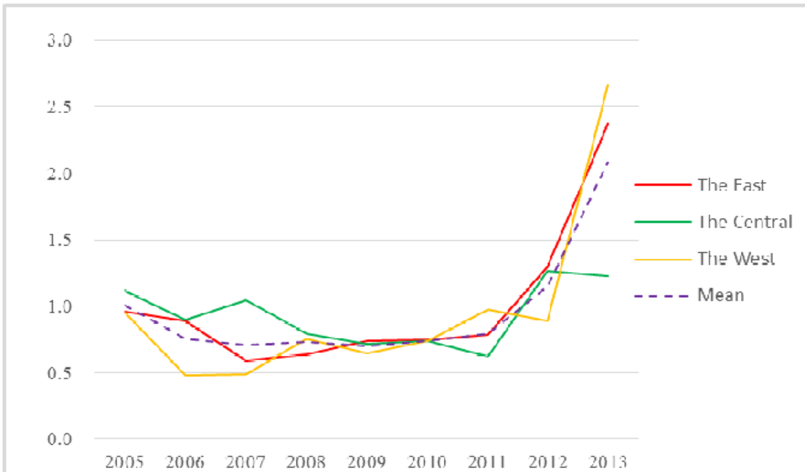
Table 3 Technology finance efficiency of China across regions (%)

DMU	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean
The East	96.08	88.53	58.82	63.91	74.02	74.67	78.45	129.57	237.38	100.16
The Central	111.51	89.64	104.57	79.24	71.69	73.61	62.12	126.28	122.58	93.47
The West	94.92	48.18	48.35	75.70	64.08	73.55	97.75	88.73	266.07	95.26

The result shows the "production efficiency" of S&T finance, namely S&T Finance Efficiency. It is apparent that the index share of production frontier in eastern region is much larger than that in middle and western regions, and the distance from the frontier closer than the two regions. Starting from 2005, S&T finance efficiency in eastern region was 96.08%, a little higher in middle region, the lowest in the west. In 2006, there was a subtle change in three regions with an obvious declining trend. During 2007 and 2011, technology finance efficiency had gone through dramatic fluctuations due to the effect of the financial crisis. Until 2012, it had improved significantly in all three regions, which means that the deepening of financial reform and the emphasis on national technological development had led to the maturity of organizational structure of China's technology industry, gradual stabilization as well as its stronger risk resistance. To further demonstrate the change of S&T finance efficiency in three regions, the mean of it in three regions has been recalculated in Figure 1 below.

As Figure 1 shows, China's S&T finance efficiency had an overall upward trend, rising from 101 in 2005 to 209% in 2011, but not exactly the same track. Actually, it had experienced a steady increase after a trough, and the downward trend in central area lasted a relatively long period, with the amplitude of no more than 1. In the west, it fluctuated the most dramatically, for that the development in middle and western region of China is closely related to the policy orientation, including the implementation of slack monetary and fiscal policies in 2007 and *the New Twelfth Five-year Plan* in 2011, which proposed the regional structure adjustment and western development acceleration strategy.

Figure 1 Financial Science and Technology Super Efficiency Trend across Region



During the late financial crisis, China's financial science and technology efficiency improved steadily, indicating the crucial strategic role of high-tech industry. At the same time, it also proved indirectly the continuous development of technicalization as well as the joint improvement in technology industry structure, organization management and business innovation. Above all, it explains the greater flexibility and autonomy of science and technology innovation.

3.2 Comparative Analysis of Dynamic Financial Science and Technology Efficiency

3.2.1 The holistic of financial science and technology efficiency

Table 4 The Holistic Evaluation of Financial Science and Technology Efficiency

Year	*effch*	*techch*	*pech*	*sech*	*tfpch*
2005-2006	1.000	1.045	1.000	1.000	1.045
2006-2007	1.000	0.980	1.000	1.000	0.980

2007-2008	1.000	1.096	1.000	1.000	1.096
2008-2009	1.000	0.933	1.000	1.000	0.933
2009-2010	1.000	1.136	1.000	1.000	1.136
2010-2011	0.952	1.269	0.954	0.997	1.208
2011-2012	1.051	2.293	1.048	1.003	2.409
2012-2013	1.000	1.415	1.000	1.000	1.415
Mean	1.000	1.159	1.000	1.000	1.159

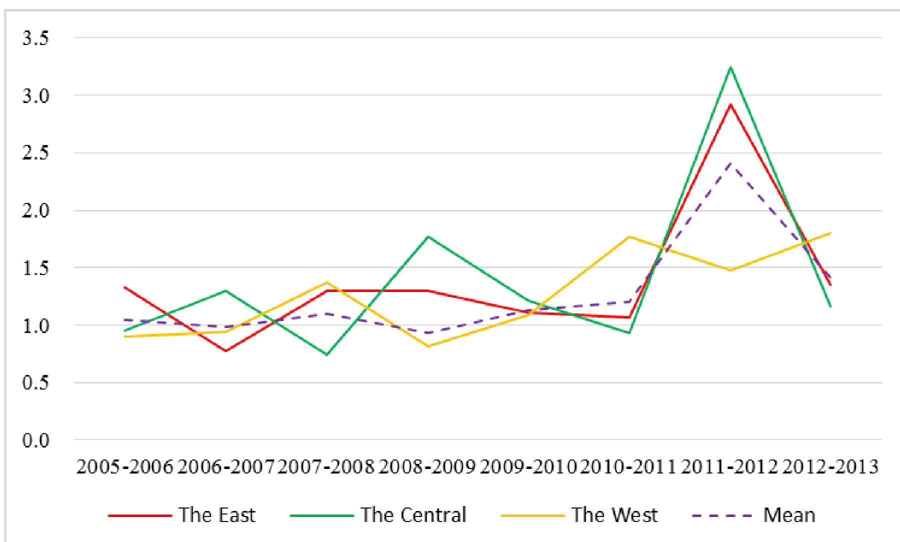
Notes: effch: change rate of technical efficiency；*techch*: rate of technical progress；*pech:* pure change rate of technical efficiency；*sech:* change rate of technical scale；*tfpch*: change rate of total factor productivity.

These 25 provinces are selected as data for Malmquist Index to represent the whole country's S&T finance efficiency. Among these Malmquist Indexes, *tfpch* indexes are no less than 1 from the year 2005 to 2006, 2007 to 2008 and 2009 to 2013, but close to 1 from 2006 to 2007 and 2008 to 2009, showing the positive trend of constant improvement of S&T finance efficiency. Since 2005, the overall macro-economy and financial market environment did run well until 2008. With the steady development of science and technology, *tfpch* values remained steadily at about 1. Financial crisis in 2008 had swept the whole globe, *tfpch* dropped to 0.933, for that floundering capital market involved financial science and technology market, which caused the insufficient input of science and technology. But then, it rose to 2.409, attribute to the technology industry's financial plan aiming to expand domestic demand. Followed by the weakened impact of macro-control, it then descended a little.

Further decomposition of *tfpch*, index of technical efficiency change rate(*effch*) and index of technological progress(*techch*) are obtained. If *effch*> 1 and *techch* <1, indicating that the increase of yield rate attributes to the effective management of high-tech enterprises such as the enhancement of resources utilization capacity, however, the technology level and innovation capacity remains to be improved. Table 3 shows that *effch* is in slight fluctuation around 1 from 2005 to 2013, meaning that science and technology industries in China stayed stable with little improvement space. Wherein 2009 to 2010 and 2011 to 2013, the rapid growth of *tfpch* is mainly benefit from technical progress. In addition, the loose monetary policy has widened the financing channels for technology companies, under this circumstance, their asset scale expanded rapidly, thus, technological progress and innovation had become the driving factor of output growth. In addition, *techch* kept high except in 2008, showing that technological advance and high-tech industries' innovation enhancement improved the total factor efficiency. Therefore, it is imperative to further promote technological progress and efficiency to adapt to the competitive external environment led by scientific and technological innovation. At the same time, the index *effch* can be subdivided into *pech* (pure technical efficiency) and *sech (*scale efficiency), overall scale efficiency rarely changed during the measurement period, with most pure technical efficiency value below 1. In summary, there is still a long way to go for high-tech industry management.

3.2.2 Dynamic evaluation of financial science and technology efficiency across regions

Figure 2 Trend of *tfpch* Index across Region



S&T finance efficiency in eastern part was higher than the other two regions, and amplitude of fluctuation declined successively from the east, the central and the west. The uncertainty of S&T financial development is small in the east, followed by the central region and the west smallest, which revealed the vulnerability and irregularity of scientific and technological development in three regions. For detailed *tfpch*, *effch* hardly fluctuated almost staying at 1, that is to say, the technical efficiency had not been significantly improved over nearly eight years in three regions. It is thought to be the result of single structure of current high-tech industries, internalization failure of profit and capital gain maximization. *techch* value equaled to *tfpch* value mostly explaining the “Effect of Moving on Stochastic Frontier” was closely related to the effectiveness of China's financial technology development. At the same time, *techch*> 1 represents the technological progress, technological innovation capability in central and western regions was unstable in given years, which was thought to be caused by the weak sense of marketing as well as insufficient overall marketing strategy. At this point, it called again for the necessity of special financial guidance on S&T to optimize resource allocation in these two areas. Based on this, robust special financial policies on S&T finance should be proposed to ensure rapid, steady and coordinated technological growth. In the east, technological financial support should be enhanced focusing on output growth speed and effectiveness.

4. Conclusion

Super-efficiency DEA model and Malmquist index is used to construct S&T financial model while improving the classic DEA deficiency in ranking effective evaluation units. Static S&T finance efficiency in three different regions are obtained through the index and distance in production frontier to formulate the trend of efficiency in different regions. Meanwhile, the overall dynamic S&T finance efficiency in China is analyzed through Malmquist indexes and trend chart, after that, by further decomposing Malmquist indexes, deficiencies in current S&T finance are found out to provide reference to policy makers.

Reference

Andersen P, Petersen N C. A procedure for ranking efficient units in data envelopment analysis[J]. Management science, 1993, 39(10): 1261-1264.

An-shun S, Xiang-li M I. A Game Analysis of Going out of Sole Price Competition in China’s Insurance Market under the Change of Economic Development Pattern[J]. 2012.

CHEN J, ZHAO S, YANG L. Multi-agent Decision-making and Simulation of Catastrophe Insurance Based on Grey Game Model [J]. Soft Science, 2012, 7: 029.

Carlota Perez. Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages[M]. Northampton (USA): Edward Elgar Pub, 2003.

Cullmann A, Schmidt-Ehmcke J, Zloczysti P. R&D efficiency and barriers to entry: a two stage semi-parametric DEA approach[J]. Oxford Economic Papers, 2012, 64(1): 176-196.

Färe R,Grosskopf S,Norris M and Zhang Z. Productivity growth, technical progress,and efficiency changes in industrialised countries[J].American Economic Review, 1994,(84):66-83.

Fandel P. Technical and scale efficiency of corporate farms in Slovakia [J]. ZEMEDELSKA EKONOMIKA-PRAHA-, 2003, 49(8): 375-384.

Liu E, Study on Intensifying Supervision of Senior Management of Basic Level Banks[J]. Economic Survey, 2012, （7） : 67-70.

Nasierowski W, Arcelus F J. On Perceptions of Technical Efficiency of the Basis of the Innovation Union Scoreboard[J].

Vasilescu L G, Popa A. Venture Capital Funding–Path To Growth And Innovation For Firms[J]. Annals-Economy Series, 2011, 1: 204-213.

WANG H, YE Y. Study on Efficiency Evaluation of Science Technology and Finance Integration [J]. Policy-making Reference, 2003, 2.

W. Nasierowski. Assessment of technical efficiency of NIS with the use of DEA[A], 2008: 104-109.

Zvi Griliches, Frank Lichtenberg. Inter industry Technology Flows and Productivity Growth: A Reexamination[J]. The Review of Economics and Statistics, 1984, 66（2）: 324-329.

Zhao Z, Research on S&T Finance effect on Technical Innovation [J], Financial Economy, 2012, （20） : 67-69.

HUA Y, ZHAO N. Study of T&F Efficiency Based on DEA Model——a Case of Anhui Province [J]. Research of Finance and Education, 2013, 3: 009.