Analysis on Technologic and Innovation Efficiency of Knowledge Intensive Industries: An Empirical Analysis on Chinese Zhongguancun Based on DEA-Malmquist Index

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***Abstract*—Knowledge intensive industries in Chinese Zhongguancun Science Park have been used to analyze technologic and innovation efficiency relying on DEA-Malmquist index at period from 2010 to 2013. The results demonstrate that technologic and innovation efficiency of knowledge intensive industries in Chinese Zhongguancun Science Park have been stable, but seven main industries of them have declined which is due to scale efficiency down.**

***Index Terms*—knowledge intensive industries, technologic and innovation efficiency, DEA-Malmquist index, empirical analysis**

I. Introduction

Following Chinese economics is going into New Normal, optimizing industries' structure and fostering economical increase are paid more attention. The driver on economic development turns to innovation driver from essence driver and capital driver. As the beginning of technologic and innovation, knowledge intensive industries are more important. Lots of empirical results proved that scientific innovation efficiency increasing is more relying on conduction of industries parks, where resources, technologic and service are flowing conveniently. Superiority on region and purity on chain are both making cost down, leading to improving firms' performance. There is much literature of study on technologic and innovation efficiency of knowledge intensive industries. For example, Zhao and Wang (2015)[1] analyzed results of 109 samples in Wuhan East Lake High Science and Technologic Park using SEM, stating that there are interactions between enterprise cluster and technological innovation, and meanwhile enterprise cluster has a significant impact on enterprise scale. Furthermore, enterprise cluster has an impact on economic development. Liu and Wu (2015) [2]compared 8 economic forms of 5 famous capital economic circle using method of range threshold, finding that big city sick can not be resolved by single Beijing except for cooperative development between Beijing, Tianjin and areas around them. This could help achieve industries structure optimizing. Rashmi (2009)[3] proposed that different areas may lead to performance that efficiency occurs upstream and downstream firms, impeding knowledge spread and diffusion. Michele Smith and Frederick Hansen (2002)[4] analyzed management behavior of knowledge intensive industries from the perspective of strategy and proposed firms should put intellectual property strategy into business strategy in the process of technologic and innovation of knowledge intensive firms, rather than separating intellectual property strategy from business strategy. The results help industries parks make management method and construct corresponding institution.

Chinese Zhongguancun Science Park has established more than 30 years. It developed from electronic industry, the most advanced science, to complex industries, including the Second and Third Industry. Zhongguancun Science Park is important for Chinese science parks, and it is the biggest and famous industries cluster in China, heading most knowledge intensive industries cluster. Zhongguancun has been divided into one zone and 16 parks, including 15455 firms, 1898756 clients, developing 7890.3 billion industrial output values. Study on technologic and innovation efficiency of knowledge intensive industries in Chinese Zhongguancun Science Park helps understand situations of Chinese science parks' construction and find domain problems of Chinese science parks, in order to offering advice for Chinese other science parks.

II. Methodology

At the beginning, Malmquist Sten (1953) posed Malmquist index and it was named as his. Till 1982, Caves (1982) etal applicated Malmquist index to measure productivity efficiency change. And then, in terms of illustrating dynamic change of relative efficiency, researchers combined Malmquist index with DEA theory. The application of DEA-Malmquist index method in the measurement of productivity efficiency is increasingly widespread.

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A. The Definition of Malmquist Index

There are n DMUs and every DMU uses m kinds of input and s kinds of output at moment t. $x_j^t = \left(x_{1j}^t \quad x_{2j}^t \quad \cdots \quad x_{mj}^t\right)^T$ means input numbers of DMU j at moment t, respectively, $y_j^t = \left(y_{1j}^t \quad y_{2j}^t \quad \cdots \quad y_{sj}^t\right)^T$ means output numbers of DMU j at moment t. And at meanwhile, the numbers of input and output are both positive numbers, t=1，2，…，T.

The foundation of formulating Malmquist index is distance function. To make the distance function of $\left(x^t \quad y^t\right)$ at moment t as $D^t\left(x^t \quad y^t\right)$, the distance function of $\left(x^t \quad y^t\right)$ at moment t+1 as $D^{t+1}\left(x^t \quad y^t\right)$; to make the distance function of $\left(x^{t+1} \quad y^{t+1}\right)$ at moment t as $D^t\left(x^{t+1} \quad y^{t+1}\right)$, the distance function of $\left(x^{t+1} \quad y^{t+1}\right)$ at moment t+1 as $D^{t+1}\left(x^{t+1} \quad y^{t+1}\right)$.

Under the technological materials of moment t, the change of technological efficiency at period from moment t to moment t+1 as $M^t = \frac{D^t\left(x^{t+1} \quad y^{t+1}\right)}{D^t\left(x^t \quad y^t\right)}$. And under the technological materials of moment t+1, the change of technological efficiency at period from moment t to moment t+1 as $M^{t+1} = \frac{D^{t+1}\left(x^{t+1} \quad y^{t+1}\right)}{D^{t+1}\left(x^t \quad y^t\right)}$. Using geometric mean of above two Malmquist index of productivity, the change of productivity efficiency at period from moment t to moment t+1 as follow:

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

B. The Form of Decomposition of Malmquist Index

Data envelopment analysis(DEA) measures the relative efficiency of decision making units (DMUs)with multiple inputs and multiple outputs. DEA-based Malmquist productivity index measures the productivity change over time. The DEA-based Malmquist productivity index can be decomposed into two components: one measuring the technical change and the other measuring the frontier shift. (Yao Chen, Agha Iqbal Ali. 2004) Fare (1994), Ray S C (1997), Zhanxin Ma (2013) proposed decomposing Malmquist index into two components, namely technical progress index (TC) and comprehensive technical efficiency change index (TEC). Furthermore, comprehensive technical efficiency change index (TEC) is component of pure technical efficiency change index (PTEC) and scale efficiency change index (SEC). The formulation of decomposition is as follow:

$$M\left(x^t \quad y^t \quad x^{t+1} \quad y^{t+1}\right) = TC \times TEC = TC \times PTEC \times SEC$$
$$= \left[\frac{D_c^t\left(x^t \quad y^t\right)}{D_c^{t+1}\left(x^t \quad y^t\right)} \times \frac{D_c^t\left(x^{t+1} \quad y^{t+1}\right)}{D_c^{t+1}\left(x^{t+1} \quad y^{t+1}\right)}\right]^{\frac{1}{2}} \times \frac{D_v^{t+1}\left(x^{t+1} \quad y^{t+1}\right)}{D_v^t\left(x^t \quad y^t\right)} \times \frac{D_c^{t+1}\left(x^{t+1} \quad y^{t+1}\right) / D_v^{t+1}\left(x^{t+1} \quad y^{t+1}\right)}{D_c^t\left(x^t \quad y^t\right) / D_v^t\left(x^t \quad y^t\right)}$$

Inside above formulation,

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

$$PTEC = \frac{D_v^{t+1}\left(x^{t+1} \quad y^{t+1}\right)}{D_v^t\left(x^t \quad y^t\right)}$$

$$SEC = \frac{D_c^{t+1}\left(x^{t+1} \quad y^{t+1}\right) / D_v^{t+1}\left(x^{t+1} \quad y^{t+1}\right)}{D_c^t\left(x^t \quad y^t\right) / D_v^t\left(x^t \quad y^t\right)}$$

$D_c\left(x \quad y\right)$ means distance function of constant scale return; $D_v\left(x \quad y\right)$ means distance function of variable scale return

C. Economical Meaning of Malmquist Index

Malmquist index measures dynamitic change of total factor productivity at period from moment t to moment t+1. When the number is more than 1, total factor productivity at period from moment t to moment t+1 is improving and efficiency enhances. When the number is less than 1, it demonstrates that total factor productivity declines and efficiency is down at this period. When the number equals 1, then total factor productivity and efficiency are both as the same as formal.

Technical progress index (TC) means frontier shift at period from moment t to moment t+1, revealing the degree of change of productive technologic. In productive activities, this index demonstrates innovative level of firms. If the number is more then 1, then DMU is projected onto a facet which has a positive shift and the technology of DMU progresses. If the number is less than 1, it indicates that DMU will be projected onto a facet which has a negative shift and the technology of DMU declines.

Technical efficiency change index means degree of progress of DMUs comparing productive frontier at period from moment t to moment t+1, namely degree of innovative technological change. In productive activities, this index indicates whether the management method of firms is proper and whether the decisions of managers are right. If this number is more than 1, it means technical efficiency is improved and the method of management and decisions are both right. If this number is less than 1, then it demonstrates that technical efficiency declines and methods and decisions are not proper.

D. Application of Malmquist Index

Fuh-Hwa Franklin Liu and Peng-Hsiang Wang (2008)[5] measured production efficiency of Taiwanese semiconductor packaging and testing firms using DEA-Malmquist index. Yao Chen (2003) [6] measured production change index in Chinese textile industry, chemical industry and metal manufacturing at the period of four five-plan relying on DEA-Malmquist index. In this paper, we use DEA-Malmquist index to analyze technologic and innovation efficiency of knowledge intensive industries in Chinese Zhongguancun Science Park, because it could release mistakes of results due to no need to confirm formulation, which is convenient to compare with other industries at the same time.

III. Empirical Results

Statistics are from annual technical reports of Zhongguancun Science Park. And we choose typical knowledge intensive industries to compare development level of Zhongguancun, including Silicon Valley in USA, Cambridge Science Park in UK, Marne la Vallee in France, Seoul Science Park in Korea, Tsukuba Science City in Japan, Bangalore Software Park in India and Taiwanese Hsinchu Science Park. Comparing statistics are from American National Bureau of Statistics (http://census.gov), British National Bureau of Statistics (http://www.ons.gov.uk), French National Bureau of Statistics (http://www.insee.fr), Korean National Bureau of Statistics (http://kostat.go.kr), Bureau of statistics of the Ministry of internal affairs (http://www.stat.go.jp), Indian National Bureau of Statistics (http://www.mospi.gov.in), Chinese National Bureau of Statistics (http://data.stats.gov.cn) and Zhongguancun Science Park (http://www.zgc.gov.cn). The domain industries are semiconductor and computer in Silicon Valley. In Cambridge Science Park, there are mainly high technical medium and small enterprises. Technological research and development industry and leisure industry are main in Marne la Vallee. In Seoul Science Park, digital industry, biotechnological science and finance service are domain industries. Tsukuba Science City is built in the center of science and technologic. Software packaging is leading industry in Bangalore Software Park. In Taiwanese Hsinchu Science Park, the dominant industries are semiconductor, photoelectric, computer and communication. In total, these science parks are established by knowledge intensive industries.

Measuring technologic and innovation efficiency of knowledge intensive industries needs input factors and output factors. As previous literature, we choose full time R&D personnel (X_1) as human input and R&D fund expenditure (X_2) as capital input, and meanwhile, selecting annual patent application amount (Y_1), revenue (Y_2) and sales profit (Y_3) as output.

The results of technologic and innovation efficiency of knowledge intensive industries in Zhongguancun Science Park are as Table I using DEAP2.1.

TABLE I. Decompositon of Technologic and Innovation Efficiency from 2010 to 2013

Year	PTEC	SEC	TEC
2010	1.000	1.000	1.000
2011	0.991	0.984	0.975
2012	1.000	1.000	1.000
2013	1.000	1.000	1.000
Mean	0.994	0.998	0.996

From the results of Table I, technologic efficiency index declines at period from 2010 to 2013, mainly in 2011, down 25%. This means management method may not be proper and management efficiency has declined from 2010 to 2011. Technologic efficiency index divides into pure technologic efficiency index and scale efficiency index. Pure technologic efficiency index has declined 9% and scale efficiency index has declined 16% from 2010 to 2011. These two indexes interact with each other and they have declined 25%. Namely, when the input resources are constant in knowledge intensive industries of Zhongguancun Science Park, output capability has declined and scale of industry has been limited. At other three periods, technologic efficiency index is 1, meaning the level of technologic is stable in these periods.

Between 2010 and 2013, except 2 industries in Zhongguancun Science Park changed in 10 main industries, other 8 industries are stable, which are communication and electronic industry, civil engineering construction industry, software and information industry, professional technical service, business service, technology promotion and application service industry, research and experiment development; telecommunications and satellite transmission service. Except civil engineering construction industry, other 7 industries are all belong to knowledge intensive industries. The results of empirical analysis for 7 main industries as Table II.

TABLE II. 7 Knowledge Intensive Industries Technologic and Innovation Efficiency between 2010 and 2013

Industry	PTEC	SEC	TEC	TC	M
Communication and Electronic	1.000	0.800	0.800	1.169	0.935
Software and Information	1.000	0.869	0.869	0.919	0.799
Professional Technical Service	1.057	0.844	0.892	1.109	0.989
Business Service	1.000	1.000	1.000	1.041	1.041
Technology Promotion and Application Service	1.000	1.000	1.000	0.981	0.981
Research and Experiment Development	1.000	0.838	0.838	0.961	0.805
Telecommunica-tions and Satellite Transmission Service	1.183	0.749	0.886	1.081	0.958
Mean	1.032	0.867	0.895	1.034	0.926

TABLE III. THE MAIN ECONOMIC INDEX COMPARING IN SCIENCE PARKS

Science Park	Per capita land area	Revenue income proportion	Profit proportion	Service industry proportion
Silicon Valley in USA	5670	72.33	92.37	92.55
Cambridge Science Park in UK	5320	71.35	91.96	90.64
Marne la Vallee in France	5781	65.49	46.70	87.40
Seoul Science Park in Korea	2091	89.78	96.89	71.90
Tsukuba Science City in Japan	1179	81.07	98.60	81.40
Bangalore Software Park in India	5742	88.77	97.32	83.76
Taiwanese Hsinchu Science Park	813	82.37	94.33	90.58
Zhongguancun Science Park	3891	65.63	77.67	72.11

The results from Table II demonstrate that, in 7 main knowledge intensive industries of Zhongguancun Science Park, business service industry's technologic and innovation efficiency has increased 4.1%, while other 6 industries have decreased in different degrees. Software and information service industry has decreased 20.1% and research and experiment development industry has decreased 19.5%, who are the most decreasing two industries. Professional technical service industry and technology promotion and application service industry have declined a little more, respectively 1.1% and 1.9%. Through decomposition of Malmquist index, we could find the reason leading to technologic and innovation efficiency declining is decrease of technological efficiency index. Specifically, 5 industries' technical level indexes are more than 1, meaning that these 5 industries have developed, while technological efficiency indexes have been down more, which leading to the results of total declining. 5 of 7 knowledge intensive industries' technological efficiency indexes have descended except business service industry and technology promotion and application service industry at period of 2010 to 2013. This result means that there are some problems on management method and skill in knowledge intensive industries, and management efficiency is not enough satisfied. Furthermore, the reason of technical efficiency index declining is that pure technical efficiency index is equal to or more than 1, while scale efficiency index is declining deeply, leading to total declining tendency. This result demonstrates that 7 industries are effective on pure technical efficiency and invalid on scale efficiency.

Comparing other famous science parks, revenue income of knowledge intensive industry in Seoul Science Park is occupied 89.78% in knowledge intensive industry in Korea, which is the highest. And profit of knowledge intensive industry in Tsukuba Science City is occupied 98.60% of total knowledge intensive industry's profit in Japan, which is the highest. While these two factors are not competitive in Zhongguancun Science Park because many science parks around economic developed areas, famous universities and research institutions in China, which are scattering distribution of knowledge intensive industry. These two statistics are still proving that position of Zhongguancun Science Park is very high in Chinese knowledge intensive industry. It is worth to say that the proportion of knowledge intensive service industry in science park, Silicon Valley in USA is most developed and mature, while Zhongguancun in China is low. This means China have paid more attention to knowledge intensive manufacturing industry, meanwhile, service to support these industries is not following and cooperate to develop these industries is not suitable, which are leading to scale efficiency below.

Technologic and innovation efficiency of knowledge intensive industry has changed because of many factors. This paper chose 5 foundational factors to analyze change of technologic and innovation efficiency of knowledge intensive efficiency in Zhongguancun Science Park, constructing Tobit regression model as below: β_0 is intercept, and $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are variable regression coefficient, meanwhile i is on behalf of the industry serial number (i=1, 2,…,7) and t is on behalf of the period (t=1,2,3,4), ε as residual term. ME is representative to technologic and innovation efficiency or Malmquist efficiency. HD represents human density which is measuring by proportion of R&D clients and total clients. RD means research density whose measurement standard is proportion of R&D expenditure and total output value. And MC represents market competition which is measured by number of firms. KE means knowledge efficiency which is proportion of inventions patents and patents application. PE is on behalf of product efficiency which is proportion of new product sale income and total income.

TABLE IV. THE RESULTS OF REGRESSION OF TECHNOLOGIC AND INNOVATION EFFICIENCY OF KNOWLEDGE INTENSIVE INDUSTRIES IN SCIENCE PARK

Explanatory Variable	Coefficient	Standard Error	T	Sig.
	1.087^{***}	0.132	8.234	0.000
HD	0.518^{*}	0.299	1.738	0.096
RD	0.016^{*}	0.250	0.063	0.095
MC	0.020	0.000	0.094	0.926
KE	0.007^{*}	0.249	0.034	0.097
PE	0.152^{*}	0.302	0.571	0.057

* means result is significant at the level of 0.1.*** means result is significant at the level of 0.01.

The results of regression reveal that human density, research density, knowledge efficiency and product efficiency are through the significance test except market competition. The coefficient of market competition is 0.020, which demonstrates that number of firms in the same industry is improving effect on enhancing technologic and innovation efficiency in knowledge intensive industries but not significant. This may be because supporting facilities, policy guidance and service level are not following the pace of scale expansion of industries, although increasing number of firms and expansion of scale indeed improve technical innovative capability.

From the analysis of statistics, we find knowledge intensive industry's programming in Zhongguancun Science Park has some problems. First, the overall industry plan is still relatively messy. There is no control on scale of industries, which leads to scale efficiency declines. This problem pulls down the benefits from the enhancing technological innovative level. Therefore, technologic and innovation efficiency is not increased although level of innovation is enhanced. Secondly, development of industries is uneven. The essential reason is declining of scale efficiency. Many enterprises settled into the park, just piling up not formulating integration. There is redundancy in the upstream and downstream industry chain, which makes no worthy economic benefits following service costs enhanced. Between various industries, there is not smooth interaction with each other and the circle of capital economic center is not reflecting real radiation effect. Finally, there are some problems in the overall management methods and skills of knowledge intensive industrial park, which makes the management efficiency is not high and the speed of the industrial technologic and innovation efficiency is increased.

IV. Conclusion and Implication

In this paper, we use DEA-Malmquist index to analyze technologic and innovation efficiency of knowledge intensive industries in Zhongguancun Science Park. The results demonstrate the level of overall technologic and innovation is no significant changeable at period of 2010 to 2013. In 2011, the level has declined because of interaction effect both pure technological innovative efficiency and scale efficiency. Through analyzing 7 major knowledge intensive industries' technical innovative efficiency, we find that technical level of industries and industrial technological innovative development are both showing a rising trend. Due to larger decreasing in scale efficiency, these industries have occurred the performance of lack of technologic and innovation efficiency. The scale efficiency change index of telecommunication, radio and satellite transmission service industry is the biggest, reaching 25.1%.

This paper argues that the technologic and innovation efficiency of the region should be promoted from the following aspects:

First, through the institutional innovation, the government planning model is based on the market mechanism. Through the construction of mechanism of government planning and market guidance to gather technologic and human resources, and to improve the level of R&D innovation, to enhance the scientific transformation ability, to promote the formation of new products and new technology, to promote economic development. On one hand, government use market mechanism to amplify financial leverage through turn special funds into guiding funds. One the other hand, the government begins to transform to a creative role fostering fair competition in the market environment, paying more attention to create a platform for innovation and entrepreneurship, space and environment. On 3th of December in 2014, Chinese Prime Minister Li Keqiang presided over the State Council executive meeting and pointed out that it will promote construction of Zhongguancun 10 pilot policy, accelerate the national independent innovation demonstration area's construction, and further encourage public entrepreneurship and pubic innovation. In previous studies, there are some explorations on market mechanism to regulate the economic development of knowledge intensive industry. Alfred D. Chandler (2014) argues that the practice of American high-tech firms in Silicon Valley is to the market mechanism to natural regulation of production resources allocation, and it is relying on visible and invisible hand. Zhao (2015)[7] has compared Chinese Zhongguancun with Silicon Valley, and believes that construction of independent innovation system in Zhongguancun exist many gaps with Silicon Valley. The institutional innovation's speed is much lower than that of the speed of innovative development. Zhao believes that whether a national independent innovation system is good or not could be measured from three dimensions of scale competitiveness, brand influence and vigor of system.

Secondly, planning the construction of the park rationally is convenient to co-ordinate the distribution of enterprises. To solve the problems of enterprises association lowness in park, no industrial ecosystem and no Jacobs spatial externality (2015), park should strengthen service system's construction to construct the ecological environment of science and technology and to improve service capability of science, technology, research, consulting, trade and transformation. The time relying on aggregation of upstream and downstream chain has passed. In the era of network, park needs looking for differences in localization in terms of research, experiment, industrialization, incubation and market application function, to guide the innovation resources on the functional layout. Jonathan (2000) [8] and Ramkrishnan (2009)[9] both believe that the process of technological innovation depends on the construction and the perfection of the information system. Park should improve public service platform construction, maintain public information network, develop public R&D projects, change past weak relation network of enterprises and formulate cooperative innovation mechanism of close cooperation between industries, research institutions and universities.

Furthermore, improving the efficiency of knowledge intensive industries in park is on the foundation of researching policy mechanism to deal with enterprise scale expansion and following management control ability declining due to the unbalanced development of industries and scale inefficiency (2015) [10]. Ling (2015) [11] has researched medium and small firms in Zhongguancun Science Park, and found that the leading enterprises in the park are basically large state-owned enterprises. From 1994 to 2012, comparing the output value of 20 leading enterprises with general enterprises, by 1.7 times up to 500 times, gap is pulled apparently bigger. Small and medium enterprises often struggle in the edge of survival. This phenomenon needs equality and inclusive manner of communication, free and open atmosphere for innovation transformation, thereby to stimulate innovative behavior and achieves continuingly producing, to achieve the vigorous situation of public entrepreneurship and public innovation.

Finally, providing adequate geographical area, the plant experiments, communication environment and supporting infrastructure to construct national laboratories in park makes national key scientific and technological innovation projects from universities' theoretical frame to docking process with knowledge intensive industries. This has an important role on theoretical research into conversion efficiency and transformation of commercialization. This could solve the previous and complex problem of difficulty to concentrate on a large number of research groups and difficulty to realize interactive innovation in R&D progress.

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