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The Innovation Efficiency of High-tech Zones of China by Entropy Method

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The efficiency of high-tech developmental zones in China is difficult to be evaluated since it is influenced by a variety of factors, and few works have been conducted for researching the comprehensive efficiency of high-tech zones in China. According to the Entropy Method, the comprehensive efficiency of high-tech developmental zones in China, which are established from 2007 to 2016, was estimated. The results indicated that the efficiency of patent output increased stably while the relationship between efficiency of technological investment and efficiency of revenue differed in three stages. In the first stage, the development of high-tech industries was driven by investment, however, in stage two, the main driving force was replaced by patents output of the last stage, while the rate of increase began to decrease in stage three, even with a higher patent output and technological investment. The reasons were illustrated and the suggestions were given.

1. Introduction

As the largest developing country and second largest economy entity in the world, China, has been seeking opportunities to transform its industry structure. At this point, Chinese workers are encouraged by government to innovate to compete with the high-income countries such as US and Japan (Martín-de Castro, 2015). High-tech industry, as the fundamental impetus for economy development, is the driving force for this transition (Hong et al., 2016). As innovation practices are filled with uncertainty and risk (Nelson,1982), the research of innovation efficiency has become significant both for scholars and governments. The innovation efficiency refers to the ability to translate innovation inputs into innovation outputs (Liu et al., 2018), and it could be improved by generating higher percentage of output by investing same or lower percentage of recourses or optimizing the strategy of input. By evaluating innovation efficiency, both advantage and disadvantage of high-tech policies can be identified. Furthermore, the ways to improve the innovation efficiency can also be achieved from the analysis of current policies. The importance of innovation efficiency ignites passions of scholars and many empirical studies have been conducted to explore the ways to decompose, depict, evaluate and improve innovation efficiency (e.g., Guan and Chen 2012).

The high-tech developmental zone (high-tech zones), where hundreds of high-tech companies are clustered, develops rapidly since 1995, when high-tech zones had been firstly built in China. There are 156 high-tech zones in China until 2018. In 2015, there were 146 high-tech zones and the overall revenues of them reached to 8,065.76 billion (one thousand million) RMB, which accounted for 11.9% of the GDP of China. The export income of high-tech zones made up 18.5% of the total export income of the country. Among the 146 high-tech zones, 82,712 companies with a wide coverage of industries were included. These companies had made a total profit of 1,790.89 billion (one thousand million) RMB and paid the total tax of 1,424 billion (one thousand million) RMB. Meanwhile, the cost of the technological initiatives was 757.83 billion (one thousand million) RMB, which increased by 10.2% than the year of 2014. The R&D funding in 2015 was 452.16 billion (one thousand million) RMB, which was 41.6% of total amount of R&D funding in China, with an increase of 10.9% compared to the year of 2014. As to the employees of high-tech companies in high-tech zones, 18.1% of them, 3,117 thousand, engaged in the work directly related to technological innovation activities while 1,755 thousand of employees worked in R&D programs. As to their education levels, 5,507 thousand of employees

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owned a master or doctorate. With regard to the output of these companies in high-tech zones in 2015, there were 353 thousand of applications for patents, and these companies owned 926 thousand of patents in total.
According to the information stated above, it is obvious that the high-tech zones make a unique contribution to the development of Chinese technology and economy. The high-tech zones develop in a stable and constant way. Industry cluster brings about opportunities to the companies in the high-tech zones, which leads to a win-win situation both for the companies and high-tech zones. However, there still exist some problems and limitations during the development process of high-tech zones in China. First of all, the space of the high-tech zones would not satisfy the demand of the rapid development of the high-tech industry. It is urgent to put forward scheme for the future development of high-tech zones. Additional, markets of a large amount of high-tech industries begin to become saturate gradually, which takes these companies to the bottleneck. These problems are produced partly due to the innovation policy of government. According to Drucker (1985), the innovator was always independent and would seize the inspiration randomly rather than being arranged by others to innovate. When the companies in the high-tech zones are required to innovate in a specified sector by the government rather than the market, both company and government will be disappointed. Moreover, previous research on the high-tech zone mainly focus on the exploration of theories, the development paths and the innovation efficacy among the different regions (Li, 2017). Research on efficiency of all the high-tech zones in China from the view of technological investment, patent output and revenue system is rare. This work makes a unique contribution by analysis of the connections among the three systems from 2007 to 2016 and explaining the underlying reasons.

2. Methodology

Dozens of measurements of innovation performance have been proposed in the prior research, such as new product sales income, patent counts, patent counts per capita, and innovation efficiency (Cruz-Cázares et al., 2013; Kang and Park, 2012). Innovation efficiency is the key predictor for the performance of high-tech zones in China, which is important for both theorists and practitioners (Guan and Chen, 2010). Innovation efficiency takes both the innovation inputs and innovation outputs into account, which reflects to what extent, and what underlying process of co-functions of factors influence the output (Alegre and Chiva, 2008). Therefore, it is appropriate to assume that innovation efficiency is closely linked to innovation performance. Following the mainstream research, this paper adopts innovation efficiency to measure the development of high-tech zones in China. Some researchers have expended efforts in investigating the innovation efficiency of high-tech industry (Brown and Mason, 2014; Hong et al., 2015; Ma et al., 2016; Tseng et al., 2009).
To evaluate innovation efficiency, the entropy methods were widely used (Liu et al., 2017; Zhao et al., 2018). The entropy is originally a definition in thermodynamics and the concept was widely used in society, economy, engineering and other subjects to appraise efficiency of indicator system ((Li et al., 2012; Wang et al., 2015). Repetitive information and subjective bias can be minimized by using the entropy method. The entropy method was first developed by Shannon (1948) in order to represent degrees of uncertainty or variation in relation to the quantity of information used in a study (Liu et al., 2018). It is important to calculate the weight for each indicator before assessment of innovation efficiency. The basic idea of entropy method is that the bigger differences of the values among the evaluating objects by the same indicator, that indicator is the more valuable for the indicator system (Zou et al., 2006; Zhang, 2009; Liu et al., 2016). In other words, when an indicator plays more important role in decision-making process, it can usually provide more useful information. When the values of an indicator among different objects are equal, which indicates that the indicator's weight score is zero and it would be discarded in the process of evaluation. The process of the model formulation and calculation is listed below.

3. Equations, figures, tables, and measurements

3.1 Equations

The detailed procedures of entropy method are described as follows (Amiri et al., 2014; Han et al., 2015):
Before calculating the weight of a given indicator, the original data must be standardized by using formulas (1) in order to eliminate the influence of dimension, magnitude, and positive or negative orientation. All indicators can be divided into two types, positive and negative, and the greater a positive indicator is, the more beneficial the conditions for the development of the system are (and conversely, the greater the negative indicator, the less beneficial).

Assuming that there exists m years and n indicators in the model and the original matrix is $X = (\mathrm{x}_{\mathrm{ij}})_{m \times n}$ (i=1, 2….m; j=1, 2….n). The process of dealing with data is divided into seven steps (Wu and Zhong, 2011).

Firstly, standardize the data. Since different indicators own different units, it is necessary to standardize all the indicators by the Eq (1)

$$x'_{ij} = (x_{ij} - \overline{x}_j) / \sigma_j \tag{1}$$

In this equation, x'_{ij} represents the indicator after being standardized, $\overline{x}_j$ is the average value of indicator j, and σ_j is the standard deviation.

Secondly, transform the negative figures to positive ones. When standardizing all the indicators, there might exist negative figures. The negative figures have no impact of the overall appraisal but the calculation. For the convenience of the calculation, it's needed to transform the coordinate position by using the Eq (2).

$$y_{ij} = x'_{ij} + b \tag{2}$$

In this equation, b is the degree of the translation, $b > \left|\min(x'_{ij})\right|$. When the score of b is closer to $\left|\min(x'_{ij})\right|$, the result of the appraisal will be more significant.

Thirdly, calculate the indicator j in year i by using the Eq (3).

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{3}$$

Fourthly, use the Eq (4) to calculate the information entropy value of indicator j.

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (0 \le e_j \le 1) \tag{4}$$

Fifthly, get the effect value of the indicator j by using the Eq (5).

$$g_j = 1 - e_j \tag{5}$$

Sixthly, calculate the weight of indicator j by using the Eq (6).

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \tag{6}$$

Seventhly, calculate the score of the technological investment efficiency, patent output efficiency and revenue efficiency by using the Eq (7).

$$si = \sum_{j}^{m} w_j \times p_{ij} \quad \text{(i=1, 2…n)} \tag{7}$$

3.2 Tables

When choosing the indicator, we need to consider whether the indicators are accurate, necessary and accessible. Based on these principles, we choose the three kinds of the indicators, technological investment, patent output and revenue, similar to the research of Sperandio et al. (2017) and Castaneda et al. (2017).

Table 1: Appraisal system for the innovation efficiency of high-tech developmental zones in China

Indicator	Sub-indicator	Unit	Weight
Technological investment	Funding	Billion	0.1429
	Employee	Million	0.1439
Patent	Invention	Piece	0.1368
outcome	Utility	Piece	0.1343
	Exterior design	Piece	0.1460
Revenue	Production value	Billion	0.1464
	Profit	Billion	0.1497

As shown in Table 1, the technological investment system includes the investment of technological funding and investment of technological employees. The patent output system includes the invention, utility and exterior design patent. We use the 3 years as lag phase since it usually takes 3 years for application into technology. We did not use the number of papers as an indicator of patent outcome. Because it takes 25 to 35 years when the theoretical knowledge to be applied in technology and be accepted by the market (Drucker, 1985). The production value and profit are the indicators for revenue. We get the indicator system as shown in Table 1, and Billion refers to one thousand million. Based on the formula of the Entropy Method, the weights of the indicators and the innovation efficiency of high-tech zones in China are calculated and shown in Table 2.

Table 2: Weights of indicators and innovation efficiency of the high-tech zones in China

Year	Funding	Employee	Invention	Utility	Exterior design	Production value	Profit	Efficiency
2007	0.0385	0.0385	0.0420	0.0475	0.0350	0.0395	0.0350	0.0393
2008	0.0455	0.0475	0.0500	0.0525	0.0405	0.0410	0.0425	0.0455
2009	0.0570	0.0611	0.0600	0.0600	0.0640	0.0509	0.0500	0.0575
2010	0.0710	0.0646	0.0690	0.0670	0.0660	0.0729	0.0700	0.0687
2011	0.0840	0.0731	0.0825	0.0790	0.0915	0.0874	0.0890	0.0839
2012	0.0980	0.1051	0.0990	0.0910	0.0995	0.1034	0.1094	0.1009
2013	0.1190	0.1271	0.1155	0.1139	0.1255	0.1234	0.1294	0.1222
2014	0.1425	0.1426	0.1270	0.1314	0.1400	0.1469	0.1454	0.1396
2015	0.1620	0.1617	0.1575	0.1609	0.1560	0.1563	0.1599	0.1592
2016	0.1825	0.1787	0.1975	0.1969	0.1820	0.1783	0.1694	0.1833

From the Table 2, the weight of funding ranges from 0.0385 in 2007 to 0.1825 in 2016, and weight of employee input reaches to 0.1787 in 2016 with a start point of 0.0385 in 2007, and the weight of efficiency, which represents the efficiency of high- tech zones in China, increases stably and constantly, thus the unique contribution of high-tech zones is tested.

3.3 Figure

The results of analysis are shown in Figure 1, the efficiency of patent output is always higher than the efficiency of technological investment and revenue in the last ten years, and trend of the gap seems to be bigger in the near future. The efficiency of patent output in 2010 does not grow as fast as the other years, which means policies of the high-tech companies are explorative and can be influenced by market. However, the efficiency of patent output in 2016 increases in a fastest way ever since, which indicates the development of high-tech zones becomes much more mature than the previous years.

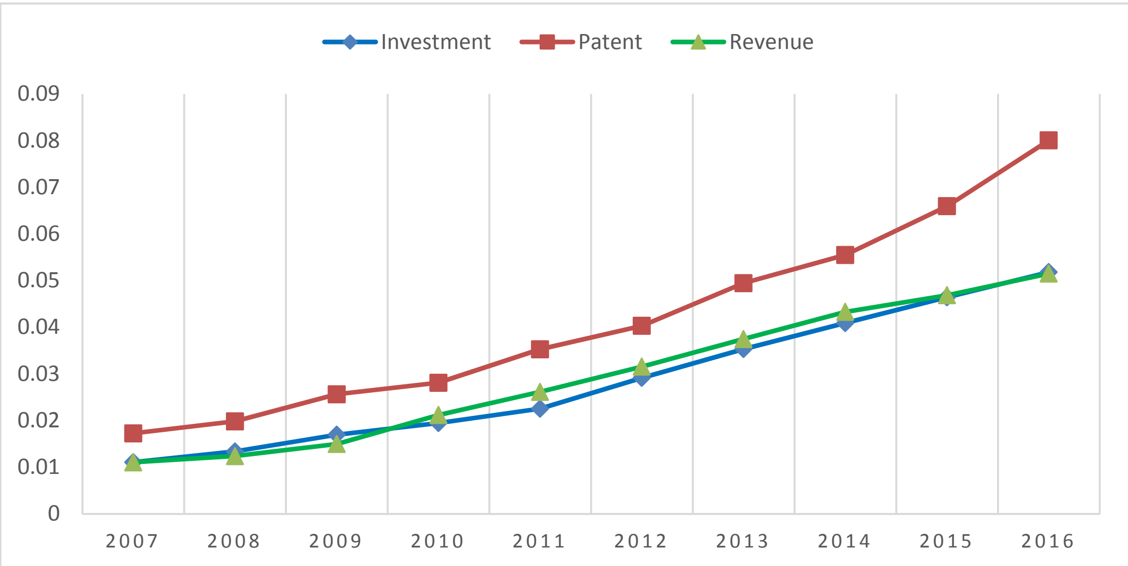

Figure 1: The efficiency of high-tech zones in China

As to the system of technological investment and revenue, there exists three stages of development for high-tech zones in China in the last ten years. From the 2007 to 2009, the efficiency of technological investment system is always higher than the efficiency of revenue system, which might be the result of that economic development is to a large extant dependent on the investment and the mechanism of innovation-driven economy has not been established. The second stage lasts from 2010 to 2016. The efficiency of revenue system began to excel that of technological investment system, which indicates that the development of economy is not entirely dependent on the investment. During this stage, technological investment and patents accumulated in the past years and the mature system of innovation act as the impetus of the increase of revenue. The last stage is from 2016 to now. The profit system begins to overlap with the investment system and promisingly leads the investment system in the near future. Thousands of high-tech companies develop rapidly as the result of the incentive of the patents and the sound institution of China, however, after the first few years, the market begins to be saturated and the entry cost becomes higher and higher, and the competition is becoming more and more fierce. Some companies begin to fail form the high-tech industry.

4. Results and Discussion

From the analysis above, it is obvious to see the three stages of the technological investment and economic efficiency, whereas the innovation output increase stably and constantly. In the first stage, the revenue is promoted by the investment. In the second stage, investment partly push the growth of the revenue, which relies more on the innovation and other factors. In the last stage, the market becomes statured gradually and the impact of investment on revenue is not significant.

There might exist several problems in the high-tech zones. Firstly, the co-functioning mechanism of the technological investment, innovation output and economic efficiency is not mature. The technological investment intensity is not high. Secondly, the structure of the patent output is not proper. The utility patent takes up 56 percent of the total patents in the last ten years, compared to the invention patent (37 percent) and exterior design (7 percent). Thirdly, the repetitive investment exists in many high-tech developmental zones, which threatens the high-tech industry by providing the saturated market. Fourthly, the disadvantage of over-innovation emerges, which increases the cost of the companies.

To cope with the problems in the development process of the high-tech developmental zones, government and company should cooperate to carry out their responsibilities. For government, it is wise to incentive rather than arrange innovation. Government should optimize the grant policy and inspire the motivations of high-tech companies for innovation. Also, supervision on the illegal competition and fake accounting information is necessary. Moreover, the government should make policies to encourage the utility and exterior design invention as well as control the repetitive investment. For the company, the mechanism of technological investment should be dynamic and adapted to the development of the high-tech industry.

5. Conclusion

This work was among the first to analysis the innovation efficiency of all high-tech zones in China, and the results imply interesting findings. From 2007 to 2016, technological investment, patent output and revenue of high-tech zones in China increase at different rates, which can be divided into three stages. In the first stage, the development of high-tech industries is driven by investment, however, in stage two, the main driving force is replaced by patents output, while the rate of increase begins to decrease in stage three, even with a higher percentage of patent output and technological investment. The reason for that are as follows. Firstly, the current industries structure is not suitable for the development of economy and should be reformed. Secondly, the high-tech industries might be over invested. To solve these problem, government should update policies to support the development of high-tech zones by providing more freedom of innovation initiatives rather than designing innovation plan. For companies in the high-tech zones, it is necessary to adapt to the needs of market.

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