THE ANALYSIS OF INNOVATION EFFICIENCY OF ENTERPRISES IN HUBEI PROVINCE BASED ON DEA METHOD

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ABSTRACT

With the data collected from 168 enterprises in Hubei province , innovation efficiency is evaluated and analyzed in terms of efficiency, effectiveness, returns to scale, and projection analysis by using DEA method .The results indicate that only15.48% of the enterprises operate on the best-practice frontier and there exist significant discrepancy between different types of enterprises in terms of innovation efficiency. Increasing returns to scale are found among 46.43% of the enterprises and decreasing returns to scale are found among 35.12% of the enterprises. Scale efficiency is the main factor which leads to low innovation efficiency; and the insufficient input of R&D personnel and the inappropriate allocation between R&D Personnel and R&D expenditure are the fundamental reasons leading enterprises non DEA effective. The empirical results indicate that there is much room for enterprises to improve its innovation efficiency, and specific adjustments are proposed for each type of enterprises on the basis of empirical analysis. Corresponding recommendations are put forward from the enterprise, industry, government level.

Key words: Data envelopment analysis; innovation efficiency; return to scale; projection analysis

INTRODUCTION

In today's knowledge-based economy, technological progress plays an increasingly important role for sustaining and improving the national economy. R&D activities are widely recognized to be one of the main impetuses of technological advancement, which has assumed centre stage in obtaining core competiveness for enterprises. The highly competitive market drives countries to accelerate innovation by continually increasing the investment in R&D activities to upgrade its technology development. China has constantly increased its investment on R&D activities, according to the 2013 China high-tech industry statistics, the input on R&D personnel and R&D expenditure has increased from 427000 to 526000, from 123.8billion to 149.1 billion for medium and large high-tech industries ,the growth rate has reached 23.19% and 20.44 % respectively within the year 2011-2012.According to the OECD(2013) report ,China's total investment in R&D activities ranks the second in the whole world, while the innovative capacity ranks 35th and falls far behind than modern countries such as Us and Germany(Li , et al ,2014). Xiao et al(2011) empirically find that "the increased R&D investment is not in line with the total factor productivity growth", as more emphasis has been focused on how to increase the investment for innovation rather than on how to improve innovation efficiency (Wang & Huang, 2007).

Innovation efficiency is defined as the ability to maximize innovation outputs given a certain amount of innovation inputs or to minimize the innovation inputs given a certain amount of innovation outputs(Chi, et al, 2004). Song et al (2007), Chiesa and Frattini (2009) both take the view that " a larger availability of higher level resources does not necessarily lead to superior performance". Since R&D investment is one of the most crucial elements in promoting scientific and technological progress, any country that uses the resources inefficiently will end up in achieving a much slower progress .Therefore, appropriate evaluation methods are needed for measuring the innovation efficiency so as to improve resource allocation and utilization, thus fostering the technological progress and innovation performance.

Scholars at home and abroad make a comprehensive evaluation of innovation efficiency from national, regional and industrial level. On the national level, Cai et al(2012) estimate the efficiency of the national innovation system(NIS) for 22 countries by data envelopment analysis(DEA) and find that the BRICS differ greatly in terms of the efficiency of NIS, among them China and India enjoy a quite high efficiency, which is influenced by external factors such as government governance , market environment et al. As Aristovnik(2014) find that " regions with a mature economic system enjoy higher R&D efficiency compared to regions still developing their technology pattern based on the data of EU-27 countries over the 2005–2010 period" .Chen et al(2011) make an comparison of R&D efficiency across 24 nations based on different output indicators, and find that most nations have similar R&D efficiency in terms of patents output while differs greatly in journal publication output. On the regional level, Brenner and Broekel (2011) define the regional innovation efficiency as the ration of innovation output generated and the innovation input invested. Fritsch (2007) applies the knowledge production function to measure the efficiency of regional innovation system in Germany and find that the efficiency in the regional innovation system is inversely u-shaped with the diversity of a regions' industry structure. Broekel (2012) further empirically find that the there exists an inverted-U shape form for the relationship between regional innovation efficiency and the intensity of collaboration among regional organizations as well. Whereas native scholars in China mainly focus on the comparative research of innovation efficiencies between China's different provinces and regions. Bai et al (2010) use DEA method to measure China's regional innovation efficiency and find that the overall innovation efficiency is low, which is mainly attributed to the low pure technical efficiency. Fan et al (2012) make an empirical analysis of the innovation efficiency of China's provinces during the period of 2000-2007. The results show that the east provinces have much higher innovation efficiency than that of the middle and west provinces, which has been widely recognized by scholars. Yang (2013) further finds that the great regional difference of innovation efficiency is lead by the intensity of local export, local infrastructure and geographic location as well as government intervention. Yu et al (2014) evaluates the innovation efficiencies of China's three main innovation bodies — enterprises, universities and institutes, with the panel data covering 30 provinces in China from 1999 to 2008. The results indicate that there exist vast differences within different innovation bodies in different provinces, the enterprises perform worst, and technological inefficiency exists notably in the three bodies.

On the industrial level, researchers are more interested in the overall evaluation of the innovation efficiency of the high-tech industry as a whole and its subordinate industries, as the high-tech industry is characterized by a high involvement and intensity in R&D activities and R&D investment. Han et al (2010) applies Stochastic frontier analysis (SFA) method to measure the innovation efficiency of China's overall high-tech industry, the results indicate that the whole high-tech industry is making rapid progress in terms of innovation efficiency, among them the electronic computer industry has the highest innovation efficiency. As for the subordinate industries, Hashimoto and Haneda (2008) take the Japanese pharmaceutical industry as study sample, they apply the DEA/Malmquist index to measure its innovation efficiency and discuss its change over time at the industry level, and find that R&D efficiency of Japanese pharmaceutical industry has monotonically gotten worse throughout the study decade. Whereas Ye et al(2015) investigate the innovation efficiency of pharmaceutical industry in China based on the three-stage DEA method, and find that the low pure technological efficiency is the main reason leading the whole industry non effective. In terms of electronic equipment industry, Moon, H (2013) measures and evaluates the innovation efficiency of the Korean electronic equipment industry quantitatively by the fuzzy data envelopment analysis (DEA) and finds that there exists decreasing returns to scale in its production technology, so the industry is recommended to downsize the production scale so as to improve its innovation efficiency. Wu et al(2013) empirically find that the innovation efficiency of the information technology industry is constantly improving by years, while the industry is suffering from a poor configuration of its R&D researchers, which heavily limit the industry's further growth and prosperity. Generally speaking, the innovation efficiency differs greatly by the industry type, so a further comparison of innovation efficiency between different subordinate industries is needed to reveal the general rule.

Overall, there are three main deficiencies in the existing research: Firstly, the current research are mainly macro level analysis, concerning more about the national, regional innovation efficiency evaluation and comparison, less from micro-level to take enterprises as the main innovation bodies and investigate their innovation efficiency. The comparison of innovation efficiency for different types of enterprises is even scarce. Secondly, the existing research mainly focus on the innovation efficiency evaluation of high-tech industry, while few previous studies have seriously examined the innovation efficiency of the manufacturing enterprises as well as the automobile manufacturing enterprises, both of them play an important role in China's economic system, so a further study about the innovation efficiency of these enterprises has important practical meanings . Thirdly, most of the existing researches only make an evaluation of innovation efficiency, little concerns how to improve the innovation efficiency through projection analysis, which is quite conductive to optimize the resource allocation for each decision making unit.

In this paper, we take enterprises in Hubei province as study example, which cover five areas including the electronic information, aerospace, pharmaceutical manufacturing, automobile manufacturing and equipment manufacturing. The top three belongs to the typical knowledge-intensive high-tech industry, while the latter two belong to the traditional manufacturing industry, which can make a comparative analysis of its innovation efficiency and will help identify the most and least efficient enterprises and the benchmark enterprises to learn. The aims of this study are threefold. First, based on the existing research, we build up the enterprise innovation efficiency evaluation index system, and then determine a suitable evaluation model. Second, combined with the data of the enterprises in Hubei province, the innovation efficiency can be measured, and the fundamental reasons restricting its efficiency can be found, each enterprise can take corrective action by using their reference set enterprise as benchmark. Third, based on the empirical results, we can propose specific recommendation to enhance the innovation efficiency of enterprises in Hubei province, which has also practical reference meaning for other provinces in China.

METHODOLOGY

The DEA method

Model built to measure innovation efficiency requires the estimation of production frontier to which enterprises' performance can be evaluated. There are two set of techniques, namely parametric and non-parametric. Parametric techniques which is represented by the stochastic frontier analysis methods(SFA) specify a functional form for the production frontier while Non-parametric techniques which is represented by data envelopment analysis(DEA) method uses linear programming to measure the efficiency of enterprises. Compared to stochastic frontier analysis (SFA), the major advantage of DEA approach is that it uses a linear programming model to estimate the best-practice frontier without a specific functional form assumption. What's more, it is particularly suitable for analyzing multiple inputs and multiple outputs (Charnes et al., 1985; Zhu, 2000). Such an approach allows for the fact that managers and decision makers explore R&D innovation activities in depth to obtain deeper insights into R&D resource allocation, control performance, and eventually implement innovations(Wang, C. et al.,2011)In this paper, innovation efficiency is evaluated and analyzed in terms of efficiency, effectiveness, returns to scale, and projection analysis by using DEA method (1)BCC model is used to make a comprehensive evaluation of innovation efficiency for different types of enterprises, in which the comprehensive efficiency, pure technical efficiency and scale efficiency are measured and compared respectively.(2)The quantity and proportion of DEA effective and non-DEA effective decision making units are calculated, so as to compare the differences of innovation effectiveness between different types of enterprises.(3)Based on the return to scale analysis, the scale benefits of different types of enterprises are judged.(4) By using the projection analysis, the reasons for innovation input redundancy and output deficiency are explored so as to find the core factors restricting the innovation efficiency , and targeted suggestions and countermeasures to improve innovation efficiencies are proposed for different types of enterprises.

Based on the assumptions that whether the return to scale is constant or not, the DEA method can be divided into CCR model and BCC model, the former is widely used under the assumptions of CRS (constant return to scale) technology (Odeck & Alkadi, 2001).The latter is a modified form of the former model, which assumes the VRS (various returns to scale) technology and calculate both pure efficiency and scale efficiency of each DMU. Considering that the innovation activities of enterprises are influenced by the complex effect of core technology, knowledge, human capital, which leads to the uncertainty of marginal revenue. So in this paper we use BCC model to calculate the innovation efficiency of different types of enterprises in Hubei province, and fully analyze whether the inefficiencies of enterprises are due to an excessive use of innovation input (technical inefficiency), or to a suboptimal size (Scale inefficiency).What's more, projection analysis is also used to put forward the corresponding improvement objectives.

The DEA model for the evaluation of enterprises' innovation efficiency in Hubei province is as follows, take the j_0 decision making unit as an example, with the efficiency index of the all decision making units as constraint, it construct the following CCR model:

$$\begin{cases} \max h_{j_\circ} = \dfrac{\sum_{r=1}^{s} u_r y_{rj_\circ}}{\sum_{i=1}^{m} v_i x_{ij_\circ}} \\ s.t. \max h_{j_\circ} = \dfrac{\sum_{r=1}^{s} u_r y_{rj_\circ}}{\sum_{i=1}^{m} v_i x_{ij_\circ}} \leq 1, j = 1,2,n \\ u \geq 0, v \geq 0 \end{cases} \quad (1)$$

In this model, n, m, s are the numbers of decision making units (DMU), inputs, and outputs respectively. x_{ij} is the amount of input i of the j_{th} DMU, y_{rj} is the amount of output r of the j_{th} DMU. s_i^- and s_r^+ are slack variables of input i and output r, h is the corresponding innovation efficiency of each DMU.

By the introduction of the slack variables s_i^- and s_r^+, the above inequality constraints can be turned into equality constraints. Due to the uncertainty of the marginal innovation revenue of enterprises, an additional constraint of $\sum \lambda_j = 1$ is adopted, and by taking the dual form the above CCR model is transformed into the following BCC model (Banker et al., 1984).The equation (1) can be transformed into the equation(2)as follows:

$$\begin{cases} \min \theta \\ s.t. \sum_{j=1}^{n} \lambda_j x_j + s^+ = \theta x_\circ \\ \sum_{j=1}^{n} \lambda_j y_j - s^- = y_\circ \\ \lambda_j \geq 0, j = 1,2, \cdots n \\ \theta \quad s^+ \geq 0, s^- \geq 0 \end{cases} \quad (2)$$

Through equation（2）we can get the optimal solution, which can determine the effectiveness of all the decision making units. If, in optimality, θ is equal to 1 and all input and output slack variables s_i^- and s_r^+ are equal to zero, then j_0 decision making unit is CRS-efficient and is operating on the

CRS frontier. Otherwise, if θ is not equal to 1, and/or some input/output slacks are non-zero, then the j_0 decision making unit is CRS-inefficient, which implies that some latent resources are still not being fully utilised. (Guan et al.2006) .The comprehensive efficiency can be further decomposed into pure technical efficiency and scale efficiency, by which we can determine whether the return to scale of the decision making units is constant, increasing or decreasing.

In addition, for the non DEA effective decision making units, a new DEA effective decision making unit can be constructed through projection analysis. The original value in the non DEA effective decision making unit can then be projected on the frontier of the new DEA effective decision making unit and the effective projection value can be reached .By the comparison between the original value and the projection value, the innovation input redundancy represented by variable s_i^- and the output deficiency represented by variable s_r^+ can be calculated, which has important practical meaning for improving innovation efficiency of enterprises.

The evaluation index system

Scholars at home and abroad have not reached a unified standard for the selection of innovation efficiency evaluation index, which concerns the selection of both innovation input and output index. In terms of innovation input, most scholars take R&D expenditures and R&D personnel as two basic innovation inputs (Zhong et al.,2011;Lee et al,2010; Wang & Huang, 2007). Wang et al (2008) propose that "R&D personnel can be calculated by the total number of R&D researchers enterprise have, as they are highly involved in the R&D activities and are indicators of enterprises' innovation capacity". Szirmai et al(2008) propose that "the R&D equipment input has direct impact on new product development as well, which constitute an important innovation input index". Based on the previous research, we take R&D personnel, R&D expenditure and R&D equipment input as the main indicators of enterprises' innovation input. In terms of innovation output index, patent indicators has been considered to be the best innovation output indicator which reflect the fundamental innovation ability of enterprises, while there is a debate on whether to choose the granted patent numbers or the applied patent numbers, most scholars prefer to choose the applied patent numbers rather than the granted patent numbers, since the latter is easily influenced by the lag of administrative efficiency. Patent indicators alone may often underestimate or overestimate innovation output (Fritsch & Slavtchev, 2009; Romijn & Albaladejo, 2002).Some studies have considered to take new product rate or sales as another innovation output index combined with the patent indictor in their efficiency analysis (Guan et al., 2006; Guan and Chen, 2010). Since new products development provides the potential for innovative enterprises to gain a preferred market position in relation to their rivals and realize more reliable returns than would otherwise be possible (Lawless and Fisher, 1990). Combined with previous research, we take new products revenue and the application for patents as two indicators of innovation output.

Table 1 : The evaluation index system of innovation efficiency of enterprises

Item		Indicators
Innovation input	R&D personnel	The number of R&D researchers enterprise have
	R&D expenditure	The amount of money enterprises spent on research and development this year(×10000¥)
	R&D equipment	The amount of money enterprises spent on equipment for research and development(×10000¥)
Innovation output	New products	New product revenue this year (×10000¥)
	patents	The quantity of application for patents this year

Data Collection

In this paper, data are collected from 2013 Hubei Provincial Enterprise Technology Center evaluation, which is initiated by the development and reform commission of Hubei province, aiming to enhancing the management and construction of enterprises' innovation activities. Hubei province is the pivot and centre of the national "central rise" strategy in china, the East park high-tech zone located in Hubei province rank the third largest and most active all around China, which has cultivated numerous advanced techniques and knowledge to enhance local enterprises' innovation capabilities. So this study sample is very representative and has important reference meaning for other provinces as well. By collecting and sorting, we finally get data of 168 enterprises in Hubei province, mainly covering five areas, there are 29 electronic information (EI)enterprises, 10 aerospace enterprises(AE),33 pharmaceutical manufacturing (PM)enterprises, 39 automobile manufacturing (AM) enterprises and 57 equipment manufacturing(EM) enterprises. EI is short for the electronic information enterprises, the rule applies to AE, PM,AM, EM as well for convenience. The specific data are shown as follows:

Table 2 : Innovation input and output of enterprises in Hubei province

Types of enterprise	Descriptive statistics	R&D personnel	R&D expenditure	R&D equipment	New product revenue	Application for patents
EI（29）	Minimum	50	523	851	2705	0
	Maximum	699	9329	9506	65773	21
	Mean	192	3129	3139	20842	10
AE（10）	Minimum	105	3401	4966	3515	1
	Maximum	468	40305	29984	45438	31
	Mean	275	13126	17497	14204	13
PM（33）	Minimum	46	380	843	821	0
	Maximum	333	8923	8400	156109	20
	Mean	112	2183	2207	21900	5
AM (39)	Minimum	50	784	864	1737	0

Types of enterprise	Descriptive statistics	R&D personnel	R&D expenditure	R&D equipment	New product revenue	Application for patents
	Maximum	1398	159999	306722	7476916	47
	Mean	166	10459	10376	326090	13
EM (57)	Minimum	32	525	823	2200	0
	Maximum	1326	45003	56958	260516	100
	Mean	157	4036	4322	31072	13

NOTE: EI denotes electronic information enterprise ; AE denotes aerospace enterprises ; PM denotes pharmaceutical manufacturing enterprises; AM denotes automobile manufacturing enterprises; EM denotes equipment manufacturing enterprises.

RESULTS

Efficiency evaluation analysis

Through the use of DEAP2.1 software, the above data concerning innovation input and output of enterprises are put into BCC model, by adopting the input-DEA model, the innovation efficiency for different types of enterprises are obtained, the specific results are shown in the following table 3:

Table 3 : Results of innovation efficiency evaluation of enterprises

Innovation efficiency result		EI	AM	AE	EM	PM	Mean
Innovation efficiency	Comprehensive efficiency	0.672	0.621	0.637	0.521	0.477	0.586
	Pure technical efficiency	0.856	0.796	0.762	0.803	0.787	0.801
	Scale efficiency	0.780	0.781	0.788	0.644	0.616	0.722

The table 3 shows that the comprehensive innovation efficiency of the five types of enterprise are low, with an average of 0.586.Among them, the comprehensive innovation efficiency of electronic information enterprises rank the highest, coming next are aerospace, automobile manufacturing, equipment manufacturing, the innovation efficiency of pharmaceutical manufacturing enterprises rank the lowest, with only an average of 0.477.Apart from the aerospace enterprises, the scale efficiency of the remaining enterprises are all lower than the pure technical efficiency , which means that the inefficiencies of enterprises are mainly attributed to the low scale efficiency .

Efficiency analysis

Based on the principle of judging whether the decision making unit is technology or scale effective, and combined with the empirical results. We summarize the efficiency analysis results for the above five types of enterprises, as shown in table 4.

Table 4 : Results of innovation efficiency analysis of enterprises

Innovation efficiency analysis		EI	AM	AE	EM	PM	Sum
Quantity	DEA effective	6	7	4	7	2	26
	Weak DEA effective	10	12	1	7	5	35
	Non-DEA effective	13	20	5	43	26	107
	Sum	29	39	10	57	33	168
Percent (%)	DEA effective	20.69	17.95	40	12.28	6.06	15.48
	Weak DEA effective	34.48	30.77	10	12.28	15.15	20.83
	Non-DEA effective	44.83	51.28	50	75.44	78.79	63.69
	Sum	100	100	100	100	100	100

The table 4 shows that among the 168 enterprises, the number of DEA effective, weak DEA effective and non-DEA effective enterprises are 26, 35 and 107 respectively, accounting for 15.48 %,20.82% and 63.69% of the total enterprises respectively. The 26 DEA effective enterprises are both technical effective and scale effective, and the aerospace enterprise enjoy the highest DEA effective proportion , coming next are the electronic information, automobile manufacturing, equipment manufacturing, the pharmaceutical manufacturing enterprises has the lowest proportion of DEA effective units.

A total of 35 enterprises are weak DEA effective, accounting for 20.83% of the total enterprises, namely the 35 enterprises are either technical effective or scale effective. Among them, 30 enterprises are technical effective but scale ineffective, which represents that scale ineffectiveness is the main reason which leads to these enterprises weak DEA effective . A total of 107 enterprises are non DEA effective, accounting for 63.69% of the total enterprises, indicating that there are great room for improvement for more than half of the enterprises in Hubei province, especially for the pharmaceutical enterprises, the proportion of non DEA effective enterprises reaches as high as 78.79%.

The return to scale measurement analysis

Based on the above analysis that a large amount of enterprises are scale ineffective, the reasons that lead to the low scale efficiency are further explored through the return to scale analysis, as shown in table5.

The table 5 shows that among the 168 enterprises, a total of 31 enterprises are constant return to scale, accounting for 18.45% of the total enterprises. Namely these 31 enterprises are scale effective and achieve the best economies of scale. Increasing return to scale are found in 78 enterprises, accounting for 46.43% of the total enterprises, which means that more than 40 percent enterprises can achieve a higher innovation output along with the increase of innovation input, as the lack of innovation input is the main reason restricting their scale efficiency. Decreasing return to scale are found in 59 enterprises, accounting for 35.12 % of the total enterprises.

Table 5 : Results of analysis of returns to scale of enterprises

Return to scale analysis		EI	AM	AE	EM	PM	Sum
Quantity	Constant	8	6	5	9	3	31
	Increasing	17	12	5	17	27	78
	Decreasing	4	21	0	31	3	59
	Sum	29	39	10	57	33	168
Percent （%）	Constant	27.59	15.38	50	15.79	9.09	18.45
	Increasing	58.62	30.77	50	29.82	81.82	46.43
	Decreasing	13.79	53.85	0	54.39	9.09	35.12
	Sum	100	100	10	100	100	100

Projection analysis

Through the projection analysis we can find out the underlying reason restricting enterprises' efficiencies, as is indicated in table 6,there are altogether 107 Non DEA effective enterprises, during which 24 ,40,56 enterprises' inefficiencies are due to an excessive use of R&D Personnel input, R&D expenditure input, R&D equipment input respectively, and the redundancy of R&D equipment input is the main reasons resulting in enterprises' inefficiencies, especially in the equipment manufacturing and pharmaceutical manufacturing enterprises. It should be pointed out that the above mentioned R&D equipment input redundancy is the relative redundancy under current scale of enterprises, not the absolute redundancy. Since the return to scale analysis in table 5 indicates that a large amount of enterprises are faced with the lack of innovation input. That is to say the relative redundancy of R&D expenditure input and R&D equipment input suggest the comparative lack of R&D Personnel input, resulting in the inappropriate allocation between R&D Personnel and R&D expenditure input. Combined with the two analysis results, we can safely come to the conclusion that the lack of R&D Personnel input and the inappropriate allocation between R&D Personnel and R&D expenditure are the fundamental reason leading enterprises non DEA effective.

Table 6:Results of projection analysis of Non-efficient enterprises

Projection analysis			EI	AM	AE	EM	PM	Sum
Quantity	Non-DEA effective enterprises		13	26	5	37	26	107
	Input redundancy	R&D personnel	4	6	4	5	5	24
		R&D expenditure	4	6	4	13	13	40
		R&D equipment	8	12	3	20	13	56
	Output slack	New product revenue	3	6	2	4	8	23
		Application for patents	7	14	4	8	7	40

Through the projection analysis, the input redundancy and the output deficiency can be clearly measured, which thus provide a specific improvement scheme to enhance enterprises' innovation efficiency. As is indicated in table7, there are much room for the adjustment of innovation input for the Non DEA effective enterprises, with an average 35% adjustment range, which are mainly focused on the adjustment in the R&D expenditure input and R&D equipment input, especially for the aerospace, equipment manufacturing, pharmaceutical manufacturing enterprises, huge adjustment and improvement are needed . There are great discrepancies in terms of output adjustment for different types of enterprises. The adjustment in both the new product revenue and the application for patents are relatively low for the electronic information enterprises, in contrast, for the automobile and aerospace enterprises, there are great room for the improvement in terms of new product revenue, which is 67.77% and 52.2% respectively, for the pharmaceutical manufacturing enterprises, the adjustment range for the application of patents amounts to as high as 82%.

Table 7 : Adjustment of innovation input and output of Non-DEA efficient enterprises

Types of enterprise	Adjustment	R&D personnel	R&D expenditure	R&D equipment	New product revenue	Application for patents
EI	Original value	140.7	3078.9	3071.1	18573.9	8.2
	Target value	87.8	2152.6	1725.7	26775	9
	Adjustment Range（%）	37.6	30.09	43.81	44.15	9.76
AM	Original value	138.3	8163.4	2260.8	197865.4	10.7
	Target value	72.8	2983.7	1354.9	291966.3	13.8
	Adjustment Range（%）	47.36	63.45	40.07	47.56	28.97
AE	Original value	210.8	12610.3	14291.9	7814.2	11.2
	Target value	156.7	7933	5845.7	9893.4	15.3
	Adjustment rang（%）	25.66	37.09	59.1	26.61	36.61
EM	Original value	138.1	3485.3	3709.7	23270	11.1
	Target value	82.9	1348.7	1253.5	30583	15.3
	Adjustment Range（%）	39.97	61.30	66.2	31.43	37.84
PM	Original value	122.8	2375.7	2392.6	17947.8	5.0
	Target value	86.3	1234	1010.5	24213.2	9.1
	Adjustment Range（%）	29.72	48.06	57.77	34.91	82

nOTE: Limited by the space, only the average adjustment values are listed.

DISCUSSION AND CONCLUSION

By using DEA method, we make a comprehensive evaluation and analysis of different types of enterprises' innovation efficiency in Hubei province, the results can not only alert managers of the inefficient enterprises which require immediate attention, but also offer insights into practices toward improving innovation efficiency for each specific type industry and provide them with best practices of other enterprises as a reference and benchmark. What's more, the evaluation result can help prevent mangers from improving one metric at the expense of hurting overall enterprise efficiency.

The empirical innovation efficiency analysis result for each type of enterprises

a. For the electronic information enterprises, the average innovation efficiency is 0.672, which ranks the highest in the 5 types of enterprises. 20.69 % of enterprises are DEA effective through the efficiency analysis, which realise the best technical efficiency and economies of scale. Increasing returns to scale are found among 58.62% of the total enterprises, for these enterprises the innovation input should be increased so as to achieve the best economies of scale. From the projection analysis result, the Non DEA effective enterprises are mainly restricted by the redundancy of R&D equipment input and the lack of new product revenue, with the adjustment range reaches as high as 43.81 % and 44.15%. In order to enhance the innovation efficiency of the electronic information enterprises, the input in R&D equipment should be reduced and the commercialization of new products be promoted, which can be realized by the close industry-university-institute cooperation and more emphasis should be put on market-based research and development, so as to expand new product revenue.

b. For the automobile manufacturing enterprises, the average innovation efficiency is o.621. 17.95% of enterprises are DEA effective through the efficiency analysis. Decreasing returns to scale are found among 51.28% of the total enterprises, for these enterprises the innovation input should be decreased so as to achieve the best economies of scale. The blind expansion of enterprise scale and innovation input will lead to a waste of resource. From the projection analysis result, the Non DEA effective enterprises are mainly restricted by the redundancy of R&D expenditure input and the lack of new product revenue, with the adjustment range reaches as high as 63.45 % and 47.56%.In order to enhance the innovation efficiency of the automobile manufacturing enterprises, the input in R&D expenditure should not be blindly increased but be more streamlined. The allocation between R&D personnel and R&D expenditure should be more coordinated and optimized.

c. For the aerospace enterprises, the average innovation efficiency is 0.637, which ranks the second highest in the 5 types of enterprises. 40% of enterprises are DEA effective through the efficiency analysis, this proportion ranks the highest among the 5 types of enterprises. Increasing returns to scale are found among 50% of the total enterprises, Constant returns to scale are found for the remaining enterprises. So the innovation input should be increased so as to achieve the best economies of scale. From the projection analysis result, the Non DEA effective enterprises are mainly restricted by the redundancy of R&D equipment input and the lack of application for patents, with the adjustment range reaches as high as 59.1 % and 36.61%.In order to enhance the innovation efficiency of the aerospace enterprises, the input in R&D equipment should be reduced and the application for patents be promoted, which can be realized by the increased input in R&D personnel and R&D expenditure ,so as to enhance its innovation ability.

d. For the equipment manufacturing enterprises, the average innovation efficiency is 0.521. 12.28 % of enterprises are DEA effective through the efficiency analysis, which raises the concern that the innovation efficiency of the manufacturing equipment industry need great improvement and great attention should be put on it. Decreasing return to scale are found among 54.39% of the total enterprises, the increase in innovation output can not match up with the increase in innovation input, the innovation efficiency can be improved by reducing the enterprise scale. From the projection analysis result, the Non DEA effective enterprises are mainly restricted by the redundancy of both R&D expenditure and R&D equipment input, as well as a lack of application for patents, with the adjustment range reaches as high as 61.3 %, 66.2% and 37.84% respectively. In order to enhance the innovation efficiency of the equipment manufacturing enterprises, the input in R&D expenditure and R&D equipment should be reduced, while the input in R&D personnel should be increased so as to promote the creation of new products.

e. For the pharmaceutical manufacturing enterprises, the average innovation efficiency is 0.477, which ranks the lowest in the 5 types of enterprises. Only 6.06 % of enterprises are DEA effective through the efficiency analysis, which raise great alarm that more emphasis should be put on this industry. Increasing returns to scale are found among 81.82% of the total enterprises , which suggests that the increase in innovation input will contribute to a higher proportion of innovation output increase. From the projection analysis result, the Non DEA effective enterprises are mainly restricted by the redundancy of both R&D expenditure and R&D equipment input, as well as the lack of application for patent, with the adjustment range reaches as high as 48.06 %, 57.77% and 82% respectively. The relative redundancy of both R&D expenditure and R&D equipment input indicates that enterprises are faced with a serious lack of R&D personnel input, which greatly restrict the overall innovation ability of enterprises. In order to enhance the innovation efficiency of the pharmaceutical manufacturing enterprises, the increased input in R&D personnel should be the top priority, and the allocation between R&D personnel and expenditure be optimized, so as to contribute to an increasing return to scale.

Based on the above conclusions, targeted recommendations are proposed from the enterprise, industry, government level as follows.

The recommendations and Managerial implications

a. From the enterprise level, the top priority is to increase its input of R&D personnel and optimize its allocation between R&D personnel and R&D expenditure input, which are the fundamental reasons restricting most enterprises' innovation efficiency. An effective mechanism for the introduction of technical talent should be established and enterprises should put more emphasis on the training and cultivation for the R&D personnel ,so as to boost the innovation capacity and realize original innovation .The lack of application for patents and new product revenue indicate enterprises' shortage in basic innovative capacity and lack of commercialization ability of new product, more emphasis should be put on basic scientific research and R&D activities. The overall evaluation of innovation efficiency of different types of enterprises also enables enterprises to discover which benchmark enterprise is the most appropriate learning target for improving R&D innovation efficiency.

b. From the industry level, the industry-university-institute cooperation innovation strategic alliance should be established, aiming to integrate its technical resource and human resource and enhance the multilateral cooperation. The abundant resource of universities and research institution in Hubei province can not only provide technical support for the enterprises but also knowledge transfer and technology upgrading .Especially for the equipment manufacturing and pharmaceutical manufacturing industry, comparatively they have the lowest comprehensive innovation efficiencies. The lack of the application for patents and new product revenue reflect enterprises' weakness in basic research capacity and the effective commercialization capacity of technological achievements. Through the close cooperation the whole industry can not only take advantages of universities' infrastructures and resource, avoiding the repeated investment of resource but also benefit from the knowledge spillover effect and be better positioned to utilize the newest technologies. So the platform for the fruit commercialization, marketing and industrialization of enterprises should be fostered.

c. From the government level, government participation and intervention should serve as an important guide for the technological development of enterprises. As the innovation efficiency of enterprises in Hubei province is mainly restricted by the low scale efficiency, so the top priority of government is to change their development concept, the blindly encouragement of the expansion of the scale should be forbidden, a more intensive and rational investment strategy should be promoted, more emphasis should be put on enhancing the allocation of resource. What's more, efforts should be made to improve the market circumstance, governance, and create a sound environment for innovation. The government should implement incentive policy based on the establishment of a series of science parks, "Wuhan · China Optical Valley" has significant influence at home and abroad, it is an important hub of the optoelectronic industry, through which enterprises can enjoy specific advantages such as the cluster effect and close proximity to upstream and downstream supply chains. The highest ranked innovation efficiency of the electronic information enterprises is a vivid proof of the advantages brought by science parks. More preferential policy for the attraction of R&D personnel should be issued as the brain drain in Hubei province is serious and enterprises suffers greatly from the lack of R&D personnel .The provision of additional incentives such as research subsidies, infrastructure, favourable tax and trade regimes, and funding is also indispensable so as to create a sound environment for innovation.

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