An Empirical Research on the Evaluation of R&D Input in Henan Province of China Based on DEA*

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Abstract Using the method of the Data Envelopment Analysis(DEA)，this paper has made the comparative evaluation and analysis of the efficiency of input into Henan R&D from 2000 to 2007, as well as the comparison among 30 domestic cities and provinces in 2007. The result of the DEA model reflects the efficiency of input into Henan R&D objectively. At last, results are interpreted in details, based on analysis results and present situation; the author give some corresponding suggestions of the input into R&D in Henan.

Key words R&D; DEA; Empirical research; Efficiency

1 Introduction

In recent years, competition between countries gradually moves to the basic research, which is an important kind of strategic resources (Li Zhengfeng, 2002). Based on this situation, all countries and regions regard the R & D input as a strategic investment and increase investment in basic research so as to seize the high point of the system of science. With the increased investment in basic research, its potency，efficiency and accountability are becoming the focus of attention in various aspects (Ge Guoyao, Song Ziliang, 2003). Whether the R&D input can really promote the regional science innovation level or enhance local economics has a great deal with its effectiveness.

In the 1970s, the demand for performance evaluation of basic research came out in the face of the pressure from taxpayers. National Science Foundation (NSF) and National Institute for Health (NIH) established the first assessment office and began to research and explore the performance on R&D activities. Since then, performance evaluation gradually got more and more attention from governments all around the world. The initial evaluation on R & D activities in China are mainly qualitative evaluation and the subjective evaluation of the competent leader, peer views are supplement. (Xu Qingrui, Zheng Gang, et al, 2002). With the increasing enlarged scale of R & D activities and the promotion of scientific research level, various assessment methods and theories are applied to the evaluation of R & D in practice.

Data envelopment analysis(DEA) was one of the main methods used to measure technical efficiency (Fang –Ming hsu, Chao-Chin Hsueh, 2008). DEA is a nonparametric method, no input or output function is estimated from the data. This precludes evaluation of each index in the priority of weight, and errors caused by subjective factors. DEA is the effective method of evaluating the efficiency of the allocation resources, especially used to evaluate the efficiency nonmarket agencies like schools, hospitals, and courts, which produce identifiable and measureable outputs from measurable inputs but generally lack market prices of outputs.

In order to build an innovative province, the amount of R&D spending is growing gaining around in Henan. During the past five years, with an average 29.52 percent rate of growth, the Intramural Expenditures on R&D reached 12.409 billion in 2008; compared with 2007, the number of persons for R&D Amounted to full-time increased by 12.23 % reached 72,830 person-years; scientists and engineers for R&D Amounted to full-time reached 56316 person-years, with an increase of 16.07% over the previous year. Compared with other provinces in central of china, Henan Province is in a leading position in the amount of R & D resources, but the R&D investment intensity (R&D/GDP) is still lagging behind others. Still, there is a big gap between Henan and the developed areas in east, whether in absolute quantity or relative quantity.

In the current situation, Henan Province must continue to increase the R & D input and use the limited R&D resources to maximize scientific research output. By analyzing the efficiency of R&D

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input in Henan, this paper want to find a suitable and efficient way to develop science and technology.

2 Analytical Model and Analytical Framework

2.1 Instruction of DEA model

This study presents a Data Envelopment Analysis (DEA) approach to assess technical efficiency of R&D input/output in Henan. The discussion is based on the non-parametric, mathematical programming framework. The specific technique used is DEA, which first introduced by the Operation research scholar Charnes, Cooper, and Rhodes, assess the relative efficiency of a homogenous set of decision making units in the presence of multiple input and output measures.

DEA is a nonparametric method, no input or output function is estimated from the data. This precludes evaluation of each index in the priority of weight, and errors caused by subjective factors. DEA is the effective method of evaluating the efficiency of the allocation resources, especially used to evaluate the efficiency nonmarket agencies like schools, hospitals, and courts, which produce identifiable and measureable outputs from measurable inputs but generally lack market prices of outputs.

This part we will introduce two models of DEA. The first classical model is CCR, first introduced in to Operation Research literature by Charnes, Cooper, and Rhodes（CCR）. CCR model is applicable only to technologies characterized by constant returns to scale (CRS). In what turned out to be a major breakthrough, Banker, Charnes, and Cooper (BCC) extended the CCR model to accommodate technologies that exhibit variable returns to scale (VRS).

Assume there are data on N inputs and M outputs for each of I firms. For the i *–th* firm these are represented by the column vectors $\mathbf{x}_i$ and $\mathbf{q}_i$, respectively. The $N\times I$ input matrix, X, and the $M\times I$ output matrix, Q represents the data for all I firms. The piecewise linear input requirement set under constant returns to scale (CRS) can be expressed as the following equation:

$$L(q)= \{(x,q) \le \lambda Q, x \ge X\lambda\}$$

The CCR model was presented in the following equation: :

$$\text{Min}_{\theta\lambda}\theta,$$
$$\text{Subject to} \quad \begin{aligned} -q_i + Q\lambda &\ge 0 \\ \theta x_i - X\lambda &\ge 0 \\ \lambda &\ge 0 \end{aligned} \qquad (1)$$

where $\theta$is a scalar value representing the efficiency score for the i-th firm. and λ is a I×1 vector of constants. If θ, with a value of 1 indicating a point on the frontier and hence a technically efficient firm; ifθ<1, which denotes that the evaluating of the i-th firm is technical inefficiency.

The CRS assumption is appropriate when all firms are operating at an optimal scale. However, imperfect competition, government regulations, constraints on finance, etc., may cause a firm to be not operating at optimal scale. Banker, Charnes, and Cooper (BCC) adjusted the CRS DEA model to account for variable returns to scale (VRS) situations. The CRS linear programming problem can be easily modified to account for VRS by adding the convexity constraint: $\lambda \mathrm{I} = 1$ to equation (1) to provide:

$$\text{Min}_{\theta\lambda}\theta,$$
$$\text{Subject to} \quad \begin{aligned} -q_i + Q\lambda &\ge 0 \\ \theta x_i - X\lambda &\ge 0 \\ \lambda I &= 1 \\ \lambda &\ge 0 \end{aligned} \qquad (2)$$

The piecewise linear input requirement set under variable returns to scale (CRS) can be expressed as the following equation:

$$\mathrm{L}(q)= \{(x,q): q \le \lambda Q, x \ge X\lambda, \lambda I = 1\}$$

A scale efficiency (SE) measure for each DMU can be obtained if technology exhibits VRS. If there exists a difference score between constant returns to scale (CRS) technical efficiency score (TE) and VRS TE score for a special DMU, the DMU is characterized by scale inefficiency where the scale efficiency can be calculated as ratio of CRS TE to VRS TE. The VRS TE score can then be divided into two components, scale efficiency and pure technical in efficiency.

2.2 Analytical framework of R&D efficiency using DEA approach

2.2.1 Analytical framework

In order to realize the current status of efficiency of input of R & D in Henan, discover the existing problem and causes, and propose the counter- measures to optimize the R&D activities, this paper will analyze following the two aspects: (1) making the comparative evaluation and analysis of efficiency of R&D input from 2000 to 2007 in Henan, (2) making the efficiency research of R&D of 30 regions[1] with the DEA model.

2.2.2 Measures and data collection

Three input indicators employed in this study are detailed below: (1) Number of persons for R＆D Amounted to full-time: refers to the workload of the persons in R&D activities, which including full-time staff and all part-time staff in a year; (2) Intramural Expenditures on R&D: refers to the actual expenditure spending on internal R&D activities in a report period of the investigation unit; (3) scientists and engineers for R＆D Amounted to full-time: the workload of the scientists and engineers in R&D activities, which including full-time staff and all part-time staff in a year.

Four output measures used in this study are described as follows: (1) Number of scientific papers: refers to the amount of scientific paper, which published on the National University or academic publications, or on the issue of overseas tertiary institutions or academic journal (2) The publication of scientific monographs: refers to the amount of science and technology monographs, textbooks, popular science books, which compiled and published by official press. Account the same title as a book, nothing to do with the circulation of the book. (3) The amount of patents granted: refers to the patent which the official agency has no objection to application, registered and given the authorization or patent license. Patent, which is an important output of R & D and technological innovation activities, always are closely related technological development. (4)The volume of contracts realized on technological market: the number of the contracts which traded or realized on technology markets in all regions. It is market that is an important detector of testing any innovation's true value.

Table 1 Measures of Inputs and Outputs of R&D Activities

Dimension	Measures	Items and definition
inputs	Number of persons for R＆D Amounted to full-time	the workload of the persons in R & D activities, which includes full-time staff and all part-time staff in a year
	Intramural Expenditures on R&D	refers to the actual expenditure spending on internal R & D activities in a report period of the investigation unit
	scientists and engineers for R & D Amounted to full-time	the workload of the scientists and engineers in R & D activities ,which includes full-time staff and all part-time staff in a year
outputs	Number of scientific papers	refers to the amount of scientific paper, which published on the National University or academic publications, or on the issue of overseas tertiary institutions or academic journal
	The publication of scientific monographs	the amount of science and technology monographs, textbooks, popular science books, which compiled and Published by official press. Account the same title as a book, nothing to do with the circulation of the book
	The amount of patents granted	the patent which the official agency has no objection to application or review does not hold meaning, registered and given the authorization or patent license. Patent, which is an important output of R & D and technological innovation activities, always are closely related technological development
	The volume of contracts realized on technological market	the number of the contracts which traded or realized on technology markets in all regions.

Owing to the characteristics of R&D activities, outputs are lag a certain amount of time behind inputs. After co-integration, this paper finds that the maximum delay between R&D input and output is 1 year. That is, the 2007 R & D investment, will output in 2008.

The data used in this article come from the "Zhejiang Science and Technology Yearbook" (2007-2008), "Henan Statistical Yearbook" (2001-2009),"China Statistical Yearbook" (2008) and"

[1] Some related indicators for statistics of Tibet used is this paper are not exist, so Tibet is removed from the samples.

Statistical of Chinese S&T Papers(2009)".

3 Empirical Results Obtained by DEA Approach

3.1 Applying DEA in evaluating of R&D input between years 2000 and 2007 in Henan

According to the statistic annals of Henan province, obtained the data of the number of persons for R&D Amounted to full-time (x_1) , intramural Expenditures on R&D (x_2) scientists and engineers for R&D Amounted to full-time (x_3); the number of scientific papers (Y_1), the publication of scientific monographs (Y_2), the amount of patents granted(Y_3), volume of contracts realized on technological market (Y_4). This paper use CCR and BCC models of DEA method, and take the year from 2000 to 2007 as decision-making units. It selects data of Henan R&D input from 2000 to 2007 and R&D output from 2001 to 2008, and put it into the model and results are got automatically by using Win4Deap software.

Table 2 Evaluating Result of R&D Input in Henan Province from 2000 to 2007

DMU	θ CRS(TE)	σ VRS(TE)	$\sum\lambda$	Economy of scale.	θ/σ VRS(SE)
2000	0.986	1.000	0.836	irs	0.986
2001	0.864	1.000	0.818	irs	0.864
2002	1.000	1.000	1.000	-	1.000
2003	1.000	1.000	1.000	-	1.000
2004	1.000	1.000	1.000	-	1.000
2005	0.930	1.000	1.224	drs	0.930
2006	0.990	1.000	1.266	drs	0.990
2007	1.000	1.000	1.000	-	1.000

3.1.1 CRS technical efficiency analysis

Table 2 lists the descriptive statistics of R&D input/output efficiency with scores from 2000 to 2007. In the years from 2002 to 2004 and 2007, the TE scores of R&D activities equal to 1, then this indicates that R&D input/output in these years in Henan province rated as fully efficient. As table 2 observed, the years of 2000-2001, and 2005-2006 are non-DEA efficient units. But all the units are technical efficiency when VRS is assumed, that means all the decision-making units are operating at an optimal pure technical efficiency. Favorite in a word, DMUs' technical inefficiency result in scale inefficiency while not pure technical inefficiency.

3.1.2 Scale efficiency analysis

Results from Table 2 suggest that 2000-2001 Henan Province achieved the optimal pure technical efficiency, while the SE scores of R&D input/output are less than 1, which indicate that in 2000-2001 Henan R&D activities' operation exhibit increasing returns to scale. Insufficient input are the real reason leading to non-DEA efficient in 2000-2001.On the contrary, 2005-2006 Henan SE evaluation are greater than 1, shows that R&D input/output in this period is decreasing returns to scale, A serious shortage of R&D output due to non-DEA efficient. In 2002-2004 and 2007, Henan R&D activities are operating at both Scale efficiency and pure technical efficiency.

3.1.3 Projection analysis

In order to identify the specific reasons of invalidity for R&D investment, non-efficient DMUs' evaluation is made by using DEA projection theory method.

Compared to R&D activities on the efficient production frontier, owing to preserve the current output scale, more excessive resources such as personnel, R&D Expenditures and the scientists and engineers engaged in R&D activities are wasted in the years 2000-2001 and 2005-2006.

In 2000, the slack of the workload of R&D staff and intramural expenditures is only about 1.42%. As increase investment is put into R&D, the degree of redundancy of R&D input in 2001 is larger than 2000, which the slack of both the two DMUs' inputs rise to 8.63%. 2001, the slack of scientists and engineers engaged in R&D activities decreased slightly, reduced from 14.94% to 12.18%.Afterwards, the redundancy in R&D activities' input has been gradually decreased in Henan province. 2006, the slack of the workload of R&D staff and intramural expenditures decreased to 0.96%, and the slack in scientists and engineers dropped to 5.05%.

Table 3 Result of Projection Analysis of Non DMU

DMU / indicator	2000	2001	2005	2006
S_1^-	493.327	3121.001	4014.776	561.207
X1redundancy rate	1.42%	8.63%	7.89%	0.96%
S_2^-	0.353	2.445	3.877	0.725
X2redundancy rate	1.42%	8.63%	6.97%	0.96%
S_3^-	4413.606	3399.697	2719.891	2362.258
X3redundancy rate	14.94%	12.18%	6.97%	5.05%
S_1^+	0	1292.433	3.223	2969.126
Y1 insufficient rate	0	5.83%	0.007%	6.20%
S_2^+	0	0	255.398	122.156
Y2 insufficient rate	0	0	10.81%	4.53%
S_3^+	267.937	185.883	0	0
Y3 insufficient rate	38.94%	22.63%	0	0
S_4^+	262.958	0	1783.657	1257.131
Y4 insufficient rate	38.95%	0	63%	33.32%

In the year 2000 and 2001, patents granted are present shortage, of which 38.94% increase in 2000 and 22.63% in 2001, technical and scale efficiency can be achieved. Since 2002, as shown in tabel3, the number of patents granted has reached largest volume of production. In the year 2005 and 2006, except the patents granted has reached its maximum production, the rest of three science and technology output of R&D activities present shortage. Scientific monographs' production capacity should be increased by 10.72% in 2005, 2006 by only 4.53% and scientific papers are present a shortage of 6.20%. Compared to output of scientific monographs and papers, there is a serious shortage of the contracts realized on technological market. Contracts realized on technological market should increase by 38.95%, 63% and 33.32% in 2000, 2005 and 2006, technical and scale efficiency can be achieved.

The analysis implies that insufficient output of scientific and technological is the main reason for poor performance of R&D activities in Henan. Low high-technology transformation contributed to the inadequate scientific and technological outputs.

3.2 Evaluating the efficiency of R&D input of 30 regions with the DEA model

According to the "Zhejiang Science and Technology Yearbook" (2007-2008), "China Statistical Yearbook" (2008) and" Statistical of Chinese S&T Papers(2009)",obtained the data of the number of persons for R＆D Amounted to full-time (x_1) , intramural Expenditures on R&D (x_2) scientists and engineers for R&D Amounted to full-time (x_3); the number of scientific papers (Y_1), the publication of scientific monographs (Y_2)[2], the amount of patents granted(Y_3), volume of contracts realized on technological market (Y_4).

Take 30 regions nationwide as decision-making units, It selects data of R&D input of 30 regions in 2007 and R&D output in 2008, and put it into the model and results are got automatically by using Win4Deap software.

3.2.1 CRS technical efficiency analysis

The results shown in Table 4 suggest that Tianjin, Zhejiang, Shandong, Hainan, Yunnan, Xinjiang, Shanghai, seven provinces' TE scores of R&D activities equal to 1, then this indicates that R&D input/output in these regions in 2007/2008 rated as fully efficient, which means that the R&D personnel and financial inputs have been fully utilized and achieved the maximum possible output results. There are 23 regions' TE scores less than 1, that about 76.66% of DMUs are non-DEA efficient region, which also exist scale inefficiency. Among the 23 non-DEA efficient regions, only Beijing is marginal efficiency unit which TE score is close to 1. Marginal efficiency unit refers to the unit which DEA value is between 0.9 and 1, which after slightly adjustment of the input and output DEA value will attained. 1. Among the 22 significant non-efficiency units (DEA value is less than 0.9), there are 16 regions which TE scores of R&D are less than 0.6, accounting for 53.33% of all the regions nationwide. That means more than half the regions in china have poor performances in R&D activities, and it is very difficult to improve their performances in a short time. The CRS TE of Henan is 0.402, which implies that Henan province has not only a poor performance in R&D activities, but also a significant non-efficiency unit in

[2] The latest figures of Scientific output which published by National statistics, the measure of "the publication of scientific monographs" of 30 provinces is not involved, so this paper eliminated the index in lateral analysis.

2007, it will take a long period and more effort to improve its performance.

Table 4 Evaluating Result of R&D Input Efficiency in 30 Regions in China, 2007

DMU	θ CRS(TE)	σ VRS(TE)	θ/σ VRS(SE)	∑λ	Economy of scale.
Beijing	0.950	1.000	0.950	6.372	Drs
Tianjin	1.000	1.000	1.000	1.000	-
Hebei	0.409	0.410	0.996	0.560	Irs
Shanxi	0.410	0.434	0.944	6.259	Drs
Inner Mongolia	0.354	0.365	0.969	0.213	Irs
Liaoning	0.796	0.955	0.833	3.562	Drs
Jilin	0.643	0.646	0.955	0.380	Irs
Heilongjiang	0.530	0.569	0.931	13.275	Drs
Shanghai	1.000	1.000	1.000	1.000	-
Jiangsu	0.547	0.568	0.963	22.491	Drs
Zhejiang	1.000	1.000	1.000	1.000	-
Anhui	0.572	0.598	0.956	1.31	Drs
Fujian	0.468	0.471	0.994	1.051	Drs
Jiangxi	0.342	0.345	0.989	0.499	Irs
Shandong	1.000	1.000	1.000	1.000	-
Henan	0.402	0.404	0.966	0.542	Irs
Hubei	0.602	0.602	0.999	0.700	Irs
Hunan	0.884	0.910	0.971	7.543	Drs
Guangdong	0.784	1.000	0.784	1.805	Drs
Guangxi	0.392	0.401	0.977	2.111	Drs
Hainan	1.000	1.000	1.000	1.000	-
Chongqing	0.585	0.602	0.972	4.383	Drs
Sichuan	0.458	0.460	0.997	0.439	Irs
Guizhou	0.881	0.926	0.951	4.025	Drs
Yunnan	1.000	1.000	1.000	1.000	-
Shaanxi	0.469	0.477	0.984	3.663	Drs
Gansu	0.593	0.598	0.992	0.600	Irs
Qinghai	0.584	0.944	0.618	0.414	Irs
Ningxia	0.404	0.491	0.822	0.101	Irs
Xinjiang	1.000	1.000	1.000	1.000	-

3.2.2 Scale efficiency analysis

Among the 30 provinces participating in the evaluation, only Tianjin, Zhejiang, Shandong, Hainan, Yunnan, Xinjiang, and Shanghai etc., are operating at both Scale efficiency and pure technical efficiency. There are nine provinces' with SE scores less than 1, results in Table4 indicate that including Jilin, Hubei, Henan, Qinghai etc., nine provinces' R&D operation exhibit increasing returns to scale. The rest regions of 14 provinces' R&D activities including Guangdong, Guangxi, Shaanxi etc., are operating at decreasing returns to scale. More than 46% R&D investment in china is diseconomies of scale. The VRS TE scores of Henan R&D activities is 0.542, indicates that R&D investment in Henan province exist a serious shortage; the VRS scores of Henan R&D activities is 0.404, which implies the management of R&D investment is unscientific; the SE scores is 0.966, R&D input/output in 2007 in Henan is increasing returns to scale. Increasing in R&D input will lead to the more output increased.

3.2.3 Projection analysis

In order to identify the specific reasons of invalidity for R&D investment, non-efficient DMUs' evaluation is made by using DEA projection theory method.

The result of Input-oriented of DEA model implies that maintaining outputs invariably, minimize the inputs. As is shown in Table5, ensuring the science and technology output unchanged in 2008, the R & D resources which put in 2007 exist excessive redundancy. The slack rate of the workload of R&D staff, intramural expenditures and scientists and engineers engaged in R&D activities are about 63.52% ,59.8% and 59.8%, which implies that ensuring the science and technology output unchanged, the R&D should be reduced about 60%. The analysis demonstrates that the main reason for poor performance of R&D activities in Henan, are excessive resources wasted in R&D activities.

Table 5 Result of Projection Analysis of Henan, Input-oriented

Index	X_1redundancy rate	X_2redundancy rate	X_3redundancy rate	Y_1insufficient rate	Y_3insufficient rate	Y_4insufficient rate
Henan	63.52%	59.8%	59.79%	0	0	0

Table 6 Result of Projection Analysis of Henan, Output-oriented

Index	X_1redundancy rate	X_2redundancy rate	X_3redundancy rate	Y_1insufficient rate	Y_3insufficient rate	Y_4insufficient rate
Henan	9.28%	0	0	59.8%	59.8%	59.8%

The result of output-oriented of DEA model implies that keeping inputs unchanged, maximize the outputs. As is shown in Table6, ensuring the R&D inputs invariable in 2007, there is a serious shortage of science and technology outputs. Unless the scientific papers, patents granted and volume of contracts realized on technological market increased by 59.8%, the technical and scale efficiency can not be achieved in Henan. The content in Table6 illustrates that insufficient output of scientific and technological is the main reason for poor performance of R&D activities in Henan.

4 Conclusion

According to the current situation and existing problems of R&D activities for the Henan Province, this paper proposes the following recommendations.

The first is to maintain the existing scale of inputs, focus on improving the efficiency of R&D activities. The government and enterprises should increase the funding and personnel in science and technology, meanwhile more efforts should be made in improving the efficiency of R&D outputs.

The second is to develop the inputs’ structure, optimize the allocation of three types of R&D research funds’ ratio. The basic research funds accounted for R&D funding in Henan Province is about 2% for a long time and far below the national average (5%). Basic research funding in R&D share of total funding is above 10% in majority of OECD member countries and six observer countries, while most countries around the world this proportion is around 20%. Low proportion for basic research, contributed to the insufficient output of scientific papers, monographs and other important scientific and technological achievements. Although the R&D activities scale is big in Henan, while most of them are enterprises experimental development activities. Few enterprises involved in basic research, not only can’t for basic research take more economic benefit directly, but also has the enterprises no capacity to carry out basic research.

Third, owing to promoting integration of production and scientific research, government should create a suitable Science and Technology operation mechanism in Henan as quickly as possible. Policy makers must adjust the R&D funds’ structure and promote government and science field creating a suitable Science and Technology Development Mechanism. In order to promote the powerful cooperation of enterprises and research institutions, which maximize utility of enterprise's economic resources and colleges’ scientific and technological resources. Companies should increase their own intellectual property rights to develop and strengthen cooperation with scientific research units and technological universities. For the sake of facilitating promotion and use of new technologies, improving the technological content of products, it is necessary to enhance the horizontal communication and cooperation between scientific research institutes and firms.

Fourth, the government and science field should compile appropriate technology development planning, and promote integration of scientific and technological resources. The scale, objectively, funded key fields and financing projects' scope of R&D and basic research investment should be reification and maneuverability in the technology development planning, for the purpose of making the funds and personnel of R&D in reasonable growth and use. No scientific and rational planning, will cause duplication or blind area of funding and finally lead to the waste of resources, which is the main reason that caused the insufficient inputs and redundant outputs.

The last but not the least, is to improve policies and regulations, for sake of creating a platform for industrialization of research findings. Create a favorable macro-technology environment and provide fast, accurate market information for scientific subjects.

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