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The Relative Efficiencies of Research Universities of Science and Technology in China: Based on the Data Envelopment Analysis and Stochastic Frontier Analysis

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This paper applies data envelopment analysis (DEA) and stochastic frontier analysis (SFA) to explore the relative efficiency of China's research universities of science and technology. According to the finding, when talent training is the only output, the efficiency of research universities of science and technology is far lower than that of comprehensive universities. However, when the outputs of scientific research and social service are taken into consideration, the former will increase remarkably and even exceeds the latter. Moreover, the research universities of science and technology have a higher inner homogeneity because their standard deviation of efficiency score is obviously lower. The study also reveals that the number of research universities of science and technology with redundant inputs is more than that of comprehensive universities. Beyond that, the environmental variables and statistical noise exert no significant effect on the efficiency of Chinese research universities.

Keywords: efficiency, DEA, research universities of science and technology

INTRODUCTION

With the spread of the New Public Managerialism all over the world, the public becomes more and more interested in the internal operating mechanism of university and shows more concerns to the quality and efficiency of higher education. Meanwhile, increasingly numbers of people evaluate universities with the way they have utilized to evaluate enterprises. In fact, universities have turned into

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the special enterprises because they are engaged in "input and output" and they must pursue the maximum outputs under the restraints of resources.

In China, it is the first priority of higher education to create the world-class universities. Moreover, the government even puts all its effort to develop the top few research universities which now results in a polarization on the educational resource allocation. According to the statistics from the Ministry of Education, 39 universities that have graduate school account for 1.5% of the total universities (exclude adult college), yet their research funds occupy more than 60% , and the number of doctorate students surpasses 75%.By comparison, the inputs of research universities of science and technology are obvious higher than other universities, which further draws the public concern on efficiency issues.

Does such centralized resource in research universities of science and technology mean that they have a better efficiency in input and output? Efficiency becomes a significant issue as the resources scarcity situation has been more serious than before. Thus, this research will give a response to the question.

State of the literature

- Most studies suggest that the approach of DEA could assess the performance based on multiple inputs and outputs, making it a tool wildly used for measuring the efficiency in higher education.
- Radial DEA model applied by the most researchers could only detect the proportionate movement and ignores the slack movement of the inefficient units。
- There is definitely difference between comprehensive universities and universities of S. & T. in the structure of input and output, it is necessary to highlight the efficiency specialty of universities of S. & T.

Contribution of this paper to the literature

- Since Slack Based Measure(SBM) Model can detect both proportionate movement and slack movement in the analysis of efficiency, the scores of inefficient universities calculated by SBM are notably lower than that by BCC. However, no matter what the outputs are, these two models are highly consistent in calculating the scores of efficient DMUs.
- The efficiency score of research universities of S. & T. improves quickly, and it is higher than comprehensive universities when scientific research and social service are gradually included as outputs. As indicated, research universities of S. & T. could provide more outputs to satisfy the social needs and assure efficiency optimization.
- Research universities of S. & T. present decreasing returns to scale (DRS), meaning that some of them have input redundancy and this number is larger than comprehensive universities.

LITERATURE REVIEW

Data Envelopment Analysis (DEA) was initiated in 1978 when Charnes, Cooper and Rhodes demonstrated how to change a fractional linear measure of efficiency into a linear program forma. Decision-making units (DMU) could be assessed on the basis of multiple inputs and outputs, even if the production function is unknown. It is wildly used in industry, service (Hathroubi, Peypoch & Robinot, 2014), scientific production (Schubert, 2014) and education (Ruiz, Segura & Sirvent, 2015).

Education is one of the top five areas of DEA application (Liu, Lu & Lin, 2013). DEA continues to be used to derive measures of efficiency in all sectors of education (Johnes, 2015), including kindergartens, primary schools (Burney & Johnes, 2013), secondary schools (Haelermans & Witte, 2012), education administrative areas, post-compulsory but pre-higher education and universities (Bayraktar, Tatoglu & Zaim, 2013; Witte, Rogge, Cherchye & Puyenbroeck, 2012), especially after 1980 (Berbegal Mirabent & Solé Parellada, 2012). According to the finding of the scholar, the outcomes of DEA could provide valuable information supporting the management of higher education and describe the development possibilities in these areas (Nazarko & Šaparauskas, 2014).

Thus, DEA is applied to measure the efficiency of higher education all over the world. In recent years, lots of researchers have studied the efficiency of universities in different countries, such as the UK, Australia, Turkey, Malaysia, Thailand, Czech and China.

In England, technical efficiency and scale efficiency appear to be high on average (Johnes, 2006) as the student scale in higher education is expanding during recent years. However, it has been found that the majority of institutions' productivity has actually decreased (Thanassoulis & Johnes, 2011). When developing a flexible slacks-based model to calculate the relative efficiency of 50 universities in the UK, the author finds that eight universities are efficient (Amirteimoori, Emrouznejad & Khoshandam, 2013). Regardless of the output-input mix, Australian universities as a whole has recorded a high-level of efficiency during the 2000s (Abbott & Doucouliagos, 2003). Some scholars concern the research achievements of universities and apply a network DEA model to measure quality and quantity of universities' research services. According to their finding, Australian universities perform better when the production focuses on the research activity, but perform poorly when the grants are the outputs (Lee & Worthington, 2015).

As for Turkey, the percentage of efficient public universities is 37% in 2006, 39% in 2007, 47% in 2008, 35% in 2009, and 37% in 2010 (Selim & Bursalioglu, 2013). In terms of fulfilling the expectations of their stakeholders, private universities with higher-level quality management perform better (Bayraktar et al., 2013). When measuring the efficiency of different departments in a university, the researcher concludes that there are eight most efficient departments in Dokuz Eylul University. Other departments are not completely efficient, which may be caused by the scale or the inferior conditions (Gökşen, Doğan & Özkarabacak, 2015). The researcher evaluates the relative teaching and research efficiency of 30 universities in Malaysia by adopting a DEA model that is consisted of 16 inputs and outputs. It finally concludes that only one university is efficient in both teaching and research, and most universities are either efficient in teaching or efficient in research (Kuah & Wong, 2011).

For universities in Thailand, the average efficiency score of teaching efficiency is 0.7629, while the average efficiency score of output is 0.4562. That is to say, the majority of universities are inefficient. In terms of research efficiency, the autonomous universities outperform the government universities (Saranya & Tang, 2010).

In Czech, eight different models are applied to measure the efficiency of 26 public universities. As shown by the results, there are great differences among the universities in the same model and also exists differences among the models themselves. It means that when several universities are efficient in some certain models, they may be not efficient in other models. Indeed, the efficiency score can be easily affected by the inputs and outputs (Mikušová, 2015).

Apart from studying on single countries, some researchers also focus on 7 countries in Europe. After measuring the technical efficiency of 259 higher education institutions in 7 European countries, they find out that the universities in these countries are not efficient in publications and graduations, and the size of the institution affects its efficiency. The more the students and faculties, the higher the institutions' efficiency. Also, the funding structure influences the universities' performance (Wolszczak-Derlacz & Parteka, 2011).

For universities in China, the research performance of institutions across regions has improved, despite that the institutions as a whole have remained inefficient from 1993 to 1995 (Ying & Sung, 2000). In the assessment of the research efficiency of "211" project universities from 2006 to 2010, the efficiency of research production in humanities & social disciplines of university is very low, while it keeps a high level in science, engineering, agriculture and medical science disciplines (Hu & Fan, 2014).

Generally speaking, as long as a unit has clear inputs and outputs, its efficiency can always be calculated by economists of education, no matter it is a university or a department. However, the current research confronts with four obstacles:

①Owing to the limitation of sample size, too many indicators will make it difficult for models to distinguish. The sample size should meet two principles: not less than three times the number of inputs and outputs; not less than the number of input indicators as well as output indicators. The larger the sample size, the easier for models to distinguish.

②The selection of indexes stresses practical importance but ignores mathematical significance. Notably, the indicators of input and output in DEA model must be linear and additive. Some indicators are ratios, if their denominators are different among units, they cannot be calculated by DEA models. Otherwise, the false production possibility set will appear or even the production frontier will be out of production possibility set.

③Most existing researches utilize radial DEA model (CCR and BCC Model), which could only detect the proportionate movement of inefficient units. However, if inefficient DMU wants to improve its efficiency score, both proportionate movement and slack movement are needed.

④Most existing researches only focus on the characteristics of university but ignore the influences that environment or random factors may have on its inputs. Hence, the efficiency results cannot reflect whether the inefficiency is caused by the management or the environment or other random factors.

Accordingly, the study analyses the input and output efficiency of research universities of science and technology in China so as to solve the above problems.

METHODOLOGICAL FRAMEWORK

The methodological approach deploys 3 stages: Firstly, three different DEA models (CCR, BCC and SBM) are utilized to estimate the university efficiency score. Secondly, stochastic frontier analysis (SFA) is conducted to discern possible correlation between efficiency score and the contextual factors including environmental, exogenous, or non-discretionary variables and statistical noise. Thirdly, the initial input of each university is adjusted according to the effects of environment and statistical noise.

Stage 1: Using CCR, BCC and SBM models to evaluate efficiency

DEA measures the relative efficiency of decision-making unit with multiple inputs and outputs. Relative efficiency in DEA refers to the ratio of total weighted output to total weighted input. By comparing n decision-making units (DMU) with s inputs denoted by x_{ik}, $i = 1, 2, \ldots s$, and m outputs denoted by y_{rk}, $r = 1, 2, \ldots m$, the efficiency measure for DMU_k can be expressed as:

$$h_k = \max \frac{\sum_{r=1}^{m} u_r y_{rk}}{\sum_{i=1}^{s} v_i x_{ik}},$$

While $\sum_{r=1}^{m} u_r y_{rk} - \sum_{i=1}^{s} v_i x_{ik} \le 0$, for $k = 1, 2, \ldots n$

Where u_r, y_{rk}, v_i and x_{ik} are non-negative.

h_k ranges from 0 to 1, and DMU_k is considered to be relatively efficient if it receives a score of one. Thus, each DMU should choose a weight which maximizes self-efficiency, given the constraints.

Basic radial DEA model could be divided into two categories: (1)CCR Model (Charnes, Cooper & Rhodes, 1978) and (2)BCC Model (Banker, Charnes & Cooper, 1984).

CCR Model assumes that the production function exhibits constant returns to scale (RTS), which can be listed as following:

$$h_k = \max \sum_{r=1}^{m} u_r y_{rk}$$

Subject to $\sum_{r=1}^{m} u_r y_{rk} - \sum_{i=1}^{s} v_i x_{ik} \leq 0$, for $k = 1, 2, \ldots n$ (1)

$\sum_{i=1}^{s} v_i x_{ik}$ =1,

$v_i \geq 0$,for $i = 1, 2, \ldots s$

$u_r \geq 0$ for $r = 1, 2, \ldots m$

BCC Model assumes that the production function exhibits variable RTS, which can be listed as following:

$$h_k = \max \sum_{r=1}^{m} u_r y_{rk} + c_k$$

Subject to $\sum_{r=1}^{m} u_r y_{rk} + c_k - \sum_{i=1}^{s} v_i x_{ik} \leq 0$, for $k = 1, 2, \ldots n$ (2)

$\sum_{i=1}^{s} v_i x_{ik}$ =1,

$v_i \geq 0$,for $i = 1, 2, \ldots s$

$u_r \geq 0$ for $r = 1, 2, \ldots m$

Although CCR and BCC discriminate efficient and inefficient DMUs by the existence of slacks, these models have no scalar measure (ratio efficiency) parse and also could not gauge the depth of inefficiency. In contrast to CCR and BCC, which are based on the proportional reduction (enlargement) of input (output) vectors, Slack Based Measure (SBM) Model could directly deal with input excess and output shortfalls (Tone, 2001).

SBM considers an expression for a certain $DMU(x_0, y_0)$:

$$x_0 = X\lambda + s^-$$

$$y_0 = Y\lambda - s^+$$

With λ, s^+ and s^- are non-negative. The vector s^- and s^- are called slacks that indicates the input excess and output shortfall.

Assuming that each DMU has s output and m input, the efficiency measure for DMU_k could be calculated by two linear programs:

Input-oriented SBM Output-Oriented SBM

$$\min \rho = 1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}} \qquad \min \frac{1}{\rho} = 1 + \frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{rk}$$

$$s.t.\ X\lambda + s^- = x_k \qquad s.t.\ X\lambda + s^- \le x_k$$

$$Y\lambda \ge y_k \qquad Y\lambda - s^+ = y_k$$

$$\lambda, s \ge 0 \qquad \lambda, s \ge 0$$

The Input-Oriented Model addresses the question "buy how much can input quantities be proportionally reduced without changing the produced output quantities?" Whereas, output oriented models address the question "buy how much can output quantities be proportionally expanded without altering the used input quantities?" The Input-Oriented SBM and Output-Oriented SBM are equivalent. Since the environment factor and random factor exert impact on the input, we will apply Input-Oriented SBM to measure the efficiency.

The objective function of SBM is to minimize the efficiency score. Thus, the score calculated by SBM is generally lower than that by BCC. Although this shortcoming is criticized by many researchers, for those efficiency evaluators who always expect to evaluate the efficiency of units with the most rigorous criterion, SBM Model is harmless and has stronger applicability.

Even though Pure Technical Efficiency and Scale Effect could be easily obtained from the result of BCC Model and SBM Model, actual performances of universities are likely to be attributed by the combination managerial inefficiencies, environmental effects and statistical noise. Hence, it is essential to turn to SFA to reject these three effects.

Stage 2: Using SFA to discern *the effects of environment and statistical noise*

The objective of the Stage 2 analysis is to decompose Stage 1 slacks into these three effects. SFA is utilized to distinguish the effects of managerial inefficiency and statistical noise.

The dependent variables in the Stage 2 SFA regression models refer to the Stage 1 input slacks $s_{i,k}$. The independent variables in the Stage 2 SFA regression model refer to the elements of the p observable environmental variables $X_i = \left[X_{1i}, \ldots, X_{pi}\right]$, $\mathrm{i} = 1, \ldots, I$. The regression model takes the general form:

$$s_{i,k} = \sum_{i=1}^{p} \beta_i X_i + v_{i,k} + \mu_{i,k}$$

The parameter vectors β_i represent the environmental effects and the composed error structure $v_{i,k} + \mu_{i,k}$ will be estimated. All the parameters are allowed to vary across the input slack regressions, which allow the environmental variables, statistical noise and managerial inefficiency to pose different impacts on inputs.

Stage 3: Using DEA models *by adjusted input to evaluate efficiency*

According to the results of Stage 2 SFA regression, the initial input could be adjusted by the following formula

$$\hat{x}_{ni} = x_{ni} + [\max(\hat{X}\beta') - \hat{X}\beta'_n] + [\max(\hat{v}_{ni}) - \hat{v}_{ni}], \quad n = 1, 2, 3 \ldots N$$

$\hat{x}_{ni}$ is the adjusted input, x_{ni} refers to the initial input. The $\max(\hat{X}\beta') - \hat{X}\beta'_n$ means that the environmental effects have been adjusted to the same level, while $\max(\hat{v}_{ni}) - \hat{v}_{ni}$ adjust the random effects into the same level.

The objective of adjustment is to ensure that DMUs could exert the same effects on environment and statistical noise. It is relatively fair for each university to evaluate the efficiency.

To calculate the Pure Technical Efficiency and Scale Effect, the adjusted input will be applied in the BCC model and SBM model.

CONCEPTUAL MODEL

The adequate choice of inputs and outputs for DEA is based on the dicta "less is better" and "more is better" (Cook, Tone & Zhu, 2014). Nonetheless, there is a lack of consensus on which indicators can best represent the inputs and outputs of such institutions (Berbegal Mirabent et al., 2012).

According to the previous researches, variable inputs contain human resources and financial resources. Human resources include academic staff, non-academic staff (Selim et al., 2013; Veiderpass, & Mckelvey, 2014), and school enrollment (Aristovnik, & Obadic, 2014). Financial resources contain revenue or educational expenditure (Selim et al., 2013; Aristovnik et al., 2014), non-current assets, academic staff salaries (Köksal, & Nalçaci, 2006), scientific research projects (Selim et al., 2013), out-door and in-door area (Gökşen et al., 2015).

For the types of outputs, the past studies usually focus on the outputs of teaching and research. Teaching outputs contain the number of students (or equivalent full-time students) (Gökşen et al., 2015; Veiderpass et al., 2014) , number of bachelor degree conferred as well as master degree and doctor degree conferred (Veiderpass et al., 2014), student retention, graduate full-time employment and overseas fee-paying enrollment (Avkiran, 2001; Jones, 2006). Research publications include journal papers (Halkos, Tzeremes, & Kourtzidis, 2012), books, chapters in a book, conference papers and presentations. Although publication is the most popular indicator, the balance between quality and quantity is hard to keep. Some weight-index and some proxy variables may be utilized as the alternative solutions. Additionally, citation could be treated as a significant factor of quality of publication from the Scientometrics (Jones & Taylor, 1990). Research granting may be a commonly utilized proxy variable, such as research quantum allocation (Abbott et al., 2003). Abbott et al (2003) use research income from agencies, such as the US National Science Foundation; as outputs, it provides a way to quantify peer group evaluation. Inclusion of one source of research funds as an input and the other source as an output highlights the necessity to scrutinize the nature of a factor before classification.

We hold that the material resources put in daily running of the university, such as laboratory and classroom, they should also be regarded as important inputs because they are the same as human resources and financial resources. From the point view of higher education, however, the functions of universities include talent training, scientific research and social service. Thus, the outputs of a university should also cover social service achievement apart from teaching achievements and scientific research achievements.

In the meanwhile, according to the basic law of education, the region's economic and social development will pose a certain effect on the university, which may influence input and output efficiency (Chu, & Li, 2000). The running of a university is inevitably affected by the region's economic and social environment. Meanwhile, the region's economic development, education degree and internationalization exert important impacts on university. Thus, it is of great necessity to take environmental variables into consideration.

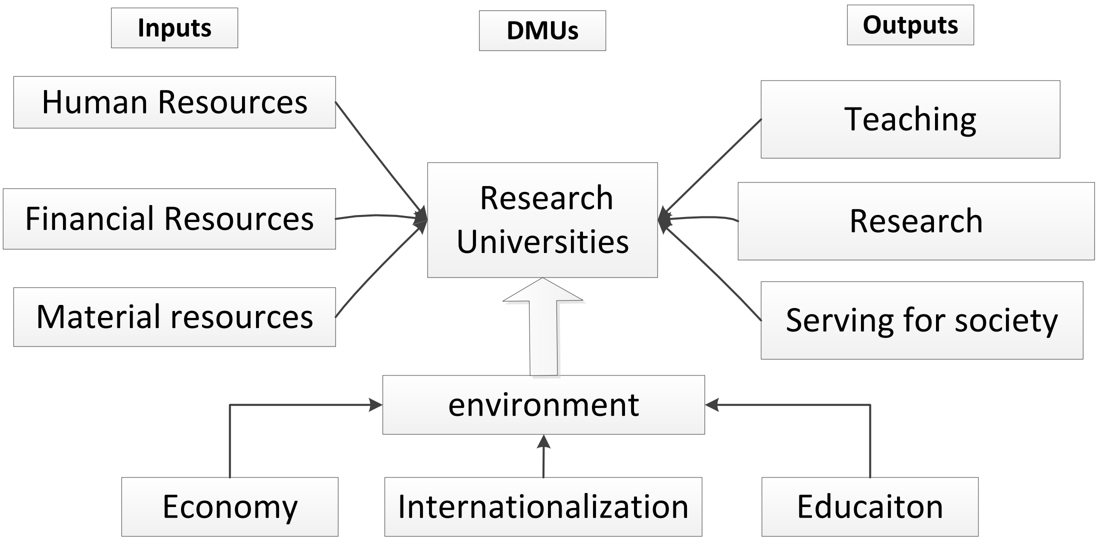

Figure 1. Conceptual model for efficiency analysis

Thus, the conceptual model is presented in figure 1.

INDEXES, DATA AND DESCRIPTIVE STATISTICS

5.1 Descriptive Statistics of Indexes

For the inputs, the index of human resources is the number of teachers whose title is above vice-senior. In recent years, multiple Chinese universities have learned from America and carried out a teachers' promotion mode -"up or out", and only those who are promoted to associate professor can obtain the so-called "lifelong tenure" faculty. Thus, the amount of instructors is not stable and the statistical number may be inaccurate. As a result, the study limits the faculty into "vice-senior title or above". The index of financial resources includes annual educational expenditure. Given that the scientific research achievement is a kind of outputs of university, some researchers believe that the investments on research funding could be an index of input as well.

However, research funding is obviously periodical (the funding of a research project is usually allocated in different years) and its specific data is uneasy to obtain. What's more, its category (whether it is an input indicator or an output indicator) is still controversial among different scholars. Thus, this study only selects annual educational expenditure as the financial investment. The indexes of material resources are the area of classroom and the area of laboratory. The area of classroom reflects the teaching condition, and the area of laboratory represents the condition of conducting scientific research. Also, these two indexes are important variables which restrict the capacity and present the scale-efficiency of a university.

For the outputs, the teaching output is measured by the number of students who can meet graduation requirement, and the indexes include the number of doctor degree granting, the number of master degree granting and the number of bachelor degree granting. The scientific research output is measured by the number of published papers, and the indexes contain the papers published in Chinese Social Sciences Citation Index (CSSCI), Chinese Science Citation Database (CSCD), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI) as well as

Science Citation Index (SCI). Finally, the social service output is measured by the

Table 1. Descriptive statistics of indexes

Variable	index	Descriptive Statistics		Data source
		Mean	S.D.	
Input	Faculties	1622	624	Websites of the Universities
	Annual Educational Expenditure(Ten ThousandS CNY)	309673	185932	The financial statements of the Universities
	Area of Classroom(square meter)	110097	53416	Websites of the Universities
	Area of Laboratory(square meter)	210231	118208	
Output	Doctor Degree Granting	575	407	Websites of the Universities
	Master Degree Granting	3103	1045	
	Bachelor Degree Granting	5285	2160	
	Papers (CSSCI/CSCD)	1977	756	CSSCI and CSCD
	Papers(SCI/SSCI/AHCI)	1876	1369	Web of Knowledge
	Patents	1306	1065	Department of Science and Technology Ministry of Education of China
Environment	GDP（Billion CNY）	30756	17252	National Bureau of Statistics of the People's Republic of China
	Education Attainment(Associate)	38601	20980	
	Foreign Direct Investment(Thousands Dollar)	127598769	154342095	

Table 2. Nonnegative Test of Index Value

	Minimum	Maximum
Faculties	655	3176
Annual Educational Expenditure(Ten Thousands CNY)	118941	1022932
Area of Classroom(square meter)	32966	279926
Area of Laboratory(square meter)	38821	590626
Doctor Degree Granting	88	1683
Master Degree Granting	1483	5970
Bachelor Degree Granting	2195	10206
Papers (CSSCI/CSCD)	759	3636
Papers(SCI/SSCI/AHCI)	402	5876
Patents	28	5152

Table 3. The Correlation coefficients of input and output

	Doctor Degree Granting	Master Degree Granting	Bachelor Degree Granting	Papers	Patents
Faculties	0.84**	0.75**	0.52**	0.87**	0.58**
Annual Educational Expenditure	0.80**	0.52**	0.06	0.78**	0.66**
Area of Classroom	0.30**	0.54**	0.70**	0.57**	0.57**
Area of Laboratory	0.53**	0.46**	0.47**	0.75**	0.60**

number of patents.

From the environmental variables, the economic development is measured by the provincial GDP; the residents' education degree is measured by the population with associate degree or above (0.1% of sample survey results); the internationalization is measured by the turnover of provincial foreign-funded enterprises. In the following table, it reveals the variables, indexes, data sources and descriptive statistics results are presented (table 1).

5.2 Nonnegative Test of Index Value

All index values in DEA must be positive and the minimum values shall be greater than 0. As shown by the descriptive statistical analysis (table 2), all the index values have passed nonnegative test and the minimum values are greater than 0.

5.3 Correlation of Input and Output

The correlation analysis of input indexes and output indexes displays: except that the number of bachelor degree granting has no significant positive relation with the annual educational expenditure, all the input indexes are moderately or above correlated with output indexes (table 3). As suggested by the results, the input and output indexes are positively correlated, that is, the outputs will not decrease when the inputs increase.

RESULTS AND AALYSISES

6.1 Results of Initial DEA Model

In order to present the overall technical efficiency as well as scale efficiency of the universities and ensure the stability and precision of the outcomes, this study shows the results of BCC and SBM. We adopt nested models to handle different types of outputs. Every model is composed by three sub-models: "T" only includes teaching outputs; "T+R" includes teaching outputs and scientific research outputs; "T+R+S" includes teaching outputs, scientific research outputs and social service outputs. We applied MAXDEA 6.4 to calculate these six models, and the efficiency results of 48 research universities are listed in the below table. As regard to the input and output efficiency of the universities, the results of BCC and SBM are completely consistent, meaning that the outcomes are highly stable and precise. Even a stricter evaluation criterion is utilized, the final results will stay the same.

The results of initial DEA model are as follows:

Firstly, the results of BCC are highly consistent with that of SBM. In the sub-model "T", 35.42% universities are efficient in their inputs and outputs; in the sub-model "T+R", 56.35% universities are efficient in their inputs and outputs; in the sub-model "T+R+S", the percentage arrives 68.75%.

Secondly, from the mean score of efficiency calculated by these two models, it can be found that SBM has a harsher evaluation criterion than BCC. Thus, in the three sub-models, the efficient score calculated by SBM is generally lower than that by BCC.

Finally, both two models show that when scientific research and social service are gradually included as outputs, the number of efficient universities and their efficiency scores will increase, especially the pure technical efficiency scores. This result indicates that the function of Chinese research universities is more than just teaching, and it actually covers talent training, scientific research as well as social service.

6.2 SFA Regression Results of Input Redundancy and Environmental Variables

According to the existing research, environment may significantly affect the input-output efficiency of university（Chu, et al., 2000). So evaluating the efficiency without considering the environmental influence will affect the objectiveness and fairness of the final result. Thus, the study applies Stochastic Frontier Analysis (SFA) to analyze the influence of environmental variables.

Table 4. Results of initial DEA model

Model	Sub-Model	Mean Score of Efficiency			Most Efficient Units Number	Returns to Scale		
		Technical Efficiency	Pure Technical Efficiency	Scale Efficiency		constant	Increase	Decrease
BCC	T	0.90	0.91	0.98	17（35.42%）	17	16	15
	T+R	0.95	0.96	0.99	27（56.25%）	27	12	9
	T+R+S	0.96	0.97	0.99	33（68.75%）	33	8	7
SBM	T	0.79	0.84	0.94	17（35.42%）	17	16	15
	T+R	0.87	0.90	0.96	27（56.25%）	27	11	10
	T+R+S	0.91	0.95	0.96	33（68.75%）	33	8	7

Table 5. The results of SFA

	Slack Movement			
	Faculties	Annual Educational Expenditure	Area of Classroom	Area of Laboratory
Constant	0.00	0.00	0.07	0.08
GDP	4.35e-10	1.13e-10	1.98e-07	2.17e-07
Persons with Associate Degree	3.06e-10	1.03e-10	1.34e-07	1.04e-07
FDI	-8.80e-14	-3.25 e-14	-4.53 e-11	-3.66 e-11
sigma_v	0.00	0.00	0.01	0.02
sigma_u	225.33	349.43	138352	110276
Log likelihood	-294.88	-393.13	-614.15	-592.15
Wald chi2(2)	0.00	0.00	0.00	0.00
N	48			

This study takes the input redundancy, which is calculated by the original SBM, as dependent variables and applies SFA to analyze the provincial GDP, the population with an associate degree and above (0.1% of sample survey results) and the turnover of provincial foreign-funded enterprises.

As revealed by the regression results, the environmental variables exert no significant effect on the input redundancy, which may be closely related to the management system of higher education in China. Research universities in China are mainly dominated by the central government and they are less affected by the local economic development. Most local Chinese colleges concentrate on teaching but are weak in conducting scientific research. Moreover, they are more likely to be influenced by the provincial economic and social environment. Based on the results of SFA, the impact of environmental variables on the input redundancy of research universities can be ignored. In other words, there is no need to adjust the inputs again. Besides, the value of sigma_v indicates that the statistical noise nearly has no effect on the input redundancy。

6.3 The Efficiency of Research Universities of Science and Technology: Based on a Comparison with Comprehensive Universities

In BCC and SBM models, the scores of 48 universities show: (1) 17 universities including Peking University and Beijing University of Chemical Technology are the most efficient ones that stand on the frontier of “production possibility set”. It indicates that these 17 universities have a high input and output efficiency, no matter in talent training, scientific research or social service; (2) 10 universities including Fudan University and Nanjing University are not very efficient in the outputs of talent training. However, if the scientific research is considered, they are on the frontier of “production possibility set” and become the most efficient universities; (3) 6 universities including Zhejiang University and Beijing Science and Technology University are not efficient in the outputs of talent training and scientific research. Nonetheless, if the social service is taken into account, they are also on the frontier of “production possibility set” and turn into the most efficient ones; (4) The other 15 universities are not efficient in all models (Appendix 1).

When only focusing on the input-output efficiency of research universities of science and technology, the study finds out:

① for the mean score of efficiency (Figure 2), in the sub-model “T”, the score of research universities of science and technology is obviously lower than that of comprehensive universities. But when the outputs of scientific research and social service are gradually included in SBM, their score increases substantially and will be even higher than comprehensive universities in the sub-model “T+R+S”, which is up to 0.9225;

②for the standard deviation of efficiency score (Figure 3), The standard deviation of efficiency score among the universities of science and technology is notably lower than that of comprehensive universities. Especially when the outputs

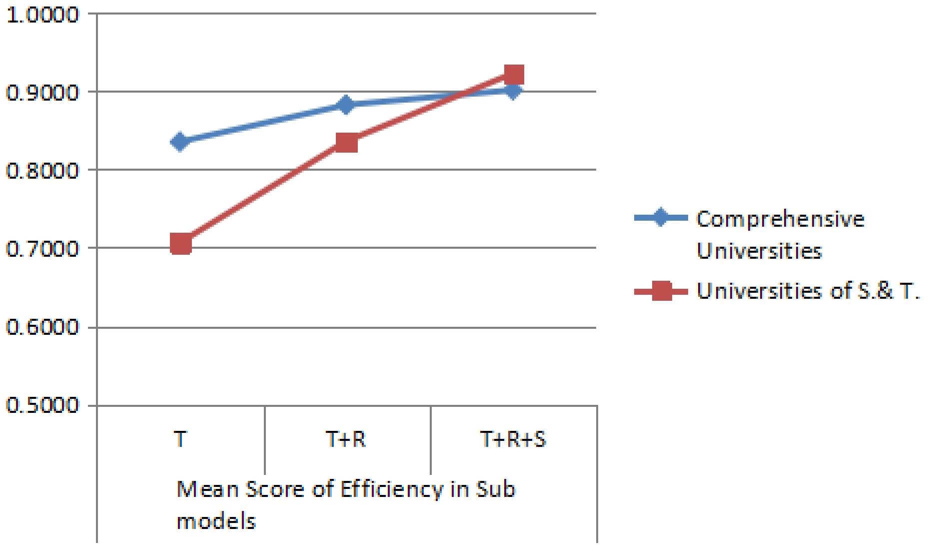

Figure 2. Mean Score of Efficiency in Sub Models (SBM)

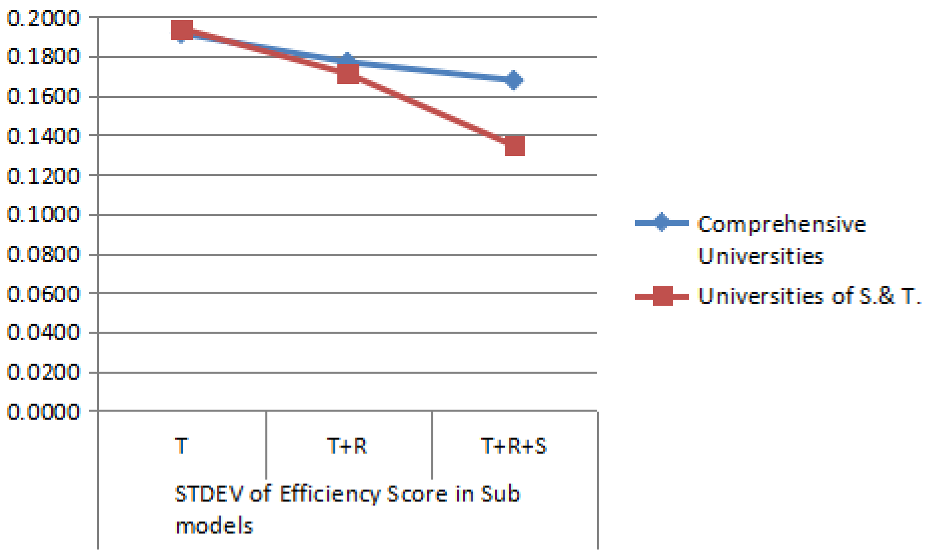

Figure 3. Standard Deviation of Efficiency Score in Sub Models (SBM)

of scientific research and social service are taken into account, it decreases remarkably. This result indicates that the variation of outputs is the common characteristic among research universities of science and technology.

③for the return to scale (RTS), the RTS is a constant in the sub-model "T", meaning that the number of research universities of science and technology with moderate scale is less than that of comprehensive universities. However, if the outputs of scientific research and social service are taken into consideration, the quantity of the former with a constant RTS will increase, and meanwhile, the total percentage exceeds the comprehensive universities (Figure 4). Nevertheless, some of the research universities of science and technology present decreasing returns to scale. Namely, when the outputs of scientific research and social service are gradually included, the number of research universities of science and technology with excessive inputs will decrease gradually, yet it is still larger than that of comprehensive universities（Figure 5).

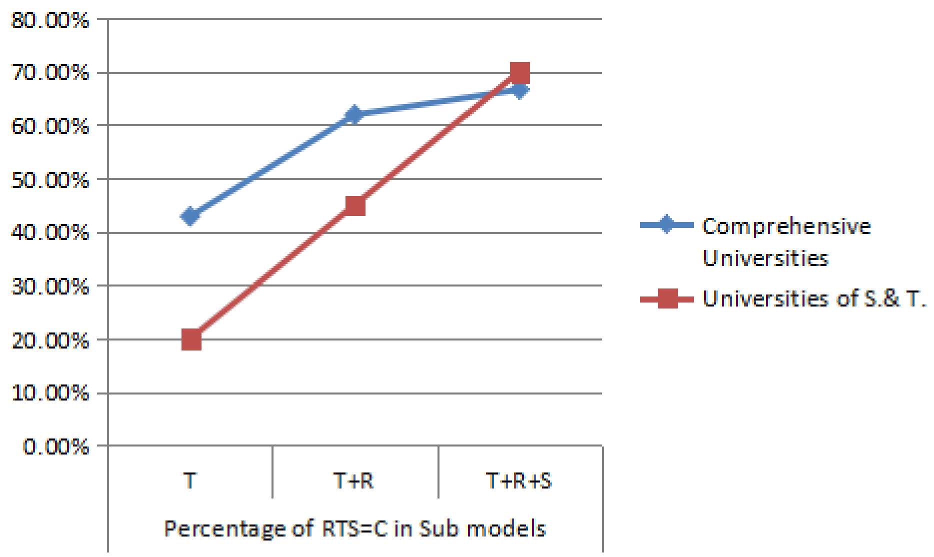

Figure 4. Percentage of RTS=C in Sub Models (SBM)

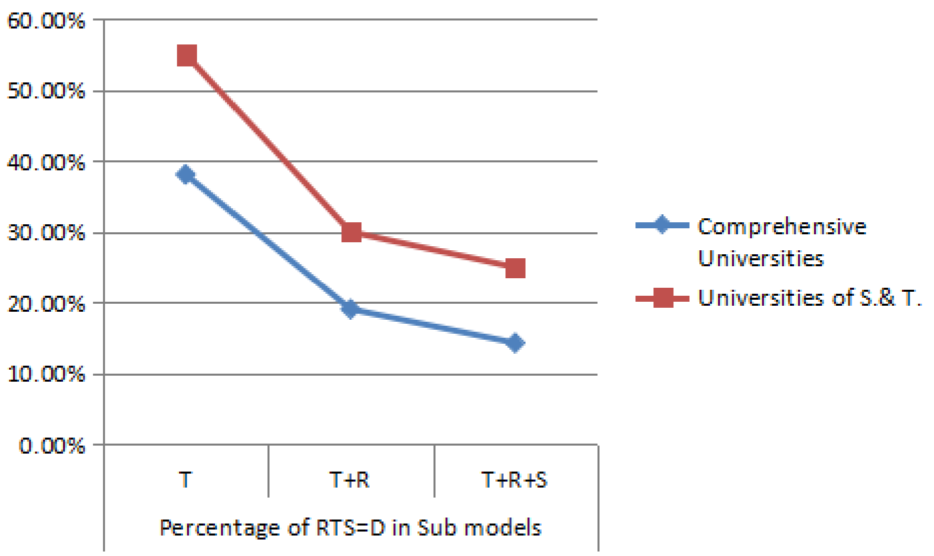

Figure 5. Percentage of RTS=D in Sub Models (SBM)

DISCUSSIONS AND IMPLICATIONS

This paper applies data envelopment analysis (DEA) and Stochastic Frontier Analysis (SFA) to explore the relative efficiency of Chinese research universities of science and technology, and identifies the more efficient one. To ensure the accurate efficiency score of research universities of science and technology, the study analyzes China's all research universities with DEA model.

BCC Model is applied in most of existing researches (Hu et al., 2014). Since SBM Model can detect both proportionate movement and slack movement in the analysis of efficiency, this study chooses it. From the whole, the scores of inefficient universities calculated by SBM are notably lower than that by BCC. However, no matter what the outputs are, these two models are highly consistent in calculating the scores of efficient DMUs.

For the efficiency scores calculated by SBM, the mean of technical efficiency score is 0.79 if the output of teaching is only considered. It increases to 0.87 when scientific research is added as an output, and arrives 0.91 when social service is included as well. This shows that the outputs of Chinese research universities are diversified. If these three outputs are considered, they will be more efficient.

To guarantee an objective and persuasive evaluation, the study applies SFA Model to reject the possible effect of environment and random on efficiency. As suggested by the result, the environmental variables exhibit no significant impact on the input-output efficiency of Chinese research universities, which matches the research results in recent years (Luo & Guo， 2014). This result is mainly caused by the dominate administration of universities, namely, the development of Chinese research universities is controlled by the central government and it has less relation with the local government.

When the study focuses on the research universities of science and technology, it finds out:

①While the model transforms from the sub-model "T" to "T+R+S", the efficiency score of research universities of science and technology improves quickly, and it is higher than comprehensive universities in the last sub-model. As indicated, research universities of science and technology could provide more outputs to satisfy the social needs and assure efficiency optimization.

②Compared with comprehensive universities, research universities of science and technology are merely heterogeneous, because their standard deviation of input-output efficiency is obviously lower. This may suggest that the similar disciplinary structure could give rise to the similar input-output's results.

③Beyond that, research universities of science and technology present decreasing returns to scale (DRS), meaning that some of them have input redundancy and this number is larger than comprehensive universities. It shows that they have a higher output level than comprehensive universities. This opinion can also be proved by a recent study, which finds that in the efficiency ranking of 40 universities under the Ministry of Education, only one comprehensive university (Hunan University) ranks in the last ten, and the other nine are universities of science and technology (Zhu, Meng, Yu, & Liu, 2013). The reasons may be lie in that the science and technology need more inputs than humanities and social science.

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Appendix. The results of models

	T		T+R		T+R+S	
DMU	Technical Efficiency Score	RTS	Technical Efficiency Score	RTS	Technical Efficiency Score	RTS
Peking University	1.00	C	1.00	C	1.00	C
Beijing University of chemical technology	1.00	C	1.00	C	1.00	C
Beijing Normal University	1.00	C	1.00	C	1.00	C
Northeast Normal University	1.00	C	1.00	C	1.00	C
Hefei University of Technology	1.00	C	1.00	C	1.00	C
Hunan University	1.00	C	1.00	C	1.00	C
Huazhong University of Science and Technology	1.00	C	1.00	C	1.00	C
Huazhong Agricultural University	1.00	C	1.00	C	1.00	C
Jilin University	1.00	C	1.00	C	1.00	C
Nanjing Agricultural University	1.00	C	1.00	C	1.00	C
Nankai University	1.00	C	1.00	C	1.00	C
Shaanxi Normal University	1.00	C	1.00	C	1.00	C
Wuhan University	1.00	C	1.00	C	1.00	C
Northwest A&F University	1.00	C	1.00	C	1.00	C
southwest university	1.00	C	1.00	C	1.00	C
Southwest Jiaotong University	1.00	C	1.00	C	1.00	C
Renmin University of China	1.00	C	1.00	C	1.00	C
Fudan University	0.94	D	1.00	C	1.00	C
Sichuan University	0.88	D	1.00	C	1.00	C
Nanjing University	0.88	D	1.00	C	1.00	C
Sun Yat-sen University	0.87	D	1.00	C	1.00	C
China University of Geosciences	0.84	D	1.00	C	1.00	C
Southern Yangtze University	0.83	D	1.00	C	1.00	C
Central South University	0.81	D	1.00	C	1.00	C
Hohai University	0.76	D	1.00	C	1.00	C
University of Electronic Science and Technology	0.63	D	1.00	C	1.00	C
Shanghai Jiao Tong University	0.48	D	1.00	C	1.00	C
Zhejiang University	0.71	D	0.86	D	1.00	C
Beijing Science and Technology University	0.75	I	0.81	I	1.00	C
Xi`an Jiaotong University	0.61	D	0.77	I	1.00	C
Southeast University	0.49	I	0.61	I	1.00	C

Appendix. (contiouned)

South China University of Technology	0.54	D	0.60	D	1.00	C
Tsinghua University	0.56	I	0.59	D	1.00	C
Tianjin University	0.54	I	0.65	I	0.89	I
Wuhan University of Technology	0.88	D	0.88	D	0.89	D
Central China Normal University	0.85	I	0.85	I	0.85	I
China Agricultural University	0.76	I	0.77	I	0.83	I
Dalian University of Technology	0.62	D	0.81	I	0.82	D
Shandong University	0.68	D	0.80	D	0.80	D
Chongqing University	0.69	D	0.75	D	0.77	D
Lanzhou University	0.62	I	0.77	I	0.77	I
Tongji University	0.46	D	0.67	D	0.73	D
East China University of Science and Technology	0.52	I	0.67	D	0.67	D
Ocean University of China	0.63	I	0.64	I	0.64	I
Northeastern University	0.59	D	0.59	D	0.59	D
Beijing Jiaotong University	0.50	I	0.56	I	0.57	I
East China Normal University	0.50	I	0.52	I	0.52	I
Xiamen University	0.48	D	0.49	D	0.51	D

Notes: RTS: Return to Scale, C (constant), D (Decrease), I (Increase)