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Data Envelopment Analysis for Relative Efficiency Measurement of Chinese Hospitals: A Systematic Review

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Abstract

The purpose was to explore the gap between China and the international world in efficiency measurement of hospitals with Data Envelopment Analysis, and to improve the standardization of healthcare efficiency measurement in China. A systematic review was conducted using appropriate search strategies. Studies were included containing DEA approaches regarding general hospital efficiency, published in international literature and in both Chinese and English about Chinese hospitals from January 2004 to October 2014. The results showed that *statistical significances were found in indicators such as number of DMUs, percentage of allocative efficiency studies, ratio of studies with multiple years, number of studies with monetary indicators in input and output sets, etc. The statistical insignificance in some indicators such as the number of input and output indicators were also found among China, Europe, USA and others. Some problems were found in current DEA-based hospital efficiency studies in China, such as inappropriate selection of input-output indicators, no bias-correction on efficiency scores, etc. The standardization of DEA methods applied in China's hospital efficiency research needs to be improved. Chinese researchers should pay more attention to latest international research findings, so as to keep pace with the cutting edge hospital efficiency research.*

Keywords
Data Envelopment Analysis (DEA), hospital efficiency, international comparison, China

1. Introduction

Since the implementation of the new round of health system reforms in China in 2009, a considerable amount of achievements have been made, such as the establishment of a combination of basic health insurance programs with universal coverage to reduce the share of out-of-pocket health spending. With population aging as well as the increase in income, Chinese people have more healthcare needs and demands. In this context, all kinds of public hospitals are going for massive expansion, such as achieving medical alliance among hospitals, expanding present site, building branch hospitals, etc. How to improve the technical efficiency of hospitals to achieve economy of scale is significant not only to hospital development, but also to better meet the increasing healthcare needs and demands.

In terms of hospital efficiency measurement, the parametric method represented by Stochastic Frontier Analysis (SFA) and the nonparametric method represented by Data Envelopment Analysis (DEA) have been widely applied. The SFA method was once applied to analysis the hospital inefficiency (Rosko & Mutter, 2008). Although the advantages of SFA were well documented, its potential drawbacks for hospital efficiency are obvious as well, such as the necessity to estimate production functions, using one single output, etc. In contrast, the DEA approach can simultaneously accommodate multiple inputs and multiple outputs (Banker, Charnes, & Cooper, 1984; Charnes, Cooper, & Rhodes, 1979), which has been considered as an effective and flexible tool for hospital efficiency measurement (O'Neill, Rauner, Heidenberger, & Kraus, 2008). DEA can be easily used to calculate hospital efficiency scores based on appropriate selection of input-output indicators.

Chinese researchers have applied DEA models for more than two decades in efficiency measurement of healthcare organizations. Lots of articles have been published in Chinese journals. However, it is surprising to find that only very few ones has been published in international journals. Besides language barriers there must be some confounding reasons. The purpose of this study is to explore the gap between China and the international world in efficiency measurement of healthcare organizations with DEA, and to improve the standardization of efficiency measurement of hospitals in China.

2. Method

2.1 Design of the Study

This research is designed to classify the literature into China, Europe, USA and other countries and regions. First, the literature was grouped into Chinese literature and international literature. Then the two respective groups of literature were further decomposed into technical efficiency and allocative efficiency. After that the literature was further grouped according to whether multiple time periods applied. The essential features of each paper was summarized in terms of input indicators, output indicators, type of efficiency, number of DMUs, DMU-indicator ratio, etc. The literature about China was further compared with the international literature (Europe, USA and other countries and regions) to explore the differences across nations and regions.

In further design, the input and output indicators would be addressed respectively. The input indicators would be classified into four categories: beds, staffs, monetary indicators and other input indicators; the output indicators were classified into 3 categories: services indicators, monetary indicators and other output indicators. In order to evaluate the standardization of indicators applied in China, the input-output indicators were counted of their citation numbers and percentage.

2.2 Literature Searching and Collection

Formula "Title = ('hospitals') * Abstract = ('data envelopment analysis' + 'DEA')" was employed to search the literature published between January, 2004 and October, 2014. Comprehensive literature searches were conducted through typical Chinese and English online databases, such as CNKI China Academic Journals Full-text Database, Wanfang Database, Chongqing VIP Chinese Scientific Journals Database, Chinese Biomedical Literature Database and Academic Search Complete (EBSCO), Web of Knowledge, Springer Link, PubMed, etc. Besides, since the focus of this review was on the study of general hospitals efficiency, articles on specialty hospitals and military hospitals were excluded. And studies on DEA-based hospital efficiency in Taiwan were excluded in our study. As a result, 75 DEA-based hospital efficiency articles in China.

2.3 Data Analysis

Descriptive analysis was applied for both the classification of collected articles and the selection of input and output indicators. In order to recognize gaps between the differences among China and international studies, variance analysis and chi-square test were used to test the statistical significances between China and other countries and regions on key variables such as number of DMUs, number of input and output indicators, ratio of studies on allocative efficiency, ratio of multiple-year studies, DMU-indicator ratio greater than 3, number of studies with monetary indicators in both input and output sets, etc.

3. Results

3.1 Description of Method Classification of Hospital Efficiency Studies

Each of the 7 groups can be summarized as follows: Figure 1 shows 3 classified groups of the studies in China: technical efficiency with single year period (Group 1), technical efficiency with multiple periods (Group 2) and allocative efficiency with multiple periods (Group 3). Figure 2 shows 4 groups of the international articles: technical efficiency with single period (Group 4), technical efficiency with multiple periods (Group 5), allocative efficiency with single period (Group 6), and allocative efficiency with multiply periods. Each of the 7 groups can be summarized as follows:

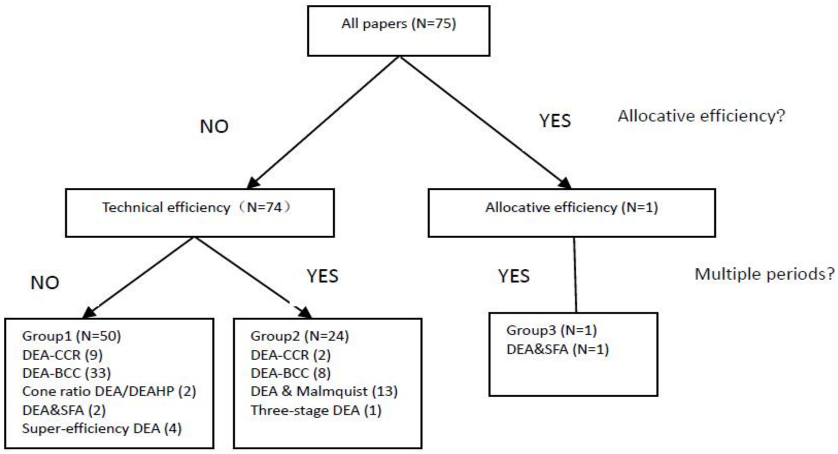

Figure 1. Classification of DEA-Based Hospital Efficiency Studies in PRC

Group 1:

The majority of hospital efficiency studies (32 out of 51 studies) in China concentrate on the application of classical DEA models (CCR and BCC). Cone ratio DEA (Luo et al., 2004) and DEAHP (Xia et al., 2009) in combination with classical DEA models and AHP were used in 2 studies. Super-efficiency model was also employed to determine the relative efficiency of effective DMUs measured (Liu et al., 2011; Wang & Pan, 2013; Yu et al., 2012; Zhou, 2013).

Group 2:

13 studies in China applied Malmquist-DEA. It was found that super-efficiency model was employed to analyze the efficiency of hospitals with multiple time periods. In addition, a three-stage DEA based Malmquist productivity index adopted by Yang and Zeng (2014) was used to measure the changes in productivity, efficiency and quality (Yang & Zeng, 2014). Initial DEA, SFA regression and re-compute efficiency was applied in the three-stage DEA.

Group 3:

Allocative efficiency measurement was found just in one study. 340 public hospitals of and above county level in Sichuan province, China from 2003-2007 were taken as the study example by Zhong (2010) in his master thesis to estimate technical, scale, cost and allocative efficiency with DEA and SFA methods (Zhong, 2010).

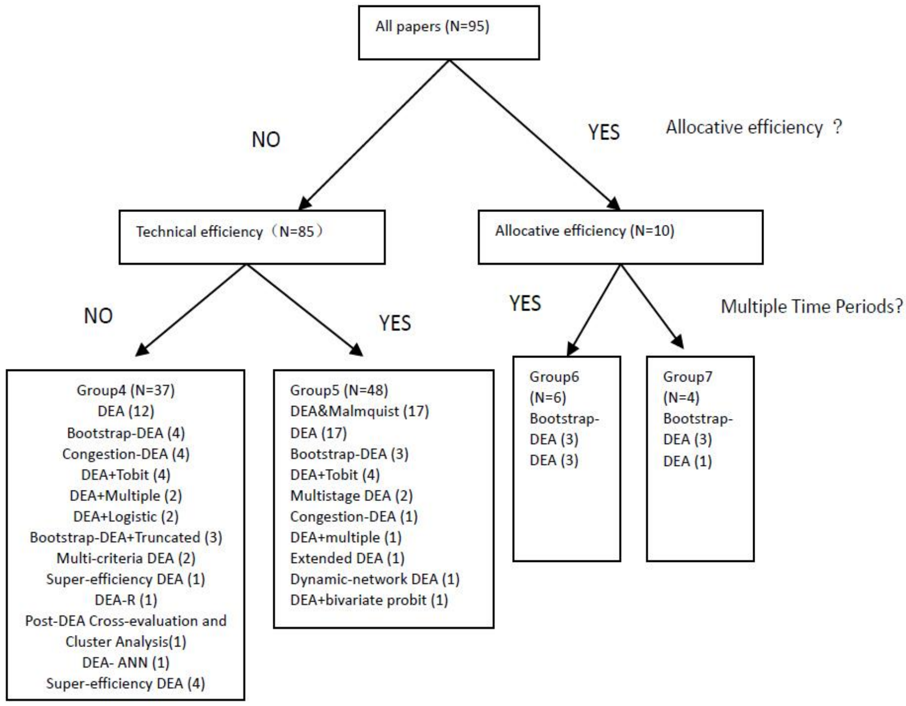

Figure 2. Classification of DEA-Based Hospital Efficiency Studies in International Studies

Group 4:

A common practice has been made to measure efficiency in two stages in the literature. Novel applications and extensions of efficiency measurement in two stages includes DEA with Tobit (Fareed et al., 2012; Kirigia & Asbu, 2013; Nayar et al., 2013), multiple (Bates et al., 2006; Gok & Sezen, 2013), logistic (Chustz, 2012; Lobo et al., 2014) and truncated regression analysis (Araujo et al., 2014; Halkos & Tzeremes, 2011; Kounetas & Papathanassopoulos, 2013; Mitropoulos et al., 2013), etc. Furthermore, a considerable extended DEA models have been developed in international studies, including bootstrap-DEA (Halkos & Tzeremes, 2011; Puenpatom & Rosenman, 2008; Simões & Marques, 2011; Varabyova & Schreyogg, 2013), congestion-DEA (Ferrier et al., 2006; Masiye, 2007; Valdmanis et al., 2004; Valdmanis et al., 2008), DEA-R (Wei et al., 2011), post DEA cross-evaluation and cluster analysis (Flokou et al., 2011), and multi-criteria DEA models (Ajlouni et al., 2013; Zaim et al., 2007), etc.

Group 5:

Some studies adopted panel data to measure hospital efficiency with DEA and other techniques such as Malmquist index, bootstrap, etc. To measure both efficiencies of separate DMUs and dynamic efficiency changes, dynamic-network DEA was applied in the efficiency evaluation in the healthcare field (Kawaguchi et al., 2014). DEA and bivariate probit was explored to examine the effects of environmental pressures on hospital efficiency and uncompensated care provision (Hsieh et al., 2010).

Group 6 and Group 7:

Due to the difficulty to obtain rational price information, studies on allocative efficiency were scant. Only 2 main approaches, standard DEA model and Bootstrap-DEA, were used to calculate the allocative efficiency of hospitals in the literature (Besstremyannaya, 2013; Blank & Valdmanis, 2010; Blank & Vanhulst, 2011; Gautam et al., 2013; Kristensen et al., 2010; Linna et al., 2006, 2010; Ma & Petr, 2005; Medin et al., 2011; Nedelea & Fannin, 2013).

3.2 Selection of Input Indicators

The input indicators of DEA-based technical efficiency studies in China and abroad were addressed respectively. The results showed that the top 5 input indicators applied in China were "actual number of beds/actual number of open beds/average number of beds" (93.24%), "total expenses/operating expenses/supplies" (62.16%), "fixed assets" (55.41%), "number of total FTEs/staff/labor size" (39.19%), and "medical technical staffs" (22.97%). The top 5 input indicators applied in international literature were "number of beds" (60.92%), "number of physicians/doctors" (35.63%), "number of nurses and/or nursing staff" (28.74%), "operating expenses/supplies" (27.59%), and "number of total FTEs/staff/labor size" (18.39%). In order to deal with the variety of input indicators, 4 sub-categories were summarized: "beds", "labors", "monetary indicators" and other atypical input indicators. Table 1 lists the input indicators based on literature on hospital technical efficiency.

Table 1. Input Indicators Based on International Literature and PRC

Input indicators	International literature		PRC	
	Citation number	Percentage (%)	Citation number	Percentage (%)
Beds				
Number of beds/number of active beds/average number of beds	58	68.24	69	93.24
Number of acute/emergency beds	4	4.71		
Number of staffed beds	4	4.71	1	1.35
Number of ICU beds	1	1.18		
Number of bed days	2	2.35		
Number of beds for treatments for dermatitis herpetiformis	2	2.35		
Number of general beds and special beds	2	2.35		
Number of other beds	1	1.18		
Staffs				
Number of total FTEs/staff/labor size	16	18.82	29	39.19
Number of physicians/doctors	37	43.53	11	14.86
Number of FTE physicians and dentists	4	4.71		
Number of specialist physicians	3	3.53	1	1.35
Number of physicians and nurses	3	3.53		
Number of FTE interns/residents	3	3.53	1	1.35
Number of pharmacists	3	3.53		
Number of nurses and/or nursing staff	30	35.29	9	12.16
Number of FTE registered nurses	8	9.41		
Number of FTE licensed practical nurses	6	7.06		
Number of clinical/medical/health staff	7	8.24		
Number of other medical/health professionals	4	4.71		

Number of other staff	15	17.65	2	2.70
Number of other nonclinical staff	5	5.88		
Number of administrative staff	4	4.71	4	5.41
Number of medical technical staffs	3	3.53	17	22.97
Number of other professions	3	3.53		
Monetary indicators				
Total expenses/Operating expenses/Supplies	24	28.24	46	62.16
Total assets			4	5.41
Fixed assets			41	55.41
Expenditures on materials, supplies, and drugs/material expenses/drugs other supplies	7	8.24		
Total equipment expense/Total facility expense	3	3.53	2	2.70
Subsidy from municipal/allowance expenditures	2	2.35		
Capital expenses	2	2.35	2	2.70
Total hospitalization costs			3	4.05

Beds

70 out of 74 studies in China adopted number of beds as an input indicator. Some studies used "actual number of beds/actual number of open beds/average number of beds" (used in 69 studies), "number of staffed beds" (only used in 1 study) instead. Table 1 lists the bed indicators based on international literature on hospital efficiency. The "number of beds" was regarded as an input indicator in 53 out of 77 technical efficiency international studies. Several studies disaggregated hospital beds into acute/emergence beds, Intensive Care Unit (ICU) beds, general beds and special beds, etc.

Labors

In our study, labor indicators were adopted in 71 China studies and in 72 international studies. 39.19% studies in China used "number of total FTEs (full-time employees)" as an input indicator, followed by "medical technical staffs" (22.97%) and "number of physicians" (14.86%) respectively. As is seen in Table 1, some typical labor indicators were widely applied in international studies, such as "number of physicians/doctors" (35.63%), "number of nurses/nursing staff" (28.74%), "number of total FTEs/staff/labor size" (18.39%) and "other staff" (16.09%).

Monetary indicators

62 out of 74 hospital technical efficiency measurement studies in China defined monetary indicators (fixed asset, expenditure, revenue) into the input set, while 30 international studies had the same consideration (See Table 1). Various types of monetary indicators in the input set in China were divided into the following sub-categories: operating expenses and capital investment, labor costs and equipment expenses. 46 studies presented "total expenses/operating expenses/supplies" as the cost input, while "fixed assets" were employed as input categories in 41 studies. "Medical staff costs" and "total equipment expenses" are used as a proxy of labor costs and equipment expenses respectively.

Other atypical input indicators

Statistics showed that in several hospital technical efficiency studies in China, some atypical input indicators were added, such as "building area", "average medical costs of discharges", while the international literature introduced "staff hours" and/or "service complexity" as input indicators.

3.3 Output Indicators

Output indicators of 74 DEA-based hospitals technical efficiency studies in China and 77 international studies were counted respectively, which were classified into 3 sub-categories: "medical service indicators", "monetary indicators" and other atypical indicators. The results indicate that the top five output indicators in China were "number of discharges" (79.73%), "number of outpatient and emergency visits" (51.35%), "operating revenues" (29.73%), "bed turnover rate/bed turnover times" (25.68%) and "number of total visits" (21.62%). It turns out that, according to our statistics, the top five output indicators in international studies were "number of outpatient visits" (40.23%), "number of total surgeries" (21.84%), "number of inpatient days" (19.54%), "total patient days" (10.34%), "number of discharges" (10.34%). Table 2 lists the output indicators based on literature on hospital technical efficiency.

Table 2. Output Indicators Based on International Literature and PRC

Output indicators	International literature		PRC	
	Citation number	Percentage (%)	Citation number	Percentage (%)
Medical service				
Number of total visits	8	9.41	16	21.62
Number of outpatient and emergency visits			38	51.35
Number of outpatient visits	39	45.88	11	14.86
Number of emergency visits	8	9.41	2	2.70
Total patient days	12	14.12		
Number of inpatient days	18	21.18		
number of inpatients	7	8.24		
Number of discharges	11	12.94	59	79.73
Number of adjusted admissions	6	7.06		
Number of total surgeries	20	23.53	5	6.76
Surgical patients	5	5.88	3	4.05
Bed turnover rate/bed turnover times			19	25.68
Average length of stay			14	18.92
Number of actual bed-days occupied			7	9.46
Monetary indicators				
Total revenues	1	1.18	14	18.92
Operating revenues	2	2.35	22	29.73
Medical revenues	2	2.35	7	9.46
Medical revenues of outpatient			3	4.05
Medical revenues of inpatient			3	4.05
Subsidy	1	1.18	1	1.35
Revenues on drugs			2	2.70

Medical service indicators

Medical service indicators as output indicators were involved in the vast majority of studies (73 in China and 72 international studies), which were classified into three sub-categories: volume of outpatient and emergency, volume of inpatient and volume of surgeries. First, these indicators, number of outpatient and emergency visits (38 studies) and number of discharges (59 studies), are commonly included as an output factors in DEA-based hospital efficiency studies in China. However, studies in abroad often distinguished between "number of outpatient visits" and "number of emergency visits". It was noted that number of inpatient days were defined as the output in DEA-based efficiency estimation in international studies.

Monetary indicators

Only a small number of international studies, about 5 out of 77, employed monetary indicators in their output set. Conversely, these indicators were considered as output indicators in majority of DEA-based hospital technical efficiency studies (48 in 74) in China, as shown in Table 2. Whereas, different indicators measuring revenues, such as "total revenues", "operating revenues" and "medical revenues" in hospitals were adopted among related studies of China.

Other atypical indicators

Atypical indicators were found in both Chinese and international studies. Some studies of China added "expenditures on materials and drugs per bed", "equivalent volume of diagnostics per physician", "expenditures per equivalent" to their output set. The international literature used "mortality rate", "FTE trainees" and "number of deliveries".

3.4 International Comparison

Studies were classified into four groups based on their country of origins: China (n = 75), Europe (n = 29), USA (n = 29) and other countries and regions (n = 29). Table 3 indicates statistical significances of differences in number of DMUs, ratio of studies of allocative efficiency, ratio of studies with No. of DMUs/No. of indicators 3, ratio of studies with multiple periods, number of studies with monetary indicators in the input set and number of studies with monetary indicators in the output set. No statistical differences in number of input indicators and number of output indicators were observed among the four groups.

Table 3. International Comparison of DEA-Based Hospital Efficiency Studies

	PRC	Europe	USA	Other countries and regions	P-value	Difference: PRC-Europe	Difference: PRC-America	Difference: PRC-other countries and regions
Number of studies	75	29	29	37				
Number of DMUs	103.73	344.56	630.76	296.49	0.000	-240.83 p = 0.333	-527.03 p = 0.000	-192.76 p = 0.052
Number of input indicators	4.04	3.52	3.90	4.05	0.392	—	—	—
Number of output indicators	3.52	3.13	3.41	3.65	0.136	—	—	—
Ratio of studies of allocative	1.33	24.14	6.90	2.70	0.000	-22.81%	-5.57%	-1.33%

efficiency (%)						p = 0.000*	p = 0.187*	p = 1.000*
Ratio of studies with No. of DMUs/indicators ≥3 (%)	77.33	100	96.55	100	0.000	-22.67% p = 0.016*	-19.22% p = 0.020*	-22.67% p = 0.002*
Ratio of multiple period studies (%)	33.33	51.72	62.07	51.35	0.034	-18.42% P = 0.115*	-28.77%% P = 0.014*	-18.05% p = 0.066*
Number of studies with monetary indicators in the input set §	62(74)	10(22)	12(27)	15(36)	0.000	0.001*	0.000*	0.000*
Number of studies with monetary indicators in the output set §	48(74)	0(22)	2(27)	4(36)	0.000	0.000*	0.000*	0.000*

* α = 0.0125, others: α = 0.05; "—" As insignificant difference was found in four groups, no further pair-wise comparisons were made. §Just for technical efficiency studies.

Statistics showed that the number of studies in the USA were more than that of China in the number of DMUs (628.34 VS 103.73, p = 0.069). Compared with China studies, the European studies measured more allocative efficiency (24.14% VS 1.33%, p = 0.000). However, no statistical differences between China and USA, other countries and regions in ratio of allocative efficiency were found. According to some researchers, the sample should have at least three times as many DMUs as the total number of input and output indicator (Banker et al., 1984; Banker, Charnes, Cooper, & Clarke, 1989; Banker, Charnes, Cooper, & Schinnar, 1981; O'Neill et al., 2008). Statistical differences were detected between China and Europe, other countries and regions (100% VS 77.33%, p = 0.012), and no studies in Europe, other countries and regions had a ratio of less than three observations per indicator. The results demonstrated significant differences in ratio of studies of multiple period between China and USA was detected (33.33% VS 62.07%, p = 0.008). Our results revealed statistical significances in number of studies with monetary indicators in the input and output set (technical efficiency studies) between China, Europe, USA and other countries and regions. Moreover, due to monetary indicators in the input set, China had significantly more number of studies than Europe (62 VS 10, p = 0.001), USA (62 VS 12, p = 0.000), and other countries and regions (62 VS 8, p = 0.000), and so is the number of studies with monetary indicators in the output set, which show statistical significances between China and Europe (48 VS 0, p = 0.000),USA (48 VS 2, p = 0.000) and other countries and regions (48 VS 3, p = 0.000).

4. Discussion

Based on above classification and comparison, some typical problems existing in DEA-based healthcare efficiency studies in China can be summarized and discussed as follows:

4.1 Lack of Allocative Efficiency Research

Allocative efficiency measurement requires that the price information of each input indicator should be known. However, due to the difficulty to obtain price information, few Chinese studies focus on allocative efficiency. Only one article was about allocative efficiency, far less than the number of technical efficiency studies (Zhong, 2010). In comparison, the European and American studies focused more on allocative efficiency, indicating significant differences with China. More hospital reforms in price transparency together with regional health information platform need to be conducted so that it will be easier for Chinese researchers to get the price information for allocative efficiency research.

4.2 Application of Simple Classical Models in Technical Efficiency Measurement

In the Chinese studies, CCR, BCC, Malmquist index, super-efficiency, cone-ratio, two-stage DEA, three-stage DEA, etc. were found. In comparison, more diversified models have been employed in international studies, such as Bootstrap-DEA, Congestion-DEA, two-stage DEA, three-stage DEA, Dynamic-network DEA, post-DEA Cross-evaluation and Cluster Analysis, DEA-R model, etc. It can be seen that, big gap exists between China and the international world in the number of DEA models applied and the former mainly applied simple classical models in technical efficiency and productivity measurement. More in-depth analysis should be in place so as to update current DEA models from recent international findings and improve the standardization of DEA-based healthcare efficiency research in China.

4.3 Inappropriate Selection of Monetary Indicators in Technical Efficiency Measurement

It is common that several monetary indicators, such as “total revenue/operating expenses/medical expenses”, “fixed assets”, etc. have been selected as input/output indicators in Chinese hospital efficiency measurement, while few international studies have done so. When estimating technical efficiency, very few monetary indicators were included into output indicators in international studies. However, significant differences were found in number of studies with monetary indicators in the output set between China, Europe, USA and other countries and regions. In our study, only 26 of 74 studies in China did not adopt monetary indicators as output ones. Li et al. (2014) held that monetary indicators should not be considered as an output (Li et al., 2014), so as to avoid the violation of technical and allocative efficiency. However, monetary indicators can be used as input indicators to measure cost efficiency. The mixing of indicators including both monetary and volume indicators have been applied in many Chinese studies, leading to double count and violation of both technical and allocative efficiency.

4.4 Inappropriate Application of Ratio Indicators

As it is well known, DEA is based on linear programming of direct inputs and outputs for optimal arrangement of production. In many Chinese studies ratio indicators such as bed occupancy rate, hospitalization days, etc. were included into output indicators, which were inappropriate in DEA efficiency measurement. However, these ratio indicators can be considered as process variables rather than direct output indicators to help researchers better understand efficiency and productivity improvements. It is important for Chinese researchers to select input and output indicators in accordance with general international standards to improve the international recognition of DEA-based healthcare efficiency research conducted by Chinese researchers.

4.5 Less Attention to Number of DMUs

According to some studies, one requirement to apply DEA is that the number of DMUs should be at least

3 times than the total number of input and output indicators. If the condition cannot be met in the research, more efficient DMUs in DEA (efficiency scores equals 1) will be counted, which is relatively inaccurate. It was found that this requirement was met in most of international studies. In comparison, 17 Chinese studies did not comply with the condition in these investigated studies. Therefore, Chinese researchers need pay more attention to the number of DMUs to improve the rationality and science of DEA-based hospital efficiency research. When the number of DMUs is too small, one solution is to apply Bootstrap-DEA method to amplify the number of DMUs by sampling with replacement from the original sample to get the bootstrap sample.

4.6 Lack of Bias-Correction to Efficiency Scores

It is well known that classical DEA models such as CCR, BCC, Malmquist index, etc. did not consider the impact of environmental and random factors on efficiency scores. The estimated efficiency scores should be biased. Simar and Wilson introduced Bootstrap method to improve the accuracy of efficiency estimation with DEA (Simar & Wilson, 1998). The method can be used to estimate confidence intervals of efficiency scores and allow the use of bias correction in central estimates to statistically test significant differences in efficiency levels (Daraio & Simar, 2007). However, no Bootstrap-DEA literature has been found in DEA-based healthcare efficiency studies in China. This gap was found by Li et al. (2014) and later on the authors Li and Dong (2015) introduced the bootstrap method from international literature to fill the gap. In future study, this method is recommended to be applied in various healthcare institutions with homogeneity in their relative efficiency measurement with DEA. Moreover, it can be anticipated that there is ample room for the combined application of classical DEA models with Bootstrap technique.

5. Conclusions

In our review study, we have found substantial gap between China and international world in healthcare efficiency measurement with DEA. Besides the need for more allocative efficiency research, the standardization of Chinese research in technical efficiency measurement of hospitals should be further improved, specifically: (1) The selection of input and output indicators should be met the same standards as required by international studies to avoid the mixing of volume indicators with monetary and ratio indicators; (2) The number of DMUs should be 3 times more than that of input and output indicators; (3) Bootstrap-DEA should be urgently introduced into current research to correct the bias and improve the accuracy of efficiency scores; (4) Current two-stage and three-stage DEA models need to combined with the Bootstrap-DEA method to further improve the accuracy of efficiency scores. It is advised that Chinese researchers should pay more attention to study latest international research findings, so as to keep pace with the cutting edge hospital efficiency research.

5.1 List of Abbreviations

DEA: Data Envelopment Analysis; DMU: Decision-making Unit; SFA: Stochastic Frontier Analysis; CNKI: China National Knowledge Infrastructure; DEAHP: Data Envelopment Analysis and Analytic

Hierarchy Process; AHP: Analytic Hierarchy Process; ANN: Artificial Neural Network; FTE: Full Time Employee; ICU: Intensive Care Unit; PRC: the People's Republic of China; USA: the United States of America.

5.2 Contributions

Dong, S. P. and Zuo, Y. L. have equal contributions in writing the manuscript. Li, H. contributes to the review design framework, discussion, and perfection of the manuscript. Guo, S. Y. and Li, M. contribute to article collection and preliminary analysis. Liu, X. L. contributes in the discussion for improvement of the final manuscript.

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