MEASURING THE EFFICIENCY AND PRODUCTIVITY CHANGES IN PUBLIC HOSPITALS OF CHINA: A BOOTSTRAPPING-MPI APPROACH

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Abstract - Objective: Improving the efficiency and productivity is one of the challenges facing the health sectors worldwide. The first and foremost task for the policy-makers is how to measure them accurately. This study aimed to measure the changes in Total Factor Productivity of public hospitals in China precisely. Methods: The Bootstrapping-Data envelopment analysis (DEA) technique was employed to estimate the technical efficiency(TE), pure technical efficiency(PTE) and scale efficiency(SE) of 86 tertiary general public hospitals in three provincial regions of China by 4 input and 4 output indicators with panel data of 2011-2013. And then the Bootstrapping-Malmquist Productivity Indices (MPI) approach was applied to measure the Total Factor Productivity Change(TFPC). Results: In the period of 2011-2013, the Total Factor Productivity of the sample hospitals had declined 2.09% yearly and the main deterioration came from technological recession (-4.46%). The technical efficiency had simultaneously increased 2.60% with the contributions coming from both the pure technical efficiency(1.72%) and the scale efficiency (0.88%).Conclusions: The overall efficiency and productivity of the sample hospitals had slightly deterioration yearly for the technological recession.

Keywords - Malmquist Productivity Indices(MPI), Data Envelopment Analysis (DEA), Bootstrapping, Total Factor Productivity(TFP), Technological Change, Technical Efficiency, public hospital, China

I. INTRODUCTION

Improving the efficiency and productivity in health service is one of the challenges facing the health sectors worldwide. With the development of universal health insurance in China [1], demands for hospital services has grown rapidly, which puts increasing pressure on the system of health care delivery. In the context of a new round health reform from 2009, raising the efficiency has been set as one of the most important goals for the hospitals. However, the first and foremost task for the policy-makers is that how to measure the efficiency and productivity more accurately. Productivity is defined as the ratio of an index of output to an index of input usage[2]. In 1953, the concept of Malmquist Productivity Index (MPI) was developed by and named after Sten Malmquist[3], which was also called Total Factor Productivity Changes (TFPC). In 1982 MPI was introduced to measure productivity changes among different production units[4]. It was not until 1994 when combinated with Data Envelopment Analysis (DEA) [5]the application of MPI was widely used research fields. There are two fundamentally different approaches to measuring efficiency of hospitals: parametric and nonparametric methods. Stochastic Frontier Analysis (SFA) is a representative of the former, while Data Envelopment Analysis (DEA) the latter. DEA was first proposed by Charnes et al. in 1978[6] and highly recommended by the World Health Organization to measure the hospital's efficiency for it is a nonparametric method that not requiring a function model and price transformation for indicators[7]. Considering technical efficiency is shaped by management, environment and luck factors, these efficiency estimation models should be stochastic to minimize the influence of luck, omitted variables and random errors [8]. But unfortunately, DEA models are rarely stochastic , which would inevitably result in estimation bias. Researchers have attempted various approaches to correct bias in DEA. One of the approaches is Bootstrap–DEA, which was proposed by Efron in 1979 [9]. Bootstrapping corrects the influence of environmental factors and all random interferences to improve the accuracy of efficiency estimation[10-12]. Furthermore, in 1999 Simar etc. firstly used the Bootstrap-DEA method in the decomposition of MPI and found that it is superior to the traditional MPI decomposition[13]. For this reason, Bootstrap-MPI was increasingly employed to measure the changes of TFP in plenty of research fields including industry, finance, management, sociology, environment and so forth. However, there is a paucity of literature measuring the efficiency and productivity of health sectors in China based on the approach of Bootstrap-MPI. This study aimed to measure the changes in total factor productivity of tertiary hospitals in this approach more accurately for the better policy-makings.

II. METHODS

2.1 Malmquist Productivity Indices(MPI)

Malmquist index was proposed by Malmquist to measure efficiency and productivity[1]. Caves et al. [2]used it to measure changes in a production unit's efficiency in transforming inputs into outputs from

time t to time t + 1.MPI or Total Factor Productivity Changes (TFPC) can be decomposed into Technical Efficiency Changes (TEC) and Technological Changes (TC), and then the former can be decomposed into Pure Technical Efficiency Changes (PTEC) and scale efficiency Changes (SEC)[3]. The MPI or TFPC can be defined as:

TFPC or MPI=TEC×TC=(PTEC×SEC) ×TC

2.2 DEA and Bootstrapping

Data envelopment analysis (DEA) is a mathematical programming approach to provide a relative efficiency assessment for a group of decision making units (DMU) with multiple number of inputs and outputs[4]. DEA was highly recommended by the World Health Organization to measure the hospital's efficiency for it is a nonparametric method that not requiring a function model and price transformation for indicators. Considering technical efficiency is shaped by management, environment and luck factors, these efficiency estimation models should be stochastic to minimize the influence of luck, omitted variables and random errors[5]. But unfortunately, DEA models are rarely stochastic, which would inevitably result in estimation bias.

Researchers have attempted various approaches to correct bias in DEA. One of the approaches is Bootstrapping, which was first proposed by Efron in 1979 [6] . It is a simulation method for conducting statistical inference of a population. It obtains a large number of new samples and corresponding statistics by sampling from the existing original set of data repeatedly with a defined and consistent probability for each sample. The characteristics of the study population are estimated using the new samples without the need for any prior assumption about the population [7].

The Bootstrapping-DEA can overcome two major barriers in traditional DEA: the normality hypothesis and the intrinsic dependency of efficiency values, which estimates both random errors and system errors, generating a more realistic and objective value for efficiency [8]. Therefore, it has been applied internationally in the relative efficiency and productivity measurements[9].

2.3 Bootstrapping-MPI

Bootstrapaping-MPI are developed and extended by Simar and Wilson[10]. This paper applied the bootstrap method to estimate confidence intervals for the MPI and its components. The bootstrapping estimates scores can then be used to construct confidence intervals and perform statistical inferences. The information from the confidence intervals is useful in identifying whether the improvement or deterioration indicated by the TFPC is significant or not at the desired significance level. Through the development of confidence intervals based on the bootstrapping technique, it is possible to identify whether the improvement or deterioration indicated by MPI is significant or not at the desired significance levels.

At the same time, we can also use the estimates to test the significance of the efficiency and technology changes. The bootstrap technique allows us to assess the "null hypothesis" of no change with respect to productivity, technology, efficiency, pure efficiency and scale efficiency change[11].

In this study, we performed bootstrap-DEA using R software and the FEAR software package[12], with 2000 returned samples. The estimated efficiency values were output-oriented. The confidence level was set at 0.05.

2.4 Input and output indicators for DEA

As described in a published systematic review of DEA[13], it is very important to select appropriate input and output indicators in measuring the relative efficiency and TFPC. In this study we selected 4 input indicators （the numbers of active beds, employees, doctors and nurse and 4 output indicators （the numbers of outpatient and emergency visits, hospital separations, inpatients surgeries, and Length Of Stay) based on that systematic review.

2.5 Data source and sample

This study was undertaken in 3 provincial regions of Tianjin, Jiangsu and Henan of China. Data were drawn from the governmental reports collected by the National Institute of Hospital Administration (NIHA) of China. A set of panel data in 2011–2013 for 164 tertiary (third-grade) public hospitals were finally selected satisfied the two basic requirements for DEA:(1) Decision Making Units (DMUs) are homogeneous, and (2)the number of DMUs is three times more than the number of input and output indicators. In this study, each hospital (in a year) was treated as a DMU.

2.6 Data processing and analysis

The Data processing and analysis were threefold: First, Bootstrapping-DEA was employed to estimate and obtain confidence intervals for the output oriented the technical efficiency, pure technical efficiency, scale efficiency of 86 tertiary hospitals in three provincial regions of China over the period 2011-2013. Second, the Bootstrapping-MPI was applied to measure the Total Factor Productivity Change(TFPC): The TFPC was decomposed into the technical efficiency change(TEC) and technological change(TC). The TEC was further decomposed into pure technical efficiency change (PTEC) and scale efficiency change（SEC）. Finally, we implemented the longitudinal analysis to observe the trends of changes in the efficiency and productivity with the scores of Bootstrapping-MPI and its components.

III. RESULTS

3.1 Characteristics of the sample hospitals

The results showed that the sample hospitals had experienced capacity and scale development from 2011 to 2013, as the means of all the input indicators had grown year after year: The number of employees grew by 19.01%, beds in use 21.14%, doctors 12.85% and nurses 28.09%. Meanwhile, the means of three output indicators showed that the volumes of services had also increased over the year: the outpatient/emergency visits increased 24.94%, Hospital separations 30.75%, and Surgeries of inpatients 37.29%. In addition, the Length Of Stay(days) shortened from 12.12 of the year 2011 to 11.09 of 2013 indicating that there was improvement in efficiency. Overall, from the perspective of descriptive statistics, it seems that the efficiency and productivity of the sample hospitals in this period had been improved distinctly for the growth-percents of outputs are more than the inputs.

3.2 The changes of MPI and its components

To observe the trends of changes in the efficiency and productivity with the time, we implemented a longitudinal analysis. Table 1 is a summary of the values of TFPC and its components by Bootstrapping-MPI approach for the samples hospitals in 2 periods of 3 consecutive years from 2011 to 2013. The observed values are geometric means and Lower and Upper values are the bounds of Confidence Intervals (95%). In the period of 2013-2011, the TFP of the sample hospitals had decreased 2.09% yearly, ranging from 1.68% to 4.23%. The main deterioration coming from technological change (-4.46%).At the same time, the technical efficiency had increased 2.60% with contributions from the increasing of both the pure technical efficiency(1.72%) and the scale efficiency (0.88%). In the year 2011-2010, the TFP of the sample hospitals had slightly deteriorated0.35%. The main reason was the technological change decreased 3.68%while the technical efficiency had increased 3.54%. The increasing of technical efficiency can be attributed to the increasing of pure technical efficiency (2.09%) and scale efficiency (1.35%).

Year	Values	TFPC	TEC	TC	PTEC	SEC
2012-2011	Observed	0.9965	1.0354	0.9632	1.0209	1.0135
	Lower	0.9428	0.9225	0.8456	0.9108	0.9295
	Upper	1.0320	1.1510	1.0419	1.1207	1.0983
2013-2012	Observed	0.9617	1.0167	0.9477	1.0135	1.0041
	Lower	0.9175	0.9157	0.8377	0.9022	0.9243
	Upper	0.9947	1.1249	1.0216	1.1124	1.0960
Average	Observed	0.9791	1.0260	0.9554	1.0172	1.0088

Table 1 The means of Bootstrapping-MPI and its components by years

In the year 2013-2012, the TFP of the sample hospitals had alsodeteriorated3.83% mainly due to the recession of technological change (5.23%).The technical efficiency had increased 1.67% and the contributions came from both the pure technical efficiency (1.35%)and the scale efficiency (0.41%).

IV. DISCUSSION

In this study we measured the efficiency and productivity of 86 tertiary public hospital in three provincial regions of China by the Bootstrapping–MPI. Bootstrap-DEA have been increasingly used for measuring hospital efficiency. However, concerns about the uncertainty of DEA efficiency values and the potentially wrong conclusions it may lead to are also growing [14]. This highlights the importance of bias-correction in DEA. We recommended the use of Bootstrapping-MPI for measuring the efficiency and productivity of health care sectors for several reasons: First, though Bootstrapping uses returned sampling to correct efficiency values, it is still less time consuming for it is not necessary to calculate the estimates for each sample. Second, Bootstrap-DEA not only gives a direct estimation of efficiency values, but also the confidence intervals through normal approximation for the estimating function, which means that it does not need to estimate confidence intervals by additional measurements[15]. As pointed out by Hu and Zidec[16], such an approach is often better than normal approximation to the estimators obtained by solving the corresponding function. Third, DEA can infer the position of a DMU by estimating the distance between the point of the DMU and the actual frontier. However, if the number of DMUs is limited, there may be a gap between the frontier calculated by the DEA models and the actual frontier [14]. Bootstrapping can solve these problems by increasing the number of DMUs through repeated sampling.

The results showed that in the period of 2011-2013, the overall efficiency and productivity of the sample hospitals had slightly deterioration yearly. The main deterioration came from technological recession. The result seem to confirm that technological progress dominates efficiency change in the production of hospital services, which is consistent with the findings of several literatures[11; 17-20], McCallionet al.(2000), and Ferrier and Valdmanis (2008)]. Rapoportet al. (1982) argued that the technological change in the hospital services is often associated with new equipment, new forms of organization, surgical procedures, and drugs as well. In the past couple of decades, China's public hospitals have been made significant investments in infrastructure, equipment and specialized facilities. As a result, there are lot of relative researched based on traditional DEA-MPI methods found that Chinese public

hospitals have experienced growth in technological change [21-23].It seems that we should jump to conclusion that Chinese public hospitals have been made great progress in technological changes (TC).

However, the results of this study were is opposite to the findings of above researches based on traditional DEA methods about China's public hospitals, but consistent with one latest study based on the Bootstrapping MPI approach by Cheng et al.[24], in which the negative shift of 2.14% in productivity from 2008 to 2014 was observed and attributed to a 23.89% decrease in technological changes (TC). Why did the technological deterioration observed in these two studies? There were several potential reasons underlying this consequence: First, the Bootstrapping-MPI approach was employed to measure productivity, which is maybe more accurately[10; 25]. Second, both of these studies did select more reasonable outputs and inputs indicators[13]. Finally, the technological deteriorations were truly existing because the technological progress was curved and limited by the financing and payment system（e.g. health insurance）for the expensive expenditure of high-tech equipment, surgical procedures and medical treatments, which are the promoting factors for technological progress.

This study has some limitations. On one hand, the study made an assumption that the efficiency distribution of the DMUs is homogeneous, but actually there are some differences among outcome medical quality of the patients. Further studies should consider the medical quality with Casemix approach. On the other hand, the samples from 3 out of 31 Chinese provincial regions were not sufficient to estimate the efficiency and productivity of all of the tertiary public hospitals. In the future, more provincial regions should be included to improve the robustness of relative researches.

CONCLUSIONS

In this study we measured the efficiency and productivity of 86 tertiary public hospital in three provincial regions of China by the Bootstrapping – MPI. the results showed that in the period of 2010-2012, the overall efficiency and productivity of the sample hospitals had slightly deterioration yearly. The main deterioration coming from technological recession. At the same time, the technical efficiency had slight increased with progress both in pure technical efficiency and the scale efficiency. One of the main reasons underlying the technological recession was that the technological progress was curved and limited by the financing and payment system（e.g. health insurance）for the expensive expenditure of high-tech equipment, surgical procedures and medical treatments, which are the promoting factors for technological progress.

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