METHODOLOGICAL APPROACH AND THEORETICAL CONCEPT FOR MEASURING HOSPITAL TECHNICAL EFFICIENCY

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ABSTRACT

Background: In the health care systems, efficiency measurement is considered as a key step in performing individual performance audits of production units such as, health centres and hospitals. It entails a rational framework through which resources are distributed and shared among health care facilities. Thus, there are two common approaches to measure hospital efficiency namely: non-parametric (DEA) and parametric (SFA). The article is aimed to review the articles to analyze the characteristics of these approaches and to identify the similarities, differences, strengths, and limitations related to them.

Materials and Methods: The literature, which related to measuring relative efficiency of hospitals were obtained from online database involving ScienceDirect, Pubmed. The keywords used for the search terms involving hospital efficiency, healthcare efficiency, parametric approach, non-parametric approach, DEA and SFA. The review only for articles published in English language.

Result: The required information about methodological approaches were obtained and summarized into the construct form. The discussion was based on approach type in term of non-parametric and parametric.

Conclusion: In a nutshell, both of DEA and SFA can be applicable in healthcare setting to measure hospitals efficiency. The selection of the convenient approach is subjected to the aim of the study.

Keywords: Methodological Approach, non-parametric, parametric technique, hospital efficiency.
1.0 Introduction

1.1 Overview of Measuring Efficiency and Health Care

In the health care systems, efficiency measurement is considered as a key step in performing individual performance audits of production units such as, health centres and hospitals. It entails a rational framework through which resources are distributed and shared among health care facilities (Kontodimopoulos, Nanos, & Niakas, 2006). Nevertheless, health care facilities seeking to enhance their performance and maximize their health care outcomes should establish strategies to measure their performance as well as identify the determinants involved the health production functions (Cantor & Poh, 2017).

1.2 Economic Theory of Production

The economic theory of production is based on a simple concept: production entails the use of various goods and services to generate output. The goods and services represent inputs, which undergo through the process of production to produce the outputs (Hollingsworth & Peacock, 2008a, p 8). According to Hollingsworth and Peacock (2008a, p 8), Economists assert that there are three different types of inputs also known as the factors of production. They include capital, land and labour. Labour represents the input gained from human endeavour, land the inputs from the natural resources, as well as capital entails plants, machines and building that facilitate production.

1.3 Definition of Efficiency

According to Farrell (1957), the term efficiency can be defined to at a facility’s (hospital) success to produce the maximum possible outputs from a particular set of inputs used (Farrell, 1957). According to Farewell (1957), there are two distinct forms of efficiency. They include the allocative efficiency and technical efficiency. Technical efficiency can be defined as maximization of the outputs for a mix and given level of inputs. Equally, technical efficiency refers to maximization of the use of outputs for a particular output level. On the other hand, allocative efficiency can be defined as the maximization of the outputs for a particular input cost level. Conversely, allocation efficiency refers to minimization of costs for a particular level of output. One can map allocative efficiency by plotting the various input combinations that minimize costs, and this is referred to ‘cost frontier’. Equally, allocative efficiency indicates that a medical facility (hospital) operates on its cost frontier (Hollingsworth & Peacock, 2008). This paper will focus on how to measure technical efficiency. Efficiency is expressed as follows (Farrell, 1957):

$$\text{Efficiency} = \frac{\text{weighted sum of output}}{\text{weighted sum of input}}$$

1.4 Concept of Hospitals Efficiency

Hospital efficiency refers to ways a health care service provider (such as physician, hospital) would ensure efficiency if it was able to minimize the outputs used to generate a particular output or maximize the output from a particular set of inputs (Hussey et al., 2009). According
to Farrell’s framework, a facility (hospital) is considered technically efficient only if it operates within its best practices production frontier on its industry (Farrell, 1957).

1.5 Methodological Approaches of Measuring Hospital Technical Efficiency

The most common two approaches in measuring hospitals efficiency are non-parametric approach known as data envelopment analysis (DEA) and parametric approaches stochastic frontier analysis (SFA) (Hollingsworth, 2003). DEA and SFA are the main two methods to measure relative efficiency through firms (hospitals) (Sarafidis, 2002). DEA and SFA relate to a type of methods for estimating efficiency named frontier analysis. Frontier analysis relates a firm’s (physicians practice, hospitals) usage of actual inputs and outputs to efficient combinations of multiple inputs and/or outputs (Hussey et al., 2009). The two methods apply diverse methods to computing the “frontier” of efficient combinations used for evaluation. Nonetheless, DEA, SFA, and ratio-based measures were formulated using similar categories of inputs and outputs, typically those in widely existing data. Moreover, DEA and SFA demand suitable specification of the relationship between the measured inputs and outputs (Hussey et al., 2009). Thus, the manuscript is aimed to review the articles to analyze the characteristics of these approaches and to identify the similarities, differences, strengths, and limitations related to them.

1.5.1 Non-parametric Approaches Data Envelopment Analysis

Charnes, Cooper, and Rhodes developed the data envelopment analysis (Charnes, Cooper, & Rhodes, 1978). They reprased Farrell’s concept into a mathematical problem. It referred to as a linear programming technique whereby various best practices involve those that never make other decisions of a linear set of units with more than one of each output (particular input). This DEA technique is used to empirically determine the operating entitiie’s relative efficiency. These operating entities are also known as decision making units (DMUs), and they are mutually considered to consume the same same inputs and generating the same outputs. Data envelopment analysis (DEA) never assumes any given functional form connecting inputs and outputs; therefore, it eliminates challenges of model misspecifications.

Also, the production possibility frontier can be empirically determined by the recorded values of the efficient DMUs (in respect to the other DMUs within the sample) and they a given an efficiency score 100% (or 1). According to (Rabar, 2017) the word ‘envelopment’ originates from the fact that a frontier envelopes a given set of observation. Its key purpose is to measure relative efficiency (Ramírez-Valdivia, Maturana, Mendoza-Alonzo, & Bustos, 2015).
Charnes et al., (1978) assert that the DEA approach can be explained and applied using the following mathematical notations (Charnes et al., 1978):

\[
\text{Maximize } \theta_0 = \frac{\sum_{r=1}^{s} u_r y_{rt}}{\sum_{i=1}^{m} v_i x_{it}}
\]

subject to

\[
\frac{\sum_{r=1}^{s} u_r y_{rt}}{\sum_{i=1}^{m} v_i x_{it}} \leq 1
\]

\[u_r, v_i \geq 0 \text{ for all } r \text{ and } i.\]

Whereas,

\[\theta_0\] = efficiency score for group of peer DMUs (j=1, ..., n)
\[u_r\] = weight of the outputs
\[y_{rt}\] = selected outputs (yrj, r =1, ..., n)
\[v_i\] = weight of the inputs
\[x_{ij}\] = selected inputs (xij, i=1, ..., m)

The operational units for decision making (DMUs) are the hospitals.

1.5.2 Parametric Approach Stochastic Frontier Analysis

The most commonly used stochastic model is Stochastic Frontier Analysis (SFA), when it comes to measuring hospital efficiency. The term is also referring to as economic frontier approach (EFA). The technique was actually developed by (Aigner, Lovell, & Schmidt, 1977). SFA defines a functional form of the relationship of cost, profit, or production between inputs and outputs, and environmental factors, and allows a random error (Berger, Hunter, & Timme, 1993). The SFA is largely cost oriented, using price data and inputs. SFA assumed that the boundary moves from one observation to another which led to the term inefficiency means cost increases above the estimated minimum cost (in cost efficiency) or profit reduction below profit limits (in profit efficiency), and the distributive assumption of random-word properties describes a natural distribution on two sides. The stochastic frontier model can be written as follows (Sarafidis, 2002):

\[c_i = f(y_i; \beta) + w_i\]

\[w_i = v_i + u_i\]

Where \(f(y_i; \beta)\) represents the cost frontier, \(w_i\) is the total observed residual, \(v_i\) represents statistical noise and \(u_i\) is the inefficiency term. Since statistical noise can go in either direction, \(v_i\) has a mean value at zero, while \(u_i\) takes only non-negative values (actual cost \((c_i)\) can never be lower than the frontier cost in the absence of data errors).
Two steps are mostly required prior estimation of stochastic frontier model. First, a precise functional form for the relationship between cost and outputs and a functional form for the likelihood distribution of the efficiency term are assumed. By estimating the slope parameters ($\beta$), we acquire estimates for the frontier. Second, by subtracting the actual cost from predicted cost ($c - f(y; \beta)$) and break down the remaining residual ($w$) into a data error component ($v$) and an inefficiency component ($u$) for each institution (Sarafidis, 2002). This approach is shown in Figure 1.

Figure 1; Illustration of the Stochastic Model (Sarafidis, 2002).

2.0 Materials and Methods

The literature, which related to measuring relative efficiency of hospitals were obtained from online database involving ScienceDirect, Pubmed. The keywords used for the search terms involving hospital efficiency, healthcare efficiency, parametric approach, non-parametric approach, DEA and SFA. The review only for articles published in English language. This manuscript used a structure form to extract the required information from reviewed articles in term of the author name, study location, year of the study, type of methodological approach, number of types of hospitals (DMUs), source of data, inputs and outputs, and type of software that used to calculate efficiency score. However, the review only includes articles key findings of each approach. In addition to, the strengths, limitations, similarities and disparities were discussed.

3.0 Result

The required information about methodological approaches were obtained and summarized into the table 1. The discussion was based on approach type in term of non-parametric and parametric.
### 3.1 Table 1 Structure Form for Obtained Articles that used DEA and SFA in Measuring Hospitals Technical Efficiency

<table>
<thead>
<tr>
<th>No. Author (Year) Location</th>
<th>Methodological Approach Type</th>
<th>Number and Type of Hospitals (DMUs), and Source of Data</th>
<th>Inputs</th>
<th>Outputs</th>
<th>Key findings related to Hospital Technical Efficiency (TE)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Applanaidu, Samsudin, Ali, Dash, &amp; Chik, 2014), Kedah, Malaysia</td>
<td>Non-parametric</td>
<td>9 public hospitals. For the year from 2008 to 2010. Data was obtained directly from the hospitals.</td>
<td>No. of doctors. No. of nurses. No. of beds.</td>
<td>No. of outpatients. No. of inpatients. No. of surgeries. No. of deliveries.</td>
<td>Under VRS assumption: 74% of hospitals were technically efficient for the period 2008 to 2010. The technical efficiency of inefficient hospitals ranging between 0.780 and 0.991.</td>
<td>The DEA software Efficiency Measurement System (EMS) produced the technical efficiency scores.</td>
</tr>
<tr>
<td>(Kirigia &amp; Asbu, 2013), Eritrea</td>
<td>Non-parametric</td>
<td>19 secondary level public community hospitals. For the year 2007 Data were obtained from MOH annual health service activity report.</td>
<td>No. of physicians (doctors). No. of nurses and midwives. No. of laboratory technicians. No. of operational beds and cost.</td>
<td>No. of outpatient department visits. No. of inpatient department discharges.</td>
<td>Under CRS assumption: 8 (42%) hospitals were technically efficient. 11 (58%) hospitals were relatively inefficient. Under VRS assumption: 13 (68%) hospitals were technically efficient. 6 (32%) hospitals were technically inefficient.</td>
<td>Tobit regression used to estimate the impact of institutional and contextual/environmental variables on hospital inefficiencies. Technical efficiency was computed using DEAP (2.1) programme. The Tobit regression was estimated by using SATA 10 statistical software.</td>
</tr>
<tr>
<td>(Hamidi, 2016), Palestine</td>
<td>Parametric, SAF</td>
<td>22 government hospitals. Over a period of 6 years, 2006, 2007 and 2009 to 2012. Data were collected from the MOH annual reports.</td>
<td>No. of beds No. of (FTE) doctors No. of (FTE) nurses No. of (FTE) medical staff.</td>
<td>Sum of number of treated inpatients and outpatients</td>
<td>The average technical efficiency was 55%. Translog function result on TE was 55%. Multi-output distance function result on TE was 51%.</td>
<td>Cobb-Douglas, Translog and multi-output distance function applied. Xfrontier command STATA 12 was applied to estimate efficiency score. A paired t test was used to determine difference between the technical efficiency score in term of the results of translog function and multi-output distance. FET Full Time Equivalent.</td>
</tr>
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<tr>
<td>(Goudarzi et al., 2014) Iran</td>
<td>Parametric</td>
<td>12 teaching hospitals affiliated to Tehran University of Medical Science. Between 1999 to 2011 Data was collected from the Annual Statistical Report of TUMS.</td>
<td>No. of FTE medical doctors. No. of FTE nurses. No. of FTE other personnel. No. of active beds. No. of outpatient admission.</td>
<td>No. of inpatient admission.</td>
<td>The mean level of technical efficiency was 59%.</td>
<td>Cobb-Douglas and Translog function form were applied. The Likelihood-Ratio (LR) was applied to estimate efficiency. Frontier V4.1 software calculated efficiency score for SFA model. FET Full Time Equivalent</td>
</tr>
<tr>
<td>(Rezapour, Ebadifard Azar, Yousef Zadeh, Roumiani, &amp; Bagheri Faradonbeh, 2015), Iran</td>
<td>Mixed Approach. Parametric and non-parametric</td>
<td>19 hospitals affiliated to Iran and Tehran University of Medical Science. From 2009 to 2012 Data were collected from data centres of studied hospitals.</td>
<td>For DEA &amp; SFA No. of physicians. No. of nurses. No. of non-medical personnel. No. of beds.</td>
<td>For DEA No. of inpatients. No. of beds days admissions. For SFA Index number of inpatient admissions.</td>
<td>DEA Model result 36.8% of hospitals were technically efficient. Average of technical efficiency for the period was 0.87. (VRS, input-oriented). SFA model results All hospitals were technically inefficient. Average of technical efficiency for the period was 0.389. (under Cobb-Douglas Production Function)</td>
<td>Cobb-Douglas function was applied. DEAP V2.1 software calculated efficiency score for DEA model. Frontier V4.1 software calculated efficiency score for SFA model.</td>
</tr>
</tbody>
</table>
3.1 Articles Related to Non-parametric Approach

As a result of reviewed articles, we found a study conducted by (Applanaidu et al., 2014) which applied DEA model as non-parametric approach. This study aimed to measure technical efficiency for 9 public hospitals in Kedah, Malaysia between 2008 and 2010. The data was collected directly from the hospitals. Due the aim of the study, it considered as one stage DEA. BCC as model type, VRS as return to scale and input-oriented model were applied. The variables of study combined of were 3 inputs variables and 4 outputs variables. The number of doctors, number of nurses and number of beds were used as inputs variables. The number of outpatients, number of inpatients, number of surgeries, and number of deliveries were employed as outputs variables. The results of the technical efficiency score was at the average of 74% of hospitals were technically efficient. The efficiency score was calculated by Efficiency Measurement System (EMS).

In the other hand, another study conducted by (Kirigia & Asbu, 2013) which has two amid to examine technical efficiency for 19 secondary level public community hospitals in 2007. The data were obtained from Ministry of Health annual health service activity report. The study applied two-stage DEA method. In the first stage, were to measure hospital technical efficiency score by DEA. In the second stage, to regress the estimated DEA efficiency score against some institutional and environmental variables. CCR and BBC were used as model type; CRS and VRS were employed, and output-oriented as a model orientation. There were four inputs, and two outputs variables. The inputs variables were number of physicians, number nurses and midwives, number of laboratory technicians, and number of operational beds and cost. The number of outpatient visits and number of inpatient discharges were used as outputs variables.

Due to the model types that used in the first stage of DEA, there were two results for technical efficiency score. The first result for was under CRS assumption which showed that 8 (42%) hospitals were technical efficient. In contrast to second assumption, which was VRS in the first stage of DEA, the result of technical efficiency was 13 (68%) hospitals were technically efficient. The efficiency score of DEA was calculated by DEAP V 2.1 software programme. In regard to the stage of this study, the Tobit regression analysis was used to estimate the impact of institutional and contextual/environmental variables on hospital inefficiencies. The result of Tobit regression analysis was the coefficient for OPDIPD (outpatient visits as a proportion of inpatient days) had a negative sign and was statistically significant; and the coefficient for ALOS (average length of stay) had a positive sign and was statistically significant at 5% level of significance. The Tobit regression analysis was estimated using STATA 10 statistical software.

3.2 Articles Related to the Parametric Approach

A study conducted by (Hamidi, 2016) which applied SFA model as a parametric approach. This study aimed to examine technical efficiency of 22 government hospitals in Palestine over a period of 6 years, 2006, 2007 and 2009 to 2012. The data were collected from the Ministry of Health annual reports. The inputs variables were number of beds, number of doctors, number of nurses, and number of non-medical staff. The outputs variable was sum of number of treated inpatients and outpatients. This study employed three models, which were Cobb-Douglas form, Translog form, and multi-output distance form. The normal-truncated normal maximum likelihood (ML) random model effect with time-invariant efficiency was applied to
all three models. The technical inefficiency models and the stochastic frontier production function are together examined by the maximum likelihood. Thus, the using normal-truncated normal maximum likelihood was used to estimate coefficients of elasticities between dependent and explanatory variables.

The Cobb-Douglas function form tested the null hypothesis. The using of multi-output distance function was due to its ability to avoid aggregation inpatient and output patients visits when examine in order to explore the defined model of hospitals production and inefficiency. The one-step maximum likelihood estimates was used to estimate the technical efficiency due to its capability to integrate the model for technical efficiency effects into the production function. Thus, both of translog function, and multi-distance function were applied to estimate the technical efficiency score. The average of technical efficiency score based on translog function was 55%.

Meanwhile the average of technical efficiency score based on multi-output distance function was 53%. Moreover, there was no full efficient hospital among the whole study duration. Doctors and nurses were the most significant factors in hospital production. A paired t test was used to determine difference between the technical efficiency score in term of the results of translog function and multi-output distance. Thus, there was no statistical significance (p= 0.23) between the two scores of technical efficiency. The Xfrontier command STATA 12 was applied to estimate the model.

Another study was conducted by (Goudarzi et al., 2014) in Iran which used SFA as parametric approach. The aim of the study was to estimates the technical efficiency of 12 teaching hospitals related to Tehran University of Medical Science for the period from 1999 to 2011. The data was collected from the Annual Statistical Report of TUMS. The inputs variables were the number of medical doctors, number of nurses, number of other personnel, number of active beds, and number of outpatient admissions. Whereas the number of inpatient admissions as output variable.

Cobb-Douglas function and translog function was applied to examine production function. The Likelihood-Ration (LR) was used to select suitable function for calculating the efficiency. Likelihood Ration tested the null hypothesis. Cobb-Douglas measures the elasticity to achieve input. The Cobb-Douglas was the proper function form for stochastic frontier model (LR=7.03, P<0.001) with comparison to the Translog function form (LR=0.42, P=0.56). The average technical efficiency was 0.59. The production was significantly and positive (P<0.05) influenced by outpatient admission, other personnel and medical doctors. The Frontier V4.1 software calculated efficiency score for the SFA model.

In contrast, A study was conducted by (Rezapour et al., 2015) which applied DEA and SFA as mixed approach of non-parametric and parametric. The study was aimed to estimate technical efficiency and identifying the level of resource allocation for 19 hospitals related to Iran and Tehran University of Medical Science from 2009 to 2012. The data were collected from data centres of studied hospitals. In regard of DEA model, the study was applied CCR as model type, VRS as return to scale, and input-oriented in order to minimize hospitals resources and maximize hospitals outputs. The inputs variables were the number of physicians, number of nurses, number of non-medical personnel, and number of beds. Whereas, the number of inpatients and the number of bed days admissions used as outputs variables. The key findings for this model were 36.8% of hospitals were technically efficient.
and the average of technical efficiency for the period was 0.87. The efficiency score was calculated by DEAP V2.1 software.

In the other hand, the SFA model was applied Cobb-Douglas Production Function. The inputs variables were as same as the inputs variables that used in DEA model. However, the index number of inpatient admissions was used as the output variable. The all hospitals under study in this model were technically inefficient with the average of technical efficiency for the period was 0.389. The Frontier V4.1 software was used to calculate efficiency score.

### 3.3 Similarities and Differences between the DEA and SFA Model

According to the review process for the articles, we found that there are some similarities and differences between DEA and SAF model. Both of DEA and SFA are shared in common characteristics. DAE and SFA are two categories of mathematical programming techniques to estimate the efficiency and productivity (Goudarzi et al., 2014). They use to measure relative efficiency to determine production frontier. They require numbers of decision making units (DMUs). Also, they require number of inputs and outputs variables, which use in production process. Both of the run specific software to calculate efficiency score.

In regard to differences between DAE and SAF, DEA model assesses technological optimization, whilst SFA concentrates on economic optimization (Hamidi, 2016). They require different specifications. In term of DEA, it requires a model specification before running analysis, which are model type (CCR, BCC) and return to scale (CRS, VRS), orientation model (input, output), and combination number of inputs and output (Cantor & Poh, 2017). In contrast, SAF requires employing specific function form model such as Cobb-Douglas function Form, whether Translog Function Form, as well as multi-output distance function or one both of them (Goudarzi et al., 2014; Hamidi, 2016; Rezapour et al., 2015).

Moreover, DEA requires multiple inputs and multiple outputs variables ; meanwhile SFA requires multiple inputs variables and only one output variable (Goudarzi et al., 2014; Hamidi, 2016). DEA can be employed whether in one stage for estimating efficiency score only or in two stages to determine the explanatory variables that influence efficiency score using specific analysis such as Tobit regression (Kirigia & Asbu, 2013). Whereas, SFA run in one stage only combined the function model as aforementioned with specific model such as Likelihood-Ratio (LR) to estimate efficiency and its determinants in one step (Goudarzi et al., 2014). Due to the different specification that use in each model, the efficiency score was different between the two models even the apply into the in one study (Rezapour et al., 2015).

### 3.4 Strengths and Limitations of DEA and SFA

In this section, there is some strengths and limitation connected to DEA and SFA. Some strengths of DEA model were its ability to manage multiple inputs and multiple outputs. It is able to determine the source of inefficiency and quantify the magnitude of inefficiency in the usage of inputs and produce the outputs (Kirigia & Asbu, 2013). DEA avoids assessing output prices that are not obtainable form services and charge-based outputs (Hamidi, 2016).

In regard to SFA strengths, SFA has ability to analyze dormant heterogeneities among DMUs. This allows distinction to be made between effects caused by inefficiency and/or statistical errors. The statistical test of hypothesis is applicable with SFA model (Hamidi, 2016).
In other hand, the limitation of DEA is deterministic approach. Therefore, any the deviation from the production probabilities frontier is lead to inefficiency (Kirigia & Asbu, 2013). Furthermore, the statistical test of the hypothesis with DEA is not applicable due to the inefficiencies scores (Hamidi, 2016).

In contrast, SFA model permits to choose only one output, thus would produce the exclusion of significant outputs (Goudarzi et al., 2014). SFA requires a prior assumption in term to defined functional form of stochastic frontier, thus the result could be affected by incorrect choice of production (Bezat, 2009).

4.0 Conclusion

According to the methodological approaches in measuring hospital technical efficiency, the DEA as non-parametric and the SFA as parametric are shared in some characteristics and differed in other. Each of DEA and SFA approaches has its own strengths and limitations. In a nutshell, both of DEA and SFA can be applicable in healthcare setting to measure hospitals efficiency. The selection of the convenient approach is subjected to the aim of the study.

Acknowledgement

Since this manuscript discussed a methodological approach and theoretical concept entirely and there were no human subjects included, it did not require ethical approval. The authors would like to thank the staff of the department for their support during preparation of this manuscript.

Declaration

Authors declare that there is no conflict of interest on the publication on the manuscript.

Authors contribution

Author 1: Information gathering, preparation and editing of manuscript.
Author 2: final reviewing of manuscript.
Author 3: final reviewing of manuscript.

References


