Chapter 2
Measurement of Efficiency and Productivity Growth of Hospital Systems: A Indian Case Study

Abhik Patra and Pradip Kumar Ray

Abstract The increased importance of the healthcare sector over the last two decades and current concern over productivity growth have stirred interest in productivity and efficiency measures in this expanding sector of the economic system. Productivity in economic position is determined as the relation between output and input. Productivity concept in manufacturing is analysed in the scope of the organization, but in the service sector like in hospital, this arena is larger and needs an external portion of the organizational position as patients. This paper deals with the measurement of efficiency and productivity growth of the hospital systems. To measure productivity and efficiency of an Indian hospital system, the Malmquist productivity index is applied, based on the data envelopment analysis (DEA). The efficiency and productivity of several departments of the given hospital are analysed and the improvement alternatives also identified.

Keywords Hospital system · Malmquist productivity index · Data envelopment analysis

2.1 Introduction

Over the past two decades, the healthcare sector in general and hospital systems, in particular, have experienced notable advancements in the field of health service operation and technological alignment. Even so, the gain in health service productivity cannot be captured by the Bureau of Labour Statistics (BLS) (Chansky et al. 2016). As the service function, the hospital system may face the difficulty in the measurement of its productivity as well as its efficiency because of the conflation in the input and output, inherent in any service function (Rosenstein 1991). With increasing health service costs, there has been utmost concerned by the

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P.K. Ray and J. Maiti (eds.), *Healthcare Systems Management: Methodologies and Applications*, Managing the Asian Century,
DOI 10.1007/978-981-10-5631-4_2

government of the developed as well as developing countries about the productivity and the efficiency of the hospital systems (Chang et al. 2011). Inefficient utilization of the resources is a major reason for the exaggerated healthcare cost (Walker and Dunn 2006). Hence, the efficient and cost-effective healthcare service delivery in the hospital organization has contributed to more efficient analysis and monitoring about the rule of the hospital productivity (Prior 2006). As a complex system, with combination of multiple inputs and outputs, hospital productivity may show some pattern with the determining factors. Thus, to distinguish the trends of hospital productivity as a whole or for any particular department, analytical approach has to be used.

In this chapter, a Malmquist output-based productivity index is applied to an Indian hospital system to identify the productivity pattern of the hospital and to analyse its relationship with other determining factors. In this study, output distance functions are employed to construct the Malmquist productivity index (MPI), established on the constant returns to scale output-oriented data envelopment analysis (DEA) model to evaluate the hospital productivity.

2.2 DEA and Malmquist Productivity Index-Based Methodology

The hospital system, as a complex service function is extremely mixed with various inspection and service units that are offered to match the needs of the patients. The typical hospital system is the combination of various interacting departments and sub-units such as Outpatient Department (OPD), Emergency Department, Inpatient Department, Operating Theatre (OT), Department of Pathology, Radiology Department, etc., within a specified area. Every department has some predefined responsibility. Referable to the integrity of the hospital system, every department is shared with some problems, such as a resource constraint, physician and facility availability, etc. Hence it is imperative to measure the operational efficiency and productivity of the select department with respect to system constraints. Overall performance of the hospital system is purely dependent on the operational efficiency and productivity of all departments.

For measuring productivity of a hospital system, the productivity index as proposed by Malmquist (1953) is recommended to be used. The Malmquist productivity index measures the changes in total factor productivity (TFP) between two data points in terms of ratios of distance functions (Caves et al. 1982). The computation of the Malmquist productivity index is based on the use of a nonparametric method, called data envelopment analysis [DEA]. DEA is an abstraction of the nonparametric method of productivity measurement (Farrell 1957). As per this approach, the proposed measure of the efficiency of any hospital is obtained as the upper limit of a ratio of weighted outputs to weighted inputs subject to the

conditions that the similar ratios for every hospital be less than or equal to unity (Charnes et al. 1978). The problem is formulated as

$$\text{Maximize } Q_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}. \tag{2.1}$$

$$\text{subject to } \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$

$u_r, v_i \geq 0$ for all r and i,

where Q_0 is the efficiency scores, the number of output r from hospital department j (y_{rj}, r = 1,…, s) and the number of input i from hospital department j (x_{ij}, i = 1,…, m). u_r and v_i are the weights for the outputs and inputs, respectively.

The efficiency of any department is measured by the relative efficiency of the set of departments (j = 1,…, n). The subscript, o represents the optimization of the objective function as well as for the constraints that indicate the maximization of the hospital department efficiency with the maximum favourable weights that the constraints permit.

The DEA methodology identifies the best practice production frontier piecewise linear function, where observed data points lie on or below that frontier (Hollingsworth 2003). The efficiency of a department is measured based on the virtual relative efficient department determined as a weighted average of the real efficient departments, and used as a comparative unit for the other departments. The virtual efficient unit is imputed from the linear combination of the inputs and outputs of the single or multiple efficient service units.

Mathematical formation of the DEA approach represents as a ratio of the weighted output and input, that should be maximized, and each constraint represents the specific hospital department reflecting the virtual inputs and outputs of the department that should be less than or equal to one. The efficient production function and efficiency score for each of the combined hospital's department are determined by solving that linear programing problem of DEA methodology where efficiency of the combined department is measured in terms of outputs.

In the DEA approach, ratio of the weighted output and input of the production or service unit is used to measure the efficiency of the respective production function. The efficiency of the hospital department is measured in terms of increase in the output vectors or decrease in the input vectors, with respect to best performing department (Chakraborty et al. 2001). For productive efficiency, calculation of the government-run organizations or nonprofit organizations, like hospital system where standard price for the output is not available, DEA has been applied very often (Sengupta 1998). DEA-based approach not only gives the efficiency score of the production or service unit but also gives the insight about the improvement alternatives for the decision-makers and practitioners, under such circumstances. DEA is considered as a better approach compared to the ratio analysis or the regression analysis (Liu et al. 2004).

The Malmquist productivity index evaluates the total factor productivity difference between two data points in terms of the ratios of distance functions. The change in the output-oriented Malmquist total factor productivity between the periods, t and $t + 1$ is defined as (Farrell 1957)

$$M_o^{t,t+1}(x^t, y^t, x^{t+1}, y^{t+1}) = \left[\frac{D_o^{t+1}(x^{t+1}, y^{t+1}) \times D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t) \times D_o^{t+1}(x^t, y^t)}\right]^{1/2} \tag{2.2}$$

where, D_o is the distance functions, y the output, x the input, t the time period and M_o the productivity factor.

The Malmquist index is expressed as the square root of the product of two indices evaluating the productivity change by measuring the ratio of distance functions grounded on the same technology for two input output functions between two successive periods. In case, the second period is evaluated with a lower distance than the first period, with an index below unity, a decrease in productivity is indicated (Zere 2000). Similarly, a value greater than unity indicates improvement in productivity. The Malmquist index is the average of two indices based on the technologies being used during a particular periods (Pilyavsky and Staat 2008).

The MPI is additionally decomposed into two parts: one measuring efficiency change and the other measuring technological change (Färe et al. 1994). The decomposition procedure is given below.

$$M_o^{t,t+1}(x^t, y^t, x^{t+1}, y^{t+1}) = \left[\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right]\left[\frac{D_o^t(x^t, y^t) \times D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t) \times D_o^{t+1}(x^{t+1}, y^{t+1})}\right]^{1/2} \tag{2.3}$$

The first right-hand side part of the Eq. (2.3) measures efficiency change and the second part measures technical change. This part can be expressed as an index for efficiency change (Färe et al. 1994):

$$\Delta\, Efficiency = \left[\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right] \tag{2.4}$$

Equation (2.4) represents the ratio of the two input and output distance functions between two successive periods, each of the ratio score representing the technology change of the corresponding period. It is apparent that a value more than unity indicates an increasing trend in individual efficiency. The index for technical change (Farrell 1957) is expressed as

$$\Delta\, Technology = \left[\frac{D_o^t(x^t, y^t) \times D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t) \times D_o^{t+1}(x^{t+1}, y^{t+1})}\right]^{1/2} \tag{2.5}$$

where it is assumed that $M_o(t, t + 1) = \Delta\text{Efficiency} \times \Delta\text{Technology}$. ΔTechnology is the square root of the artefact of two indices calculated as the ratio of the distance

functions. In this study, the same input output function is benchmarked with respect to two different technologies. For example, the selected function is evaluated as more efficient when benchmarked with a technology from an earlier period instead of with the technology from a later period, because of technological advancements. Therefore, all values of indices greater than unity indicate an advancement.

2.3 Data Collection

The relevant data are collected from a select Hospital located in Eastern India for a period of 4 months (December '15–March '16). For the productivity and efficiency analysis of the given hospital system, the details of operations of the hospital system are studied. As the ideal output and input may be measuring, conceptually as well as empirically, whereas the numbers of physicians and nurses are considered as inputs and the number of patients is considered as the output. As of data is to be collected in limited by their availability. Only one type of output is considered in the study as first approximation. Various operational data, such as the number of patients attended in the respective departments, the number of physicians and registered nurses are collected from the given hospital system. The data from the various departments are combined and added for the easy evaluation of the measures. For examples, the term SEE means the combination of skin, eye and ENT clinic, OCD means the combination of orthopaedic, chest and the dental clinic, PG means the combination of paediatric and gynaecology clinic, MSP means the combination of medicine, surgery and psychiatric clinic, etc. It is observed that there is a growth in number of patients attended in the following departments from December '15 to March '16, viz., in Skin clinic 12.44%, Eye clinic 15.75%, Orthopaedic clinic 48.88%, Dental clinic 90.84%, Paediatric clinic 20.56%, Medicine clinic 15.08%, Psychiatric clinic 70.83% whereas the number of patients attended in ENT clinic and Chest clinic decreased by 7.43 and 51.61%, respectively.

2.4 Results and Discussion

By the DEA method, the technical efficiency of the combined department of the given hospital is determined. The results as obtained are given in Table 2.1. It can be seen that the combination of skin, eye and ENT clinic (SEE) has the lowest average technical efficiency as compared to the other combined departments. Higher number of physicians and nurses employed (input) in the department as compared to other departments is the main reason of lower technical efficiency. The combination of paediatric and gynaecology clinic (PG) has the highest technical efficiency as compared to the other combined departments as the number of physicians and nurses employed (input) is lower than other departments.

Table 2.1 Efficiency of the combined departments calculated by DEA Method

Combined departments	Efficiency calculated by DEA method in the month			
	December '15	January '16	February '16	March '16
SEE	0.720	0.7488	0.754	0.657
OCD	0.746	1	1	1
PG	1	1	1	0.9124
MSP	0.8425	0.9427	0.8838	1

Table 2.2 Malmquist productivity indexes for hospital departments from December '15 to March '16

Departments	January '16/December '15	February '16/January '16	March '16/February '16	Average
SEE	1.297	0.982	0.853	1.044
OCD	1.67	0.975	0.979	1.208
PG	1.14	1.06	0.821	1.007
MSP	1.276	0.998	1.018	1.097
Average	1.3457	1.0037	0.9177	1.089

The results indicate relative differences in the efficiency of the analysed departments of the given hospital. As has been observed, a score of one for a department does not necessarily mean that it has the potential to perform. It may also imply that no linear combination of the other departments in the hospital, as a combined unit, can raise at least as much output as may be obtained from the individual input using the same or less input. Hence, it is improbable to conclude that the departments achieving efficiency at the level of 1 are considered effective all the time.

The result pertaining to changes in productivity over time for different combinations of the departments considered as well as for the entire hospital, and the corresponding values of Malmquist index are listed in Table 2.2. It is observed that the maximum productivity change has occurred during the period December '15–January '16 (34.57% increase in productivity noted in January '16 compared to the previous month). However, in March '16 there had been a productivity decrease of 8.23% as compared to the previous month.

The Malmquist index is applied to find out both the technological (movement of production function) as well as the technical efficiency change. The results are presented in Tables 2.3 and 2.4. It is observed that the technological change had been most significant during the period of December '15–January '16 and minimum during February '16–March '16.

Table 2.3 Technological change of the hospital departments in the period December '15–March '16

Departments	January '16/December '15	February '16/January '16	March '16/February '16
SEE	1.141	1.065	0.9
OCD	1.139	1.065	0.9
PG	1.14	1.06	0.89
MSP	1.14	1.064	0.9

Table 2.4 Efficiency change of the Hospital Departments in the period December '13–March '14

Departments	January '16/December '15	February '16/January '16	March '16/February '16
SEE	1.1366	0.922	0.947
OCD	1.466	0.915	1.087
PG	1	1	0.9124
MSP	1.119	0.9373	1.131

2.5 Conclusion

Since healthcare resources may be considering exceedingly scarce, it is of interest to find out if any significant deviations in the efficiency of healthcare providers can be noticed. The results as obtained through the study throw light on the productivity changes as occurring in a number of hospital departments. Outcomes indicate that there has been a real step-up in productivity during the period, December '15–January '16 and a decrease in productivity during period, February '16–March '16. As the combination of skin, eye and ENT department in particular has the lowest efficiency compared to other combined departments. Performance of skin, eye and ENT (SEE) clinics need improvement. There has also been significant in the value of technology factors indicative of significant effect of technological changes as productivity of the hospital systems.

As a future work, data from other hospitals can be collected and the select hospital can be compared to other hospitals on the basis of productivity and efficiency. Productivity and efficiency of the inpatient department of the hospital can also be valued following the combined DEA-Malmquist productivity index methodology. The relationship between the quality of the healthcare systems and the productivity of hospital system resources for different can also be explored following the proposed methodology.

Appendices

LINGO Codes for distance ratios

The codes are depicted for the SEE and OCD department for the period of January '16/December '15 and February '16/January '16 the codes for the repose of the department and for the period March '16/February '16 is similarly managed with the data adjusted with the respective stops and the departments as per the data collection. Malmquist productivity index, the technological change and the technical efficiency change can be computed by the distance ratios which will be figured by passing the following codes.

SEE

	January '16/December '15	February '16/January '16
Do(t + 1) [x(t + 1), y(t + 1)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 659; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*647 + b*858 + c*571 + d*757 ≥ 858; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;
Do(t)[x(t + 1),y(t + 1)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*508 + b*526 + c*470 + d*594 ≥ 659; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 647; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;
Do(t + 1) [x(t),y(t)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 508; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*647 + b*858 + c*571 + d*757 ≥ 659; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;
Do(t)[x(t), y(t)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*508 + b*526 + c*470 + d*594 ≥ 508; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 659; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;

OCD

	January '16/December '15	February '16/January '16
Do(t + 1) [x(t + 1), y(t + 1)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 880; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*647 + b*858 + c*571 + d*757 ≥ 858; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;
Do(t) [x(t + 1), y(t + 1)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*508 + b*526 + c*470 + d*594 ≥ 880; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 858; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;
Do(t + 1) [x(t),y(t)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 526; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*647 + b*858 + c*571 + d*757 ≥ 880; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;
Do(t)[x(t), y(t)]	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*508 + b*526 + c*470 + d*594 ≥ 526; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;	MIN = x; a*(3 + 4) + b*(3 + 4) + c*(2 + 2) + d*(3 + 3) ≤ x*(3 + 4); a*659 + b*880 + c*536 + d*758 ≥ 880; a ≥ 0; b ≥ 0; c ≥ 0; d ≥ 0;

References

Chansky, B., Garner, C., & Raichoudhary, R. (2016). Measuring output and productivity in private hospitals. In *Measuring and modeling health care costs*. University of Chicago Press.

Rosenstein, A. (1991). Health economics and resource management: A model for hospital efficiency. *Hospital and Health Services Administration, 36,* 313–330.

Chang, S. J., Hsiao, H. C., Huang, L. H., & Chang, H. (2011). Taiwan quality indicator project and hospital productivity growth. *Omega, 39*(1), 14–22.

Walker, K. B., & Dunn, L. M. (2006). Improving hospital performance and productivity with the balanced scorecard. *Academy of Health Care Management Journal, 2,* 85–110.

Prior, D. (2006). Efficiency and total quality management in health care organizations: A dynamic frontier approach. *Annals of Operations Research, 145,* 281–299.

Malmquist, S. (1953). Index numbers and indifference surfaces. *Trabajos de estadística, 4*(2), 209–242.

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*: *Journal of the Econometric Society*, 1393–1414.

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society*. Series A (General), *120*(3), 253–290.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429–444.

Hollingsworth, B. (2003). Non-parametric and parametric applications measuring efficiency in health care. *Health Care Management Science, 6*(4), 203–218.

Chakraborty, K., Biswas, B., & Lewis, W. C. (2001). Measurement of technical efficiency in public education: A stochastic and non-stochastic production function approach. *Southern Economic Journal*, 889–905.

Sengupta, J. K. (1998). Testing allocative efficiency by data envelopment analysis. *Applied Economics Letters, 5,* 689–692.

Liu, C., Jung, C., & Chen. C. (2004). Incorporating value judgments into data envelopment analysis to improve decision quality for organization. *Journal of American Academy of Business*, Cambridge, 423–434.

Zere, E. (2000). *Hospital efficiency in Sub-Saharan Africa*. Working papers No 187, UNU World Institute for Development Economics Research, p. 48.

Pilyavsky, A., & Staat, M. (2008). Efficiency and productivity change in Ukrainian health care. *Journal of Productivity Analysis, 29*(2), 143–154.

Färe, R., Grosskopf, S., Lindgren, B., & Roos, P. (1994). Productivity developments in Swedish hospitals: A Malmquist output index approach. In *Data envelopment analysis: Theory, Methodology, and Applications* (pp. 253–272). Netherlands: Springer.



http://www.springer.com/978-981-10-5630-7

Healthcare Systems Management: Methodologies and Applications
21st Century Perspectives of Asia
Ray, P.K.; Maiti, J. (Eds.)
2018, VIII, 135 p. 34 illus., 18 illus. in color., Hardcover
ISBN: 978-981-10-5630-7