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SYSTEMATIC REVIEW

Efficiency Measurement in Health Facilities: A Systematic Review in Low- and Middle-Income Countries

Firdaus Hafidz[1,2] · Tim Ensor[1] · Sandy Tubeuf[1]

Abstract

Background Limited healthcare resources in low- and middle-income countries (LMICs) have led policy-makers to improve healthcare efficiency. Therefore, it is essential to understand how efficiency has been measured in the LMIC setting.

Objective This paper reviews methodologies used for efficiency studies in health facilities in LMICs.

Methods We searched MEDLINE, Embase, Global Health, EconLit and ProQuest Dissertations and Theses databases to Week 6 in 2018. We included all types of quantitative analysis studies relating to the measurement of the efficiency of services at health facilities in LMICs. We extracted data from eligible studies, and assessed the validity for each study. Because of the substantial heterogeneity of the studies, results were presented narratively.

Results A total of 137 papers were eligible for inclusion. These articles covered a wide range of health facility types, with more than half of the studies relating to hospitals. Our systematic review showed that there is an increasing trend in efficiency measurements in LMICs using various methods. Most studies employed data envelopment analysis as an efficiency measurement method. The studies typically included physical inputs and health services as outputs. Sixty-one percent of the studies analysed the contextual variables of the health facility efficiency.

Conclusion This review highlights the potential for methodological improvement and policy impacts in efficiency measurements.

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✉ Firdaus Hafidz
umfhas@leeds.ac.uk; hafidz.firdaus@ugm.ac.id

Tim Ensor
T.R.A.Ensor@leeds.ac.uk

Sandy Tubeuf
S.Tubeuf@leeds.ac.uk

1 Leeds Institute of Health Sciences, University of Leeds, Leeds, UK

2 Universitas Gadjah Mada, Yogyakarta, Indonesia

Key Points for Decision Makers

There is no consensus of the most appropriate technique to measure efficiency in low- and middle-income countries; most of the existing studies rely on ratio analysis and data envelopment analysis.

Potential policy strategies to improve efficiency include on the supply side: labour and capital optimisation, and improving quality of services; and on the demand side: reducing financial and physical barriers, and changing health behaviours.

1 Introduction

Improving the efficiency of resource use is important in most health systems. It is an issue that is particularly acute in low- and middle-income countries (LMICs) faced by limited financing (LMICs spend US$266 on health expenditure per capita while high-income countries (HICs) spend US$5251 [1]) and pressure on services from a double

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disease burden and weak health system infrastructure [2, 3]. Between 1995 and 2014, annual spending in LMICs increased by an average of 10% per annum, placing huge pressure on limited resources [4].

Promoting efficiency is important for LMICs to ensure that resources are targeted to promote the goal of universal health coverage (UHC). Efficiency matters in both private and public sectors since limited public sector capacity in LMICs means that the private sector has an important role to play in achieving UHC [5, 6]. Similarly, improving efficiency in both secondary and primary care can enhance the overall ability of the system to improve population health. Hospitals are often relatively well resourced but inefficiently utilised with, for example, bed-occupancy rates that are well below the 85% recommended by the World Health Organisation (WHO) [7]. Primary care as the system entry point should provide services for most healthcare needs and control access to specialist services, contributing to improved system efficiency [8–10]; however, in practice, lack of resources and weak management may lead to low utilisation and bypassing.

Most studies on the efficiency of health facilities have been performed in HIC settings. Applying efficiency measurement in LMICs often requires a modification from the methods that are used in HIC settings. In HIC settings, inefficiency is sometimes presented as variations in performance resulting from excessive use of inputs to deliver services [7, 11]. However, in LMICs, inefficiency arises from the shortage, weak management and poor distribution of resources [12].

The primary objective of this study is to highlight what is known about efficiency methodologies in health facilities in LMICs. The focus is on technical efficiency defined as the ability for a health facility to use the minimum amount of input to produce a given level of output or to obtain a maximum amount of outputs from the available input [13, 14].

A variety of different techniques have been utilised to measure technical efficiency. Bitran [15] categorised them as ratio analysis, econometric estimation, stochastic frontier analysis and data envelopment analysis. Although a number of literature reviews of efficiency techniques have been undertaken in HIC settings [16–20], we found a single review in LMICs, which focused in Iranian hospitals [21]. To the best of our knowledge, this review is the first to examine the efficiency methodologies of health facilities across LMICs. The review informs the conduct of future efficiency studies across the health system and also provides evidence for policy makers in LMICs to guide efficiency-related decisions.

2 Methods

2.1 Search Strategy

A review of five literature databases was performed along with a manual search of published articles within reference lists and covered publications up to Week 6 in 2018. No time limit was imposed because we wished to capture the entire landscape of efficiency studies.

The first author (FH) searched the following databases: MEDLINE (Ovid), Embase Classic + Embase (Ovid), Global Health (Ovid), EconLit (EBSCOhost) and also grey literature using ProQuest Dissertations and Theses. The searches were designed to identify efficiency studies of health facilities in LMICs by combining the search concepts of ‘efficiency’, ‘health facilities’ and ‘low- and middle-income countries’. The search strategies suggested by Dudley and Garner [22] for ‘low- and middle-income countries’ were adopted in this review. The full search strategies and keywords that were used are presented in Online Resource 1 (see electronic supplementary material [ESM]).

2.2 Inclusion Criteria

To be eligible for inclusion, studies that measured efficiency, productivity or performance as a means of comparing services between health facilities were included. The unit of study is a health facility such as hospital, primary health care facility, or home nursing setting in both the public and private sectors. All types of quantitative analysis studies with empirical information relating to the measurement of the efficiency of services at the health facility level were considered. Because our aim is to focus on LMICs, we excluded studies conducted in HICs as defined by the World Bank (countries with a per-capita income of US$12,616 or more [23]). In addition, studies in languages other than English were excluded.

2.3 Data Collection and Analysis

FH reviewed all the titles and abstracts retrieved by the electronic searches using a reference management database (EndNote) and removed any duplicates. The titles and abstracts were screened on the basis of inclusion and exclusion criteria and full-text copies of the included studies were downloaded and assessed. Once the included studies were identified, the data were extracted using a form developed for this purpose. Difficult studies were discussed between the three co-authors. Some articles were manually identified by the co-authors independently of the searching process. For each study, the following items were extracted: the aim, country, geographic region according to the World Bank groupings, type of health facilities, sample size, year, method, orientation, input variable(s), output variable(s), contextual variable(s), outcomes and limitations. Because the included studies were too heterogeneous to conduct a meta-analysis, a narrative synthesis was conducted [24]. Information from the studies was grouped according to the study characteristics and then examined in a tabulated summary.

2.4 Validity of Studies

FH assessed the methodological validity using a validity tool adapted from an instrument used in a published systematic review of hospitals [25]. The validity tool included thirteen items related to the sample, indicators and statistical methods (Table 5 in Online Resource 2, see ESM). Each item was given 1 point if the answer was 'Yes', and 0 points for 'No', yielding a score ranging from 0 to 13 for each study. Studies that scored < 6 points were considered to have low validity, 6–8 medium validity and ≥ 9 high validity.

2.5 Measurement Techniques

Ratio analysis (RA) has been used to measure the efficiency by comparing either input to output ratios (RA of technical efficiency) or the cost of input to output ratios (RA of economic efficiency) [15]. RA is typically limited to one input (e.g. beds) and one output (e.g. bed-days). However, it is also possible to perform ratio analyses across a range of inputs simultaneously [26].

Unlike RA, parametric techniques estimate relationships between one dependent variable and multiple independent variables of inputs or outputs based on a specific functional form [27]. In this review, we divided parametric methods into econometric estimation (EE) and stochastic frontier analysis (SFA). EE estimates the technical efficiency or economic efficiency using ordinary least square regression between inputs and outputs. Production function models diagnose factors that are significantly associated with the level of the outputs, and cost function models identify factors that determine the cost [28, 29]. These average response models evaluate the inefficiency component with a random error [30].

SFA estimates a best-practice frontier using least-squares method and decomposes the error into two components, a random noise (unobserved heterogeneity) and a true inefficiency component [27, 31]. SFA is preferred over ordinary least square or deterministic regressions because SFA can better address noise present in the data. However, SFA requires assumptions about the functional form and error distribution and is vulnerable to small sample sizes [14].

Data envelopment analysis (DEA) uses mathematical programming to construct a frontier line from the data without requiring the specification of a functional or distributional form. DEA identifies health facility performance by benchmarking them to fully efficient health facilities lying at the frontier. However, it does not accommodate error, outliers, or noise measurement. DEA can also be used to analyse longitudinal data by estimating the Malmquist productivity index. This index measures the change in total productivity levels between the base and current periods with respect to either constant returns to scale (CRS) or variable returns to scale (VRS) using the distance function. CRS is applied when the providers can be operating at an optimal scale where the output changes proportionally to the inputs while VRS accommodates more flexible returns to scale [27].

2.6 Input and Output Variables

In the efficiency measurement, there are no best practice methods regarding input and output variables that should be used.

At present, there are two opposing views regarding outputs to be used to evaluate health care. First, because health is the ultimate outcome, any activities should be evaluated as changes produced in health [32]. This measurement could be misleading because the changes in health might not reflect the amount of care provided. The other view evaluates health care using the intermediate outputs measured in health facilities [32]. Intermediate outputs can be separated into two primary groups, namely activity indicators (e.g. the amount of care provided), and financial outputs (e.g. health facilities revenue) [25, 33, 34]. This review will regard both types of outputs as valid, albeit imperfect measures of performance.

Inputs can be measured as physical or financial inputs. Physical inputs such as labour and capital have the advantages of their ease of calculation and comparability, although they have the disadvantage of not always being able to capture monetary aspects such as hospital capital or total expenses [25]. On the other hand, financial inputs will answer questions about whether the output could be produced less expensively through a more efficient use or substitution of costly inputs [35]. However, financial inputs do not easily allow international comparisons because there are discrepancies between the salaries and costs of care across countries [25].

3 Results

3.1 General Description of Included Studies

The literature search identified a total of 6946 potentially relevant studies from five databases, and the manual search identified 12 articles. Once the duplicates were removed, 5376 titles and abstracts were screened, of which 5167 studies were excluded. The major reasons for exclusion were (i) the aim of the study was not to assess the efficiency of health facilities, or (ii) the setting was not an LMIC. Two hundred and nine potentially relevant studies were retrieved for full-text assessment. For the full-text review, 72 studies were excluded because full text was not available in English and 137 studies were finally included in the analysis (Fig. 1).

Regarding validity of studies, of the 137 studies, 107 studies (78%) had a high validity score and 30 (22%) had a medium validity score. Most of the studies with medium validity did not discuss one or more of the following issues: (i) only assessed one type of health facility, (ii) the calculation of sample size was not clearly justified, and (iii) they did not clearly define the study period. Conversely, the high-scoring studies mostly discussed all three issues, and were also more likely to use different indicators to measure the impact on productivity and to justify the statistical method.

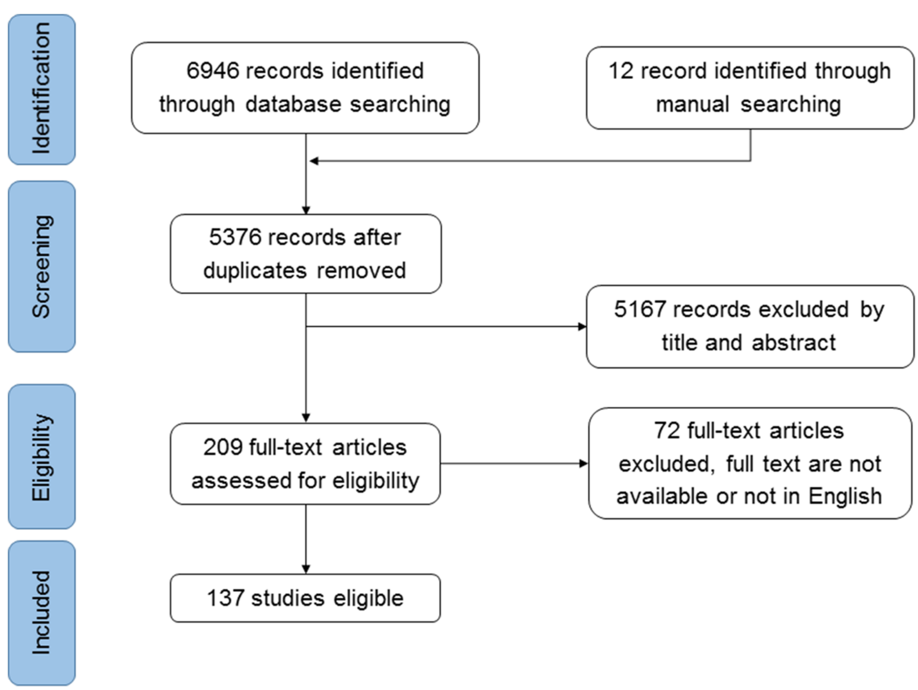
3.2 Settings

Forty-three studies (31%) were conducted in Sub-Saharan Africa (Fig. 2), especially in Ghana, Kenya and South Africa. These studies consisted of intra- or inter-country analyses from 48 countries in seven regions. There were five inter-country efficiency studies with four of them conducted in Africa [36–39], and one study [40] across several African countries as well as in Honduras and Moldova [40]. The primary aim of the latter study was to improve the quality of information and examine the efficiency in different settings. The representativeness of intra-country analyses varied; for example, the study in Iran used data from only one hospital using 5-year panel data [41]. However, a nationwide study of health facilities in Mexico included a total sample of 2105 facilities [42].

There is no noticeable difference in the type of methods used in each region (Fig. 2). DEA remained the most frequently used technique for efficiency measurements in all regions. RA was used in most of the regions except in Europe and Central Asia. In addition, there were only a small number of studies that applied SFA and EE. SFA was only used in studies in Sub-Saharan Africa, the Middle East and North Africa, and East Asia and the Pacific region, while EE alone was used in studies in South Asia, Europe and Central Asia.

The health facilities were categorised into the following types: hospitals, primary-care facilities, and other types of health facilities such as community nutrition centres, dentistry clinics and dialysis facilities. Eighty-eight studies (64.2%) were conducted in hospitals, 29 studies (21.2%) took place in primary-care settings, 11 studies (8.0%) analysed both hospital and primary-care facilities, and nine studies (6.6%) were in other types of health facilities (Table 1). With regard to ownership, the majority of health

Fig. 1 Study flow diagram of excluded and included studies



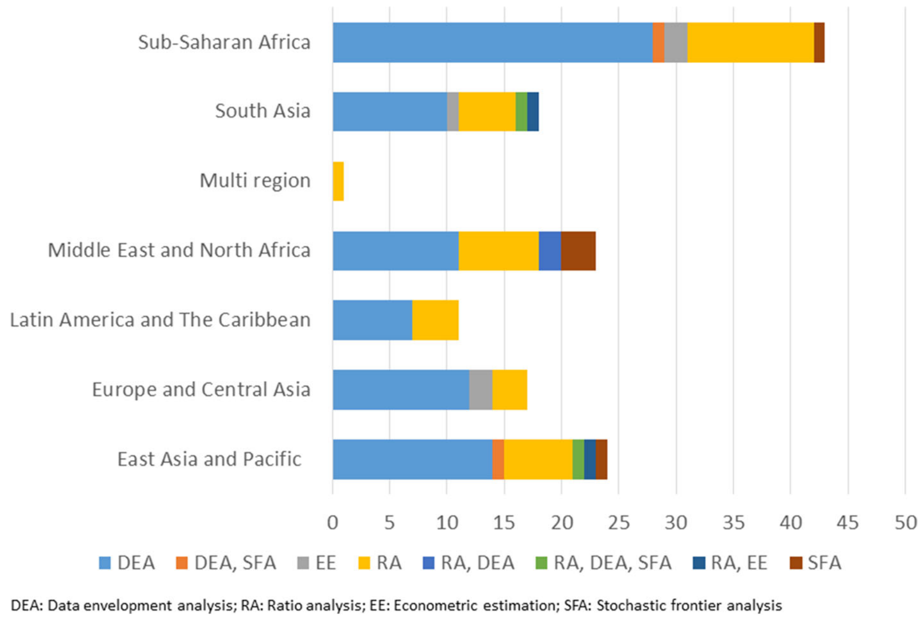


Fig. 2 Regions of included studies and applied techniques

facilities were in the public sector ($n = 97$, 70.8%), 29 studies (21.2%) analysed both public and private health facilities, and only eight studies (5.8%) analysed private health facilities exclusively. The characteristics of the included studies are given in Table 6 in Online Resource 3 (see ESM).

3.3 Techniques

The number of studies using several techniques to measure the efficiency has increased dramatically over the past few years (Fig. 3). Most of the studies (91%) were published after the year 2000 and the synthesis is dominated by relatively modern analytical methods. Almost one-third of the studies applied one of two types of RA analysis. The first type is the physical input-to-output ratio (technical efficiency); for example, bed turnover and bed occupancy rates. Ten studies used the Pabón Lasso Model, which applies several RA indicators simultaneously. The second type is the ratio of cost inputs to outputs (economic efficiency); for example, the average cost per admission and the average cost per outpatient visit. The rest of the studies ($n = 95$, 65.5%) used SFA, DEA or a mix of methods. Less than 3% of the studies applied EE exclusively.

The use of DEA to measure efficiency started from 2000 (Fig. 3); DEA has the advantages that it can handle multiple inputs and outputs and does not require a functional form to be specified. Out of 137 studies, 82 studies used DEA alone or jointly with a second-stage analysis including 19 studies that also included the Malmquist index. It is notable that the use of DEA orientations are predominantly by input orientation rather than output orientation, while only a small number of studies applied both input and output orientation together. At different levels of care, studies in hospitals are mostly input-oriented while studies in primary care are distributed equally between input and output-oriented (Fig. 4). This is possibly because hospital managers have more control over inputs, which allows them to minimise their use of resources while maintaining the same level of outputs. On the other hand, primary-care managers mostly have limited control over the level of inputs and their goal is to maximise the resulting outputs. Regarding returns to scale, most of the studies predominantly used VRS, particularly in hospitals.

3.4 Input Variables

Of the 137 efficiency measurement studies in the published literature, 82 studies used counts of physical resources as inputs, 23 studies used financial inputs, and 32 studies used both physical resources and financial inputs (Table 1). The physical input variables included different types of capital items (e.g. the number of beds, size of the facility and number of pieces of medical equipment), and different types of labour or materials (e.g. number of doctors, nurses, and drugs and medical supplies). The financial inputs included the total expenditures, capital inputs (e.g. cost to reconstruct the health facility, equipment depreciation), and different types of labour/material expenditures (e.g. salaries, drug expenditures and non-labour expenditures). Other types of inputs were also found, including a service mix as a proxy for the complexity of services and quality management efforts to satisfy customer expectations (Table 2).

Table 1 Characteristics of efficiency measures

	Number of studies	Percentage of studies (%)
Level of care		
Hospital	88	64.2
Primary care	29	21.2
Hospital and primary care	11	8.0
Other	9	6.6
Ownership		
Public	97	70.8
Private	8	5.8
Public and private	29	21.2
Not available	3	2.2
Inputs		
Physical	82	59.9
Financial	23	16.8
Physical and financial	32	23.4
Outputs		
Health services	122	89.1
Health services and quality	7	5.1
Other	8	5.8
Statistical/mathematical methods		
DEA	82	59.9
RA	37	27.0
EE	5	2.8
SFA	5	2.6
RA, DEA, SFA	2	0.9
DEA, SFA	2	0.7
RA, EE	2	0.7
RA, DEA	2	0.6
Contextual variables		
Internal	39	28.5
External	13	9.5
Internal and external	32	23.4
None	53	38.7
Data source		
Primary data	58	42.3
Secondary data	70	51.1
Primary and secondary data	9	6.6
Time frame		
Cross-sectional	82	59.9
Panel	47	34.3
Not available	8	5.8

DEA data envelopment analysis, *RA* ratio analysis, *EE* econometric estimation, *SFA* stochastic frontier analysis

3.5 Output Variables

Most of the measures (89.1%) from the published literature used health services as outputs. The most common health services items for hospitals were the number of outpatient visits, admissions or discharges, and inpatient days (Table 3). Because most of the studies used aggregated outputs, it was not possible to disaggregate services by department. The typical outputs used in primary-care settings were outpatient visits and other services including the number of fully immunised children, the number of individuals enrolled in nutrition services and the number of

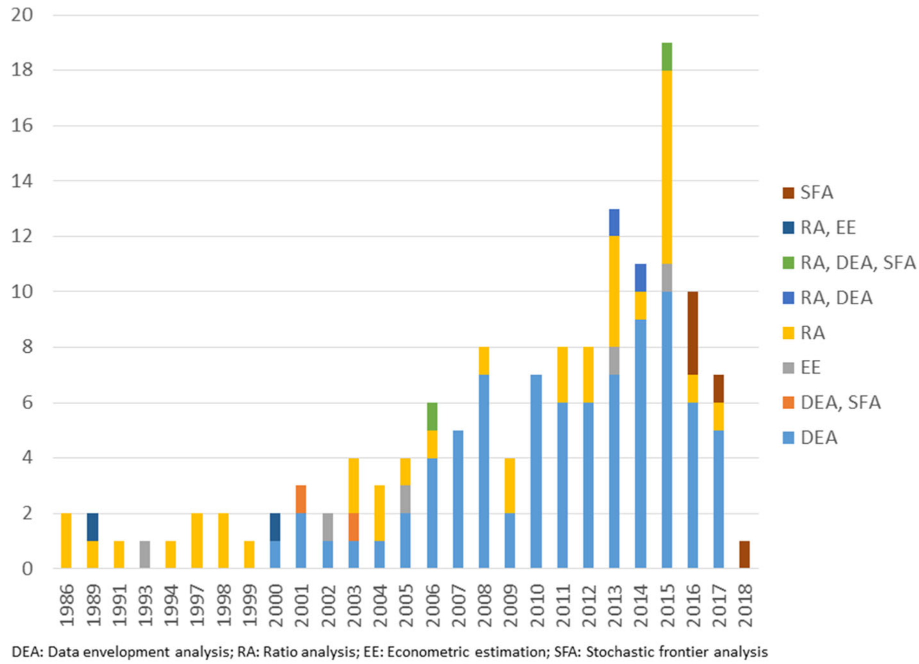


Fig. 3 Efficiency measurement technique trend

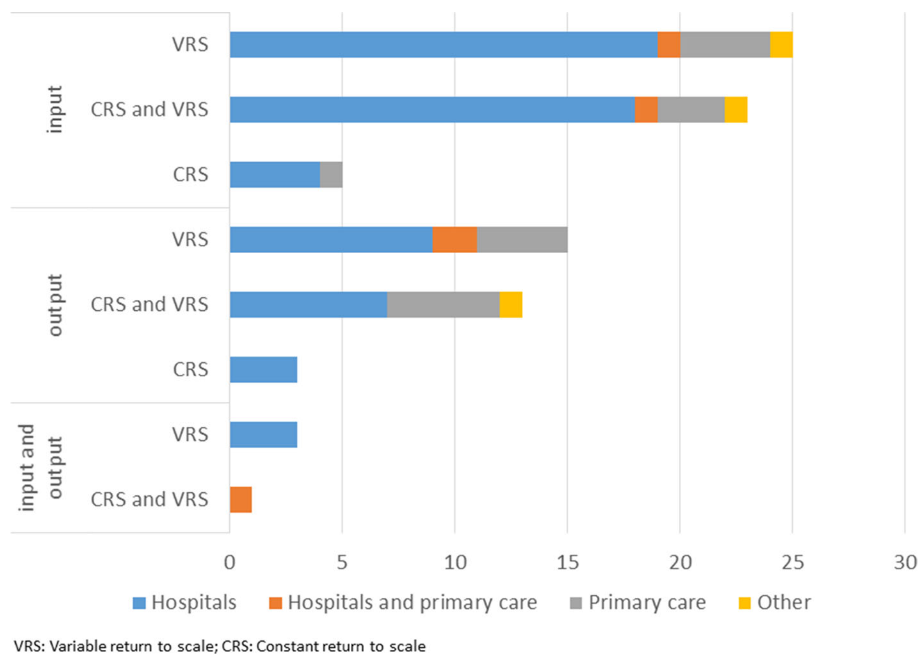


Fig. 4 Data envelopment analysis (DEA) orientation and returns to scale by the health facility level of care

prescriptions. In some studies, the outputs were categorised by the type of services (e.g. family planning, child health services) and condition (e.g. typhoid, malnutrition). Four studies [43–46] adjusted the number of cases using a case-mix index to treat all the services equally. Two of the studies [43, 45] used diagnostic-related group (DRG) weighting, and one study [46] used the intensity of complicated maternal and neonatal cases. None of the studies used the health outcomes of the population, such as the maternal mortality rates or child mortality, as outputs. Two studies [47, 48] were found to incorporate patient outcomes such as the mortality rate for admitted patients, which were used as undesirable outputs. The quality of services was sometimes used to adjust the outputs; it was proxied by the number of re-admissions [43], the survival and performance ratios [49] and patient satisfaction [50]. Another output measure was financial performance, which was applied by six studies. Financial performance was measured using the health facility revenue [51–54], purchasing value [55], return on assets and operating margin [56].

Table 2 Number and percentage of input variables used by type of health facility

Input variables	Hospitals		Primary care		Hospitals and primary care		Other		Total	
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
Physical										
Capital										
Beds	73	(27.7)	5	(6.4)	7	(20)	1	(6.3)	86	(21.9)
Size of facility	1	(0.4)	6	(7.7)	1	(2.9)	0	(0)	8	(2)
Medical equipment	2	(0.8)	2	(2.6)	0	(0)	2	(12.5)	6	(1.5)
Department	1	(0.4)	2	(2.6)	1	(2.9)	0	(0)	4	(1)
Number of health facilities	0	(0)	0	(0)	1	(2.9)	0	(0)	1	(0.3)
Labour/materials										
Doctor	47	(17.8)	5	(6.4)	7	(20)	3	(18.8)	62	(15.8)
Nurse/midwife	34	(12.9)	5	(6.4)	5	(14.3)	2	(12.5)	46	(11.7)
Non-medical staff	20	(7.6)	7	(9)	4	(11.4)	1	(6.3)	32	(8.1)
Total labour	12	(4.5)	5	(6.4)	1	(2.9)	0	(0)	18	(4.6)
Technician staff/paramedic	17	(6.4)	3	(3.8)	2	(5.7)	0	(0)	22	(5.6)
Medical staff	10	(3.8)	5	(6.4)	3	(8.6)	0	(0)	18	(4.6)
Number or length in hours of activities	1	(0.4)	2	(2.6)	0	(0)	3	(18.8)	6	(1.5)
Drugs and medical supplies	3	(1.1)	4	(5.1)	0	(0)	0	(0)	7	(1.8)
Non-medical supplies	1	(0.4)	0	(0)	0	(0)	0	(0)	1	(0.3)
Financial										
Total expenditure	22	(8.3)	11	(14.1)	0	(0)	3	(18.8)	36	(9.2)
Capital value	4	(1.5)	4	(5.1)	0	(0)	0	(0)	8	(2)
Labour/materials										
Expenditures for specific item or services	7	(2.7)	7	(9)	0	(0)	1	(6.3)	15	(3.8)
Salary expenditure	6	(2.3)	5	(6.4)	2	(5.7)	0	(0)	13	(3.3)
Other										
Service mix	2	(0.8)	0	(0)	0	(0)	0	(0)	2	(0.5)
Management quality	1	(0.4)	0	(0)	1	(2.9)	0	(0)	2	(0.5)
Total	264	(100)	78	(100)	35	(100)	16	(100)	393	(100)

n number of variable used, % percentage of variable used

Detailed methodological characteristics of the included studies can be found in Table 7 in Online Resource 4 (see ESM).

3.6 Contextual Variables

More than half (61.3%) of the included studies performed further analysis to explore the determinants of health facility efficiency. On average, three contextual variables were analysed in each study, with the number of contextual variables ranging from one to twelve per study. The typical internal contextual variables used were ownership (e.g. public or private), type of health facility (e.g. general or specialist facility), performance indicator (e.g. bed occupancy rate, average length of stay), quality indicators (e.g. patient satisfaction, mortality rate), and specific health services (Table 4). The external contextual variables in use were the geographic location (e.g. region, urban or rural area), demographics (e.g. population size coverage, population education level), economic situation (e.g. provincial income per capita, household asset value), time trend, and market concentration (Table 4).

3.7 Methodology Issues

The analysis of limitations was drawn from those identified by the authors of each study (Fig. 5).

Thirty-five studies (26%) indicated the lack of availability of a quality indicator, and thus the output variables not being adjusted for quality as a limitation. Thirty-four studies (25%) also stated a small sample size was their limitation. On average, the sample size of health facilities examined in the papers was 101, with an average of 74 for analyses conducted in hospitals and 102 in primary-care settings. The average number of outputs was three (range 1–14) while the average number of inputs was three (range 1–11).

Table 3 Number and percentage of output variables used by type of health facility

Variable items	Hospitals		Primary care		Hospitals and primary care		Other		Total	
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
Activity output										
Outpatient visit	68	(24.5)	44	(46.8)	28	(51.9)	6	(31.6)	146	(32.9)
Admission or discharge	70	(25.3)	3	(3.2)	9	(16.7)	0	(0)	82	(18.5)
Inpatient days	61	(22)	0	(0)	6	(11.1)	0	(0)	67	(15.1)
Other services	21	(7.6)	34	(36.2)	4	(7.4)	8	(42.1)	67	(15.1)
Procedure	36	(13)	6	(6.4)	4	(7.4)	3	(15.8)	49	(11)
Session	3	(1.1)	3	(3.2)	0	(0)	0	(0)	6	(1.4)
Financial										
Financial performance	10	(3.6)	2	(2.1)	0	(0)	1	(5.3)	13	(2.9)
Quality output										
Re-admission	1	(0.4)	0	(0)	0	(0)	0	(0)	1	(0.2)
Mortality rate	2	(0.7)	0	(0)	0	(0)	0	(0)	2	(0.5)
% survival rate	1	(0.4)	0	(0)	0	(0)	0	(0)	1	(0.2)
Quality of service	4	(1.4)	1	(1.1)	3	(5.6)	1	(5.3)	9	(2)
Patient satisfaction	0	(0)	1	(1.1)	0	(0)	0	(0)	1	(0.2)
Total	277	(100)	94	(100)	54	(100)	19	(100)	444	(100)

n number of variable used, % percentage of variable used

Twenty-three studies (17%) indicated that the cost and price data were difficult to collect. This limitation caused the studies to use DEA predominantly instead of SFA, which requires financial data. The lack of case-mix information to weight output weighting was also a limitation in 24 studies (18%).

3.8 Outcomes

The studies included in this review reported relative efficiency as a study outcome. Studies using the RA technique explained efficiency by examining the variation in ratio indicators among health facilities. In addition, a study that used RA with the Pabón Lasso Model explained efficiency by assessing the position of each health facility in the diagram according to the average bed occupancy and bed turnover rates. The typical DEA and SFA measures presented in the studies were technical efficiency scores, returns to scale measures, rankings of health facilities, and estimates of the input reductions or output increases required to become efficient. Wide variations in the efficiency measurement results were found.

4 Discussion

4.1 Techniques

Most of the existing studies rely on methods such as RA and DEA. RA was originally applied because of its advantages: it is simple, easy to compute, low-cost, and can be performed on small samples [15]. Additionally, even though RA cannot address multiple products, it provides useful information for detecting inefficiency. Thus, in specific circumstances involving limitations of time, data, expertise, or budget, policy makers and researchers prefer RA as a means of comparing efficiency across healthcare organisations. This finding is not unique to LMICs; a review of the efficiency measurement in the United States found that 44% of the studies used RA as a statistical method [35]. However, RA has limitations including arbitrary assumptions regarding the cost allocation and the difficulty of detecting quality and case-mix variations among providers [15]. In general, the application of RA in HICs is more advanced than in LMICs because it uses adjusted outputs such as severity-adjusted average length of stay [35].

DEA became a popular choice for researchers in both LMICs and HICs to overcome the limitations faced by RA from 2000 [34, 35]. The main advantage of DEA is that it can be used with multiple inputs and outputs. However, both RA and DEA become problematic when there are outliers in the sample.

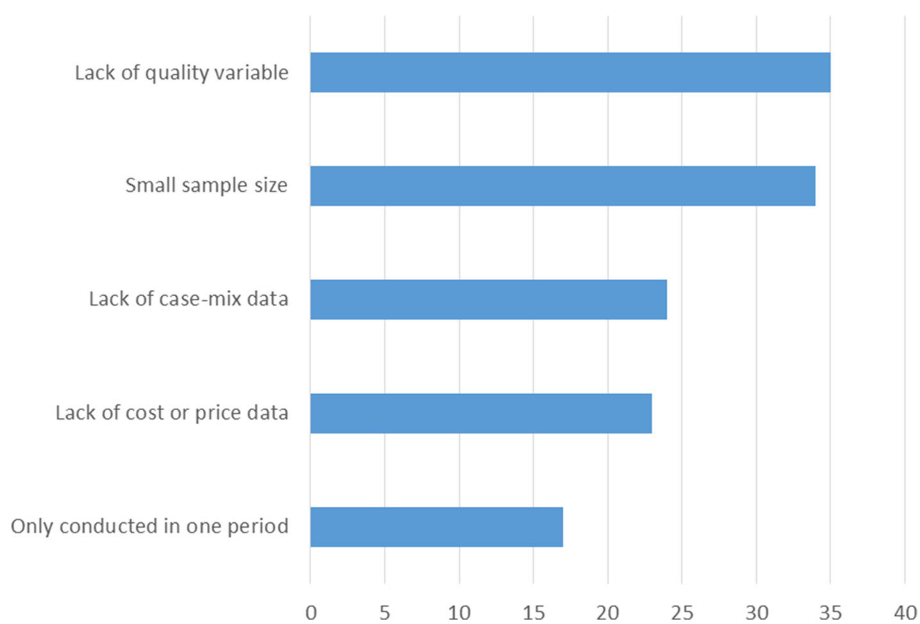
EE has the advantage to provide a better overview of the changes in outputs or total costs in response to changes in the inputs, service mix, and scale of operations through the production or cost functions. EE has been applied in HICs since the 1970s, but it only started to be used in LMICs in the late 1980s and its use was still minimal [15]. Data deficiencies, such as availability as well as inconsistencies

Table 4 Number and percentage of contextual variables used by type of health facility

Variable items	Hospitals		Primary care		Hospitals and primary care		Other		Total	
	n	(%)	*n*	(%)	*n*	(%)	*n*	(%)	*n*	(%)
Internal										
Ownership	11	(4.5)	9	(8.7)	2	(8)	3	(16.7)	25	(6.4)
Type of health facility	9	(3.7)	6	(5.8)	4	(16)	1	(5.6)	20	(5.1)
Performance indicators	19	(7.8)	1	(1)	2	(8)	0	(0)	22	(5.6)
Quality indicators	67	(27.6)	22	(21.2)	10	(40)	7	(38.9)	106	(27.2)
Specific health services	16	(6.6)	9	(8.7)	4	(16)	1	(5.6)	30	(7.7)
Size of health facility	17	(7)	0	(0)	0	(0)	0	(0)	17	(4.4)
Financing	8	(3.3)	4	(3.8)	0	(0)	0	(0)	12	(3.1)
Availability of staff	16	(6.6)	3	(2.9)	1	(4)	0	(0)	20	(5.1)
Teaching	9	(3.7)	0	(0)	0	(0)	0	(0)	9	(2.3)
Management	6	(2.5)	2	(1.9)	0	(0)	3	(16.7)	11	(2.8)
Patient mix	5	(2.1)	1	(1)	0	(0)	0	(0)	6	(1.5)
Experience	2	(0.8)	0	(0)	0	(0)	1	(5.6)	3	(0.8)
External										
Geography	25	(10.3)	18	(17.3)	1	(4)	1	(5.6)	45	(11.5)
Demography	11	(4.5)	18	(17.3)	1	(4)	0	(0)	30	(7.7)
Economy	5	(2.1)	3	(2.9)	0	(0)	0	(0)	8	(2.1)
Time	4	(1.6)	6	(5.8)	0	(0)	1	(5.6)	11	(2.8)
Market concentration	9	(3.7)	0	(0)	0	(0)	0	(0)	9	(2.3)
Security	0	(0)	1	(1)	0	(0)	0	(0)	1	(0.3)
Population health status	1	(0.4)	0	(0)	0	(0)	0	(0)	1	(0.3)
Insurance coverage	3	(1.2)	1	(1)	0	(0)	0	(0)	4	(1)
Total	243	(100)	104	(100)	25	(100)	18	(100)	390	(100)

n number of variable used, % percentage of variable used

Fig. 5 Five common limitations highlighted in the studies



between providers, are the primary constraints when using EE. EE also cannot separate between true inefficiency and random noise [30, 57]. Most of the studies applying EE in HICs use cost functions, while in LMICs; the application of cost or production functions is rare because of the limited availability of cost and price data [58].

Efficiency studies in both HICs and LMICs increasingly use SFA, however DEA remains the dominant technique [34, 59]. SFA relies on large and detailed sources for data, especially input prices and other financial data. It is more common for cost functions than production functions to be applied in SFA, because costs can easily be aggregated into a single measure that is required for an SFA frontier [60]. However, this requirement limits the application of SFA when there is poor data availability, which is especially the case in LMICs. It is important to underscore that only five studies appear to have applied SFA alone and four used it in conjuction with other methods to compare results. In addition, the complexity of SFA may prevent researchers from using SFA, as results are difficult for policy makers to interpret.

Each technique has its own advantages and disadvantages; there is no clear 'consensus' about which technique is best. RA of technical efficiency and DEA appear to be the preferred techniques to measure efficiency in LMICs if policy makers need quick, clear, simple, and practical evidence, and cost information is seldom available in routine information systems, and there are limited research resources such as budgets and expertise.

4.2 Orientation

Regardless of the techniques, efficiency results can be interpreted in multiple ways depending on the orientation [35]. This review found equal numbers of studies that applied input and output orientations. Reallocating excess medical staff and downsizing the capacity of a health facility are examples of improving efficiency based on inputs. However, from an ethical viewpoint, this may not be an appropriate way to reduce waste when there is still a major issue regarding resource availability [61, 62]. Output orientation (e.g. to improve outreach activities, to reduce physical and financial barriers, to increase utilisation rates) may therefore be more acceptable in the context of LMICs.

In addition, input optimisation orientation can be very difficult to apply in health facilities owned by governments. Bureaucratic processes can make the procedures for recruitment or dismissal of employees and the purchase or disposal of assets complex and time consuming. However, this type of orientation may be feasible if facilities are given a degree of autonomy over resource management decisions.

4.3 Indicators

The results showed that physical inputs such as the infrastructure and the staff mix were the most frequently used input variables for efficiency measurement in LMICs, while variables related to the services provided were output variables. Only a small percentage of studies used variables related to financial or quality measures as outputs. Similar findings in input and output variables were found in HICs [35].

Although medicines are an input indicator that is supposed to be beneficial in detecting underuse and overpricing of generic drugs, irrational use of drugs, as well as substandard or counterfeit drugs, this type of inputs variable was lacking in most studies [7].

In relation to outputs, the indicators that were primarily used were not able to detect whether tests and procedures had been applied according to patients' needs. Most of the studies in the literature review assumed that there was no difference in the effectiveness of healthcare services according to the severity of cases treated in all health facilities. This assumption could lead to misinterpretations of efficiency measurements because the outputs are not comparable. Therefore, it would be necessary to incorporate quality indicators (e.g. mortality rates, readmission rates), and case-mix indicators (e.g. complication case rates, diagnosis group variations) to adjust outputs [31, 34, 48, 63–67].

Quality indicators were used in a number of ways to adjust the outputs. Most of the studies in this review applied the inverse of the undesirable outputs, for example mortality rate, as an index of quality indicators [47, 68]; it was mostly used in HICs as well. Apart from mortality rate, two of the LMIC studies used a composite index score for the quality of services, as well as structural and process quality indicators [39, 69]. Quality indicators applied in HIC settings that originate from patient information (such as average length of stay and adverse outcomes [48, 65, 67]) might be a problem in LMIC settings because medical records are not particularly accurate [70].

4.4 Contextual Variables

Many studies incorporated contextual variables and often used two-stage analyses to identify the determinants of efficiency. The first stage estimates the relative technical efficiency of health facilities using DEA while the second stage is an explanatory regression model, usually a Tobit or truncated regression that predicts the technical efficiency score according to a set of contextual variables [71–73]. However, when studies apply SFA to measure efficiency, a two-step approach is not recommended due to the biases arising from the process and other undesirable statistical properties [74]. Determinants of efficiency are therefore identified using a single-step approach. From the nine studies that applied SFA, six studies analysed contextual variables. Four studies [75–78] applied a single-step approach while two others [79, 80] analysed the determinants by comparing the means descriptively and statistically using ANOVA, Pearson and Nopo matching decomposition procedure.

Contextual variables include both internal and external factors. Internal factors are elements within the health facilities that managers are able to control while external factors are elements outside health facilities that are impossible for health managers to control. In our review, contextual factors typically included ownership status, health facility size, and teaching status as internal factors while geography, demography and economic status of the population were used as external factors. Studies in HICs generally used similar sets of contextual variables [81, 82], with ownership being the most frequently used along with size and capacity, degree of specialisation, market structure and funding issues. Recent studies in HICs sometimes incorporate quality indicators in the analysis [33, 59, 83].

Public ownership in LMICs was generally found to be correlated with higher efficiency compared with private ownership, although the findings are mixed. Jehu-Appiah et al. [84] found that public hospitals performed better than private because public hospitals in LMICs operate under significant budget constraints, compelling them to provide medical care at lower costs. However, a study by Hatam et al. [85] in Iran argued that the private sector is more efficient than the public sector because there is no incentive for the public sector to minimise expenses. In HICs, a review by Herrera et al. [83] found that ownership does not seem to affect efficiency. Significant differences in health outcomes and costs were only found between private-for-profit providers and private-not-for-profit providers, in which the latter were found to be more efficient. No significant differences were found in efficiency between public providers and both categories of private providers.

In addition to the ownership, our review found that facility size measured by the number of beds was associated with higher efficiency. The findings showed mixed results, with some studies finding that the health facility size had a negative association with efficiency [48, 84, 86, 87], and others finding the opposite [26, 55, 88]. Studies in HICs generally found similar mixed results. A study in Greece found that there was no significant association between the operational size and efficiency [89], while a study in the United States as well as a review found that a larger organisational size was negatively associated with efficiency [33, 82]. A review by Hadji et al. [25] found that the relationship between size and efficiency was U-shaped, and small and large hospitals had higher efficiency than medium-sized hospitals. Other studies in HICs suggested that the effect of the size of the health facility differed according to the location and population [81, 90]. Larger health facilities were found to be more efficient in urban areas, while smaller health facilities were more efficient in rural areas [90].

The geographic location of a health facility (e.g. urban or rural region) was predominantly included as an explanatory factor in efficiency analyses. Our review findings were different from those of studies conducted in HICs such as in the United States, which showed that rural hospitals tended to operate with lower costs due to fewer severe patient complications [65]. Heimeshoff et al. [91] also argued that health facilities in rural areas in Germany were significantly more efficient because of a lower density of physicians, leading to a higher occupancy rate. However, these explanations should only be applied in homogeneous situations such as where there is equal physical access to health facilities and equal health awareness among the general population.

Nine studies incorporated quality as an explanatory variable in the second-stage analysis of healthcare efficiency in LMICs. The indicators used as a proxy for quality ranged from a single variable such as health facility accreditation, patient satisfaction or mortality rate, to a composite index of quality including structural and process indicators. Results in LMICs showed mixed results, in which some studies found there were no trade-offs between quality and efficiency [29, 39, 92], and others found trade-offs vary with size, especially in the small and medium-sized health facilities [48, 93]. In HICs, a review by Worthington [33] found that several studies showed a negative association between quality and efficiency. It was hypothesised that, in the presence of increasing quality, extra resources are likely required, including advance medical technology that is more costly, thereby reducing the efficiency [33].

The market structure, mostly measured by using an index of market competition, has been increasingly used as a contextual variable in research on efficiency in HICs. However, it is less frequently used in LMICs, and only nine of the studies in the present review incorporated market structure. Our findings in LMICs were similar to those of previous studies in HICs, where results were mixed regarding the association between market competition and efficiency [33].

Some other potential sources of technical inefficiency in health care such as corruption and fraud were never incorporated in either in LMIC or HIC settings [7].

This review shows that the efficiency of a health facility is influenced by internal factors but also by external factors that are outside of the control of health sectors. This finding emphasises the need for the inclusion of inter-sectorial actions to improve efficiency.

4.5 Policy Implications

Policy makers and other stakeholders need clear strategies to guide their decisions for better efficiency in policy planning. From this review, four primary supply side strategies are suggested to increase efficiency in health facilities: (i) optimising labour (e.g. transfering excess human resources to other facilities that need those resources or introducing early retirement for excess administrative and general support staff) [92, 94, 95]; (ii) increasing quality (e.g. adequacy of drugs and medical equipment, presence of staff, or enhancement of customer satisfaction to attract patients) [41, 96, 97]; (iii) optimising capital (e.g. closing beds, converting space to outpatient services, or adjusting health facility size) [84, 98, 99]; and (iv) developing finance strategies (e.g. prospective payment mechanisms, use of non-tax sources to increase revenue, or incentives to increase production with a set of targets) [100–102]. The demand-side strategies suggested by the findings from this review include: (i) reducing financial barriers (e.g. introducing health insurance through pooled, pre-paid contributions, subsidising health facilities, or reviewing user fees paid by patients) [84, 101, 103]; (ii) reducing the physical access barriers (e.g. improving transport infrastructure to decrease travel time, introducing an effective referral patient transport system, or launching a social program to reduce the stigma related to accessing health care) [97, 101, 104]; and (iii) changing health behaviours (e.g. increasing the health knowledge and skills of the general population, promoting health, or implementing disease prevention strategies) [61, 104, 105].

Another recommendation for policy makers is to organise a strong monitoring system to evaluate the strategies. This would require a central collection of key data from health facilities to facilitate routine monitoring and provide robust data for advanced empirical research [106]. The use of nationally standardised indicators would ensure comparability between health facilities, as well as data reliability.

The introduction of a routine efficiency monitoring or benchmarking system that considers ranking health facilities and publishes the results in annual reports could help promote efficiency [29, 68].

4.6 Limitations and Future Work

The findings of this review are subject to some limitations. Potentially relevant studies in non-English languages were excluded. This paper focused on efficiency measures specific to health facilities and excluded efficiency studies in other settings. Moreover, this study only focused on variations in efficiency according to ownership, and we did not discuss how efficiency varies with different ways of reimbursing the public and private sectors. Our objective was to provide a landscaping review, and thus the quality of the original studies was assessed using a relatively simple validity tool rather than the complex protocols used in Cochrane or Campbell reviews.

5 Conclusion

This paper reviews studies of efficiency measurement currently available in LMICs. This review identified the efficiency methods as well as the contextual factors that have predominantly been used in LMIC efficiency studies. It provides a comprehensive overview of efficiency measurements to researchers. Further work could consider a wider range of sources, including additional sources of grey literature, as well as collaborative work with researchers from other countries to capture non-English literature.

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Data Availability Statement The search terms applied and list of formatted bibliography exported from EndNote database generated during this study are included in this published article as electronic supplementary material.

Compliance with Ethical Standards

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Ethical Approval This review does not require ethical review.

References

1. World Bank Data. Health expenditure per Capita (current US$). The World Bank. 2016. http://data.worldbank.org/indicator/SH.XPD.PCAP. Accessed 12 June 2016.
2. Organization WH. The world health report 2000: health systems: improving performance. World Health Organization; 2000.

3. Orach CG. Health equity: challenges in low income countries. Makerere University Medical School; 2009.
4. World Bank Data. GDP per Capita (current USD$). The World Bank. 2016. http://data.worldbank.org/indicator/NY.GDP.PCAP.CD. Accessed 29 Feb 2016.
5. WHO. The World Health Report Health Systems Financing The path to universal coverage. Geneva: World Health Organization; 2010. Report No.: 978 92 4 156402 1.
6. World Bank. Second Annual UHC Financing Forum Greater Efficiency for Better Health and Financial Protection. Background paper. Washington: World Bank; 2017.
7. Chisholm D, Evans DB. Improving health system efficiency as a means of moving towards universal coverage. Geneva: World Health Report; 2010.
8. Starfield B. Is primary care essential? Lancet. 1994;344(8930):1129–33. https://doi.org/10.1016/S0140-6736(94)90634-3.
9. Starfield B, Shi L, Macinko J. Contribution of primary care to health systems and health. Milbank Q. 2005;83(3):457–502. https://doi.org/10.1111/j.1468-0009.2005.00409.x.
10. Aldulaimi S, Mora FE. A primary care system to improve health care efficiency: lessons from Ecuador. J Am Board Fam Med. 2017;30(3):380–3.
11. Ham C, Dixon A, Brooke B. Transforming the delivery of health and social care: the case for fundamental change. London: King's Fund; 2012.
12. Mills A. Health care systems in low-and middle-income countries. N Engl J Med. 2014;370(6):552–7.
13. Palmer S, Torgerson DJ. Definitions of efficiency. Br Med J. 1999;318(7191):1136.
14. Coelli TJ, Rao DSP, O'Donnell CJ, Battese GE. An introduction to efficiency and productivity analysis. 2nd ed. New York: the written permission of the publisher; 2005.
15. Bitran R. Technical and economic efficiency in the production of health services. Phase 1: review of concepts and literature and preliminary field work design. 1992.
16. Rosko MD. Measuring technical efficiency in health care organizations. J Med Syst. 1990;14(5):307–22.
17. O'Neill L, Rauner M, Heidenberger K, Kraus M. A cross-national comparison and taxonomy of DEA-based hospital efficiency studies. Socio Econ Plan Sci. 2008;42(3):158–89.
18. Rosko MD, Mutter RL. Review: Stochastic frontier analysis of hospital inefficiency—a review of empirical issues and an assessment of robustness. Med Care Res Rev. 2008;65(2):131–66. https://doi.org/10.1177/1077558707307580.
19. Emrouznejad A, Parker BR, Tavares G. Evaluation of research in efficiency and productivity: a survey and analysis of the first 30 years of scholarly literature in DEA. Socio Econ Plan Sci. 2008;42(3):151–7.
20. Afzali HH, Moss JR, Mahmood MA. A conceptual framework for selecting the most appropriate variables for measuring hospital efficiency with a focus on Iranian public hospitals. Health Serv Manag Res. 2009;22(2):81–91. https://doi.org/10.1258/hsmr.2008.008020.
21. Kiadaliri AA, Jafari M, Gerdtham UG. Frontier-based techniques in measuring hospital efficiency in Iran: a systematic review and meta-regression analysis. BMC Health Serv Res. 2013;13:312. https://doi.org/10.1186/1472-6963-13-312.
22. Dudley L, Garner P. Strategies for integrating primary health services in low- and middle-income countries at the point of delivery. Cochrane Database of Systematic Reviews. 2011;7. https://doi.org/10.1002/14651858.CD003318.pub3.
23. World Bank. Country and Lending Groups|Data. The World Bank. 2015. http://data.worldbank.org/about/country-and-lending-groups. Accessed 08 June 2015.
24. Popay J, Roberts H, Sowden A, Petticrew M, Arai L, Rodgers M, et al. Guidance on the conduct of narrative synthesis in systematic reviews. ESRC Methods Programme. 2006;15(1):047–71.
25. Hadji B, Meyer R, Melikeche S, Escalon S, Degoulet P. Assessing the relationships between hospital resources and activities: a systematic review. J Med Syst. 2014;38(10):127. https://doi.org/10.1007/s10916-014-0127-9.
26. Lasso HP. Evaluating hospital performance through simultaneous application of several indicators. Bull Pan Am Health Organ. 1986;20(4):341–57.
27. Jacobs R, Smith PC, Street A. Measuring efficiency in health care: analytic techniques and health policy. New York: Cambridge University Press; 2006.
28. Berman P, Brotowasisto MN, Sakai S, Gani A. The costs of public primary health care services in rural Indonesia. Bull World Health Organ. 1989;67(6):685–94.
29. Somanathan A, Hanson K, Dorabawila T, Perera B. Operating Efficiency in Public Sector Health Facilities in Sri Lanka: Measurement and Institutional Determinants of Performance. Partnerships for Health Reform Project, Abt Associates; 2000.
30. Schmidt SS. The measurement of productive efficiency and productivity growth. Oxford: Oxford University Press; 2008.
31. Mutter RL, Greene WH, Spector W, Rosko MD, Mukamel DB. Investigating the impact of endogeneity on inefficiency estimates in the application of stochastic frontier analysis to nursing homes. J Prod Anal. 2013;39(2):101–10. https://doi.org/10.1007/s11123-012-0277-z.
32. Morris S, Devlin N, Parkin D. Economic analysis in health care. New York: Wiley; 2007.
33. Worthington AC. Frontier efficiency measurement in health care: a review of empirical techniques and selected applications. Med Care Res Rev. 2004;61(2):135–70. https://doi.org/10.1177/1077558704263796.
34. Hollingsworth B. The measurement of efficiency and productivity of health care delivery. Health Econ. 2008;17(10):1107–28. https://doi.org/10.1002/hec.1391.
35. Hussey PS, de Vries H, Romley J, Wang MC, Chen SS, Shekelle PG, et al. A systematic review of health care efficiency measures. Health Serv Res. 2009;44(3):784–805. https://doi.org/10.1111/j.1475-6773.2008.00942.x.
36. Mills A, Hongoro C, Broomberg J. Improving the efficiency of district hospitals: is contracting an option? Trop Med Int Health. 1997;2(2):116–26.
37. Soucat A, Levy-Bruhl D, De Bethune X, Gbedonou P, Lamarque JP, Bangoura O, et al. Affordability, cost-effectiveness and efficiency of primary health care: the Bamako Initiative experience in Benin and Guinea. Int J Health Plan Manag. 1997;12(SUPPL.1):S81–108. https://doi.org/10.1002/(SICI)1099-1751(199706)12:1+3.0.CO;2-5.
38. Levin A, Dmytraczenko T, McEuen M, Ssengooba F, Mangani R, Van Dyck G. Costs of maternal health care services in three anglophone African countries. Int J Health Plan Manag. 2003;18(1):3–22.
39. Obure CD, Jacobs R, Guinness L, Mayhew S, Initiative I, Vassall A. Does integration of HIV and sexual and reproductive health services improve technical efficiency in Kenya and Swaziland? An application of a two-stage semi parametric approach incorporating quality measures. Soc Sci Med. 2016;151:147–56. https://doi.org/10.1016/j.socscimed.2016.01.013.
40. Brenzel L, Young D, Walker DG. Costs and financing of routine immunization: approach and selected findings of a multi-country study (EPIC). Vaccine. 2015;33(S1):A13–20. https://doi.org/10.1016/j.vaccine.2014.12.066.

41. Masoompour SM, Petramfar P, Farhadi P, Mahdaviazad H. Five-year trend analysis of capacity utilization measures in a teaching hospital 2008-2012. Shiraz E-Med J. 2015;16(2):e21176. https://doi.org/10.17795/semj21176.
42. Keith J, Prior D. Scale and scope economies in Mexican private medical units. Salud Publica Mex. 2014;56:348–54.
43. Arocena P, Garcia-Prado A. Accounting for quality in the measurement of hospital performance: evidence from Costa Rica. Health Econ. 2007;16(7):667–85.
44. Jian W, Huang Y, Hu M, Zhang X. Performance evaluation of inpatient service in Beijing: a horizontal comparison with risk adjustment based on Diagnosis Related Groups. BMC Health Serv Res. 2009;9:72. https://doi.org/10.1186/1472-6963-9-72.
45. de Castro Lobo MS, Ozcan YA, da Silva ACM, Lins MPE, Fiszman R. Financing reform and productivity change in Brazilian teaching hospitals: Malmquist approach. Central Eur J Oper Res. 2010;18(2):141–52. http://link.springer.com/journal/volumesandissues/10100.
46. Rajasulochana S, Dash U. Technical efficiency of comprehensive emergency obstetric and new-born care centres in Tamil Nadu. J Health Manag. 2012;14(2):151–60.
47. Sahin I, Ozcan YA. Public sector hospital efficiency for provincial markets in Turkey. J Med Syst. 2000;24(6):307–20.
48. Yang J, Zeng W. The trade-offs between efficiency and quality in the hospital production: Some evidence from Shenzhen, China. China Econ Rev. 2014;31(Supplement C):166–84. https://doi.org/10.1016/j.chieco.2014.09.005.
49. Ketabi S. Efficiency measurement of cardiac care units of Isfahan hospitals in Iran. J Med Syst. 2011;35(2):143–50. https://doi.org/10.1007/s10916-009-9351-0.
50. Razzaq S, Chaudhary AA, Khan AR. Efficiency analysis of basic health units: a comparison of developed and deprived regions in Azad Jammu and Kashmir. Iran J Public Health. 2013;42(11):1223–31.
51. Zaim S, Bayyurt N, Turkyilmaz A, Solakoglu N, Zaim H. Measuring and evaluating efficiency of hospitals through total quality management: a multi-criteria data envelopment analysis model. J Transnatl Manag. 2007;12(4):77–97. http://www.tandfonline.com/loi/wtnm20.
52. Gai RY, Zhou CC, Xu LZ, Zhu M, Wang XZ, Li SX, et al. Health resource allocation and productive efficiency of Chinese county hospitals: data from 1993 to 2005. Biosci Trends. 2010;4(5):218–24.
53. Aboagye AQ, Degboe AN. Cost analysis and efficiency of sub-district health facilities in two districts in Ghana. Int J Health Plan Manag. 2011;26(2):173–90. https://doi.org/10.1002/hpm.1047.
54. Alaghemandan H, Yarmohammadian MH, Khorasani E, Rezaee S. Efficiency improvement of dentistry clinics: introducing an intervening package for dentistry clinics, Isfahan, Iran. Int J Prev Med. 2014;5(2):176–84.
55. Rattanachotphanit T, Limwattananon C, Limwattananon S, Johns JR, Schommer JC, Brown LM. Assessing the efficiency of hospital pharmacy services in Thai Public District Hospitals. Southeast Asian J Trop Med Public Health. 2008;39(4):753–65.
56. Guerra M, de Souza AA, Moreira DR. Performance analysis: a study using data envelopment analysis in 26 Brazilian hospitals. J Health Care Finance. 2012;38(4):19–35.
57. Barnum HN, Kutzin J. Public hospitals in developing countries: resource use, cost, financing. Baltimore: Johns Hopkins University Press; 1993.
58. Conteh L, Walker D. Cost and unit cost calculations using step-down accounting. Health Policy Plan. 2004;19(2):127–35.
59. Hollingsworth B. Non-parametric and parametric applications measuring efficiency in health care. Health Care Manag Sci. 2003;6(4):203–18. https://doi.org/10.1023/A:1026255523228.
60. Cylus J, Papanicolas I, Smith PC. Health system efficiency: how to make measurement matter for policy and management. European Observatory on Health Systems and Policies; 2016.
61. Kirigia JM, Emrouznejad A, Cassoma B, Asbu EZ, Barry S. A performance assessment method for hospitals: the case of municipal hospitals in Angola. J Med Syst. 2008;32(6):509–19.
62. Marschall P, Flessa S. Efficiency of primary care in rural Burkina Faso. A two-stage DEA analysis. Health Econ Rev. 2011;1(1):1–15. https://doi.org/10.1186/2191-1991-1-5.
63. Varabyova Y, Schreyogg J. International comparisons of the technical efficiency of the hospital sector: panel data analysis of OECD countries using parametric and non-parametric approaches. Health Policy. 2013;112(1–2):70–9.
64. Chowdhury H, Zelenyuk V, Laporte A, Wodchis WP. Analysis of productivity, efficiency and technological changes in hospital services in Ontario: how does case-mix matter? Int J Prod Econ. 2014;150:74–82. https://doi.org/10.1016/j.ijpe.2013.12.003.
65. Ding DX. The effect of experience, ownership and focus on productive efficiency: a longitudinal study of U.S. hospitals. J Oper Manag. 2014;32(1–2):1–14. https://doi.org/10.1016/j.jom.2013.10.002.
66. van Ineveld M, van Oostrum J, Vermeulen R, Steenhoek A, van de Klundert J. Productivity and quality of Dutch hospitals during system reform. Health Care Manag Sci. 2015. https://doi.org/10.1007/s10729-015-9321-7.
67. Matranga D, Sapienzab F. Congestion analysis to evaluate the efficiency and appropriateness of hospitals in Sicily. Health Policy. 2015;119(3):324–32.
68. Ramanathan TV, Chandra KS, Thupeng WM. A comparison of the technical efficiencies of health districts and hospitals in Botswana. Dev South Afr. 2003;20(2):307–20.
69. Omondi Aduda DS, Ouma C, Onyango R, Onyango M, Bertrand J. Voluntary medical male circumcision scale-up in nyanza, kenya: evaluating technical efficiency and productivity of service delivery. PLOS ONE. 2015;10(2):e0118152. https://doi.org/10.1371/journal.pone.0118152.
70. Wong R, Bradley EH. Developing patient registration and medical records management system in Ethiopia. Int J Qual Health Care. 2009;21(4):253–8. https://doi.org/10.1093/intqhc/mzp026.
71. Hoff A. Second stage DEA: comparison of approaches for modelling the DEA score. Eur J Oper Res. 2007;181(1):425–35.
72. McDonald J. Using least squares and tobit in second stage DEA efficiency analyses. Eur J Oper Res. 2009;197(2):792–8.
73. Simar L, Wilson PW. Two-stage DEA: caveat emptor. J Prod Anal. 2011;36(2):205. https://doi.org/10.1007/s11123-011-0230-6.
74. Parmeter CF, Kumbhakar SC. Efficiency analysis: a primer on recent advances. Found Trends® Econ. 2014;7(3–4):191–385.
75. Lekprichakul T. Efficiency measurement of 89 public provincial hospitals in Thailand: parametric and non-parametric estimation methods [Ph.D.]. Ann Arbor: University of Hawai'i; 2001.
76. Atilgan E. The technical efficiency of hospital inpatient care services: an application for Turkish Public Hospitals. Isletme ve Ekonomi Arastirmalari Dergisi Bus Econ Res J. 2016;7:203–14. http://www.berjournal.com.
77. Chaabouni S, Abednnadher C. Cost efficiency of Tunisian public hospitals: a Bayesian comparison of random and fixed frontier models. J Knowl Econ. 2016;7:771–81. https://link.springer.com/journal/volumesAndIssues/13132.
78. Wei Y, Yu H, Geng J, Wu B, Guo Z, He L, et al. Hospital efficiency and utilization of high-technology medical equipment: a panel data analysis. Health Policy Technol. 2018.
79. Walker D. Efficiency of primary health care in low and middle-income countries: case studies from Bangladesh. London School of Hygiene & Tropical Medicine; 2006.

80. Novignon J, Nonvignon J. Improving primary health care facility performance in Ghana: efficiency analysis and fiscal space implications. BMC Health Serv Res. 2017;17(1):399. https://doi.org/10.1186/s12913-017-2347-4.
81. Lee K, Chun K, Lee J. Reforming the hospital service structure to improve efficiency: urban hospital specialization. Health Policy. 2008;87(1):41–9.
82. Shreay S, Ma M, McCluskey J, Mittelhammer RC, Gitlin M, Stephens JM. Efficiency of U.S. dialysis centers: an updated examination of facility characteristics that influence production of dialysis treatments. Health Serv Res. 2014;49(3):838–57. https://doi.org/10.1111/1475-6773.12127.
83. Herrera CA, Rada G, Kuhn-Barrientos L, Barrios X. Does ownership matter? An overview of systematic reviews of the performance of private for-profit, private not-for-profit and public healthcare providers. PLoS One 2014;9(12). https://doi.org/10.1371/journal.pone.0093456.
84. Jehu-Appiah C, Sekidde S, Adjuik M, Akazili J, Almeida SD, Nyonator F, et al. Ownership and technical efficiency of hospitals: evidence from Ghana using data envelopment analysis. Cost Eff Resource Allocation. 2014;12(1):9. https://doi.org/10.1186/1478-7547-12-9.
85. Hatam N, Moslehi S, Askarian M, Shokrpour N, Keshtkaran A, Abbasi M. The efficiency of general public hospitals in Fars Province, southern Iran. Iran Red Crescent Med J. 2010;12(2):138–44.
86. Gok SM, Sezen B. Capacity inefficiencies of teaching and non-teaching hospitals. Serv Ind J. 2012;32(14):2307–28. https://doi.org/10.1080/02642069.2011.582495.
87. Sepehrdust H, Rajabi E. Technical efficiency measurement of social security hospitals. J School Public Health Inst Public Health Res. 2013;10(3):Pe91–Pe8.
88. Masiye F. Investigating health system performance: an application of data envelopment analysis to Zambian hospitals. BMC Health Serv Res. 2007;7:58.
89. Mitropoulos P, Mitropoulos I, Sissouras A. Managing for efficiency in health care: the case of Greek public hospitals. Eur J Health Econ. 2013;14(6):929–38.
90. Asmild M, Hollingsworth B, Birch S. The scale of hospital production in different settings: one size does not fit all. J Prod Anal. 2013;40(2):197–206.
91. Heimeshoff M, Schreyogg J, Kwietniewski L. Cost and technical efficiency of physician practices: a stochastic frontier approach using panel data. Health Care Manag Sci. 2014;17(2):150–61.
92. Alhassan RK, Nketiah-Amponsah E, Akazili J, Spieker N, Arhinful DK, Rinke de Wit TF. Efficiency of private and public primary health facilities accredited by the National Health Insurance Authority in Ghana. Cost Eff Resource Allocation. 2015;13(1) (no pagination)(23). http://dx.doi.org/10.1186/s12962-015-0050-z.
93. Gok MS, Sezen B. Analyzing the ambiguous relationship between efficiency, quality and patient satisfaction in healthcare services: the case of public hospitals in Turkey. Health Policy (Amsterdam, Netherlands). 2013;111(3):290–300.
94. Akazili J, Adjuik M, Jehu-Appiah C, Zere E. Using data envelopment analysis to measure the extent of technical efficiency of public health centres in Ghana. BMC Int Health Hum Rights. 2008;8(1):11. https://doi.org/10.1186/1472-698x-8-11.
95. Cheng Z, Tao H, Cai M, Lin H, Lin X, Shu Q et al. Technical efficiency and productivity of Chinese county hospitals: an exploratory study in Henan province, China. BMJ Open. 2015;5(9). http://dx.doi.org/10.1136/bmjopen-2014-007267.
96. Lofgren J, Mulowooza J, Nordin P, Wladis A, Forsberg BC. Cost of surgery in a low-income setting in Eastern Uganda. Surgery (United States). 2015;157(6):983–91. https://doi.org/10.1016/j.surg.2015.01.026.
97. Nabukeera M, Boerhannoeddin A, Raja Noriza RA. An evaluation of health centers and hospital efficiency in Kampala capital city authority Uganda; Using pabon lasso technique. J Health Transl Med. 2015;18(1):12–7.
98. Jat TR, San Sebastian M. Technical efficiency of public district hospitals in Madhya Pradesh, India: a data envelopment analysis. Glob Health Action. 2013;6(21742).
99. Applanaidu S-D, Samsudin S, Ali J, Dash U, Chik AR. Technical and scale efficiency of public district hospitals in Kedah, Malaysia: a data envelopment analysis (DEA). J Health Manag. 2014;16(3):327–35. https://doi.org/10.1177/0972063414539595.
100. Ajlouni M, Zyoud A, Jaber B, Shaheen H, Al-Natour M, Anshasi RJ. The relative efficiency of Jordanian public hospitals using data envelopment analysis and Pabon Lasso Diagram. Glob J Bus Res. 2013;7(2):59–72.
101. Audibert M, Mathonnat J, Pelissier A, Huang XX, Ma A. Health insurance reform and efficiency of township hospitals in rural China: an analysis from survey data. China Econ Rev. 2013;27:326–38.
102. Bowser DM, Figueroa R, Natiq L, Okunogbe A. A preliminary assessment of financial stability, efficiency, health systems and health outcomes using performance-based contracts in Belize. Glob Public Health. 2013;8(9):1063–74. https://doi.org/10.1080/17441692.2013.829511.
103. Kirigia JM, Asbu EZ. Technical and scale efficiency of public community hospitals in Eritrea: an exploratory study. Health Econ Rev. 2013;3(6):1–16.
104. Asbu E, Walker O, Kirigia J, Zawaira F, Magombo F, Zimpita P. Assessing the efficiency of hospitals in Malawi: an application of the Pabón Lasso technique. Afr Health Monitor. 2012;14(1):28–33.
105. Osei D, d'Almeida S, George MO, Kirigia JM, Mensah AO, Kainyu LH. Technical efficiency of public district hospitals and health centres in Ghana: a pilot study. Cost Eff Resource Allocation. 2005;3.
106. Xu G-C, Zheng J, Zhou Z-J, Zhou C-K, Zhao Y. Comparative study of three commonly used methods for hospital efficiency analysis in Beijing tertiary public hospitals, China. Chin Med J. 2015;128(23):3185–90. https://doi.org/10.4103/0366-6999.170279.