ORIGINAL ARTICLE

Technical efficiency of health production in Africa: A stochastic frontier analysis

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Received: March 21, 2022 **Accepted:** June 13, 2022 **Online Published:** June 22, 2022
DOI: 10.5430/ijh.v8n2p1 **URL:** https://doi.org/10.5430/ijh.v8n2p1

ABSTRACT

Background: Inefficiency is widespread in health systems all over the world. The World Health Organization (WHO) estimates that 20%-40% of the global health spending is wasted. In African countries, inefficiency of this magnitude will seriously hamper progress towards achieving universal health coverage and other health system goals. It is thus, significant to assess the efficiency of health systems over time in order to set the ground for identifying the contextual factors leading to inefficiency and design appropriate efficiency-enhancing measures.
Methods: Using panel data for the years 2000, 2005, 2010, and 2015, the study employs a time-variant stochastic frontier production function to assess efficiency. The input measure used is current expenditure per capita in purchasing power parity (Int$) terms and the measure of output is health-adjusted life expectancy (HALE). Moreover, mean years of schooling, GDP per capita in Int$, and out-of-pocket payment as a share of current expenditure on health were used as technical inefficiency effect variables. Data were analyzed using Frontier Version 4.1.
Results: The mean technical efficiency scores were 79.3% in 2000, 81% in 2005, 85.6% in 2010 and 88.3% in 2015. Over the four periods of time, Cabo Verde registered the highest technical efficiency scores, while Eswatini and Sierra Leone had the lowest. The minimum technical efficiency scores were 58.7% (in 2000), 59.1% (2005), 67.4% (2010) and 71.8% (2015). These indicate that despite improvements, there is a significant degree of technical inefficiency. Most of the countries among those in the bottom 10% efficiency scores are countries in Southern Africa, which in 2015 had a very high prevalence of HIV among adults, compared to the top 10%, which had prevalence rates of less than 0.1%.

The mean efficiency score increased progressively over time – a nine percentage point increase between 2000 and 2015. The elasticity of current health expenditure was positive (0.06) and statistically significant. All the technical inefficiency variables had no statistically significant effect.
Conclusions: Over the period of time covered in this study, there was some improvement in the average technical efficiency scores. However, there was also marked inefficiency in many countries, which is likely to hamper their progress towards universal health coverage and other health system goals. In a context where health spending is too low to provide needed services, it is imperative to address the causes of technical inefficiency and produce more health for the money. Furthermore, low-performing health systems should learn from their relatively high-performing peers.

Key Words: Technical efficiency, Stochastic frontier analysis, Health systems, Africa

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1. INTRODUCTION

Inefficiency is widespread in health systems all over the world. A conservative estimate indicates that 20%-40% of global total health spending is wasted.[1] The situation in Africa is no exception to this.[2] In the presence of such a widespread inefficiency, the pursuit of the health targets of Sustainable Development Goal 3, which aims to ensure healthy lives and promote wellbeing for all at all ages including universal health coverage[3] becomes elusive and challenging, especially for low- and middle-income countries in Africa that have lower levels of health spending.[4] In this vein, the 2018 Astana Declaration on Primary Health Care states that waste in health care spending cannot be tolerated if universal health coverage is to be achieved.[5]

The average healthy life expectancy at birth in 2016 in the African Region of the WHO was 53.8 years - an increase of about 13 years from the level in 2012, which was 41 years. On the other hand, on average, healthy life expectancy increased from 58 years to 63.3 years globally.[6,7]

Countries of the African continent belong to two WHO regions: the African region and the Eastern Mediterranean region. In 2015, the Universal Health Coverage index of service coverage was an average of 43 in the African region of the WHO, and 53 in the Eastern Mediterranean region. This is significantly lower than the global average of 64 for the same year.[8]

Cross-country assessment of the efficiency of health systems in producing health is important for benchmarking purposes and for countries to emulate best practice health system policies and organizational forms.[9]

Efficiency has two components, technical and allocative. Technical efficiency, which is the focus of this paper, refers to avoiding wastage either through augmenting outputs or conserving inputs.[10] Output-oriented technical efficiency refers to producing maximum output that is feasible with a given technology and inputs; on the other hand, input-oriented technical efficiency is about minimizing input usage given a level of output and production technology.

The objective of this study is to assess the technical efficiency of health systems of countries in continental Africa and observe changes over time.

2. METHOD

2.1 Efficiency measurement: Overview

Analysis of country health systems technical efficiency is concerned with measuring performance in converting health system inputs or factors of production into valued outputs such as improved longevity and reduced morbidity and mortality.

The measurement of technical efficiency entails two steps that include fitting a production frontier and calculating deviations of individual decision-making units (DMUs) from the frontier. Two main approaches are used in estimating the production frontier.[11,12] These include data envelopment analysis (DEA), which is a non-parametric mathematical programming model and stochastic frontier analysis (SFA), which is a parametric econometric approach. This study employs the later method (SFA), which is discussed in the following section.

The stochastic frontier production function model was independently proposed by Aigner et al. (1977)[13] and Meeusen and van den Broeck (1977)[14] as follows:

$$lnq_i = x_i^{'}\beta + v_i - u_i \qquad i = 1, \ldots, I \tag{1}$$

Where q_i represents the output of the i-th DMU (country in this case); x_i is a K $\times$ 1 vector of the logarithms of inputs (factors of production); v_i is a symmetric random error accounting for statistical noise as in the classical linear regression model; u_i is a non-negative random variable associated with technical inefficiency.

The value of technical efficiency (TE), which is bounded by zero and one is given by the ratio of the observed output (q_i) of the i^{th} decision-making unit to the potential maximum output (${q_i}^*$) produced by a fully efficient DMU using the same input vector X_i:[15]

$$TE_i = \frac{q_i}{q_i^*} = \frac{exp(X_i^{'}\beta + v_i - u_i)}{exp(X_i^{'}\beta + v_i)} = exp(-u_i) \tag{2}$$

Equation (1) is used for cross-section data. For panel data, the model is written in the general form by adding a subscript "t" as follows:

$$lnq_{it} = X_{it}^{'}\beta + v_{it} - u_{it} \tag{3}$$

The technical efficiency effects model of Batesse and Coelli (1995) in Equation 3 can be expressed as:[16]

$$u_{it} = z_{it}\delta + w_{it} \tag{4}$$

The random variable w_{it} is defined by the truncation of the normal distribution with a zero mean and variance δ^2; z_{it} is a vector of explanatory variables associated with technical inefficiency over time, and δ is a vector of parameters to be estimated and represents the effect of the explanatory variable z on the inefficiency term. A positive coefficient implies that the corresponding variable contributes to technical inefficiency, while a negative one indicates that the variable reduces technical inefficiency. Battese and Coelli (1995) propose the method of maximum likelihood to simultaneously estimate the parameters of the stochastic frontier and the technical inefficiency effects model.[16]

Variation in the socio-economic characteristics of countries produces unmeasured heterogeneity in the data, which leads to a failure to distinguish between cross-country heterogeneity and inefficiency.[17] To account for heterogeneity, a stochastic frontier analysis using panel data on national health care systems used in the World Health Report 2000, considered additional covariates in the dataset including per capita income, income distribution, government effectiveness, and the allocation of health expenditure between the public and private sectors.[17] In our study, a few covariates described in a forthcoming section are included in the technical efficiency effects model to account for heterogeneity.

Panel datasets enable the assessment of changes in technical efficiency and the underlying technology over time and provide consistent predictions of technical efficiencies as they contain more observations compared to cross-sectional data sets.[16]

The inefficiency effects in panel data stochastic frontier models are classified according to whether they are time-invariant or time-varying.[16] Time-invariant models assume constancy of organizational efficiency over time. This does not have an appeal in circumstances where data are observed over a protracted period or when there are regulatory initiatives that are likely to change the temporal pattern of efficiency.[18]

2.2 Decision-making units

The study covers the entire population of countries of the African continent (N = 54).

2.3 Inputs and outputs

Following previous studies on health systems efficiency assessment, per capita current expenditure on health (CHE) at purchasing power parity (PPP) was used as an aggregate measure of inputs.[19–21] The current expenditure on health per capita represents the expenditure on all factors of production in the health system excluding capital formation.

The measure of output used is health-adjusted life expectancy (HALE). HALE, which is also referred to as "healthy life expectancy," is the number of years that a person can expect to live in full health considering years lived in less than full health due to disease and/or injury.[22,23] It is believed that HALE is the best available measure to reflect the health status of a given population.[24]

The input and output variables are used in the model in their logarithmic form.

2.4 Technical inefficiency effect variables

The variables included in the inefficiency component are:

- Mean years of schooling
- Gross domestic product (GDP) per capita in Purchasing Power Parity (Int$)
- Out-of-pocket payment as a percentage share of total current health expenditure

2.5 Data and source

Panel data on the input-output variables and out-of-pocket payment covering the years 2000, 2005, 2010, and 2015 were extracted from the Global Health Observatory database. Panel data on mean years of schooling and GDP per capita was obtained from relevant Human Development Reports.[25]

2.6 Data analysis

FRONTIER Version 4.1 – a computer program for stochastic production and cost function estimation was used in estimating the production function and technical inefficiency effect model.[26] Furthermore, MS Excel was used for descriptive analysis.

3. Results

3.1 General description

Out of the 54 countries in the continent, Djibouti, Libya, Somalia, and South Sudan were excluded due to paucity of the required data. Thus, the analysis is based on panel data from 50 countries.

Descriptive statistics of the input-output variables and those affecting technical inefficiency is presented in Table 1.

Table 1 shows that average HALE registered an increase of about 8 years over the period 2000-2015. The gap in HALE between the country with the highest value and the one with the lowest value decreased from 28 years in 2000 to 21 years in 2015. CHE per capita is observed to demonstrate a significant gap between the country with the highest spending and the one with the lowest. The highest CHE per capita in 2015 was Int$ 1,214 (Seychelles), while the lowest was Int$ 35 (Democratic Republic of Congo). There is a heavy reliance on out-of-pocket payments for health care in a significant number of countries on the continent.

Table 1. Descriptive statistics

Variable	Mean	Std dev	Min	Max
HALE* 2000 (years)	47.3	7.0	35.6	64.1
HALE 2005	49.3	6.7	38.5	64.4
HALE 2010	52.7	5.6	42.8	65.1
HALE 2015	55.1	5.2	44.6	66.0
CHEPC** 2000 (Int$)	143	152	7	674
CHEPC 2005 (Int$)	186	178	23	737
CHEPC 2010 (Int$)	237	245	25	946
CHEPC 2015 (Int$)	306	336	35	1,214
Mean year of schooling 2000	3.9	1.8	1.1	8.8
Mean year of schooling 2005	4.4	1.9	1.3	8.9
Mean year of schooling 2010	4.8	2.1	1.4	10.2
Mean year of schooling 2015	5.2	2.1	1.4	10.3
GDP per capita 2000 (Int$)	3,074	3,295	447	14,271
GDP per capita 2005 (Int$)	4,065	5,039	519	27,963
GDP per capita 2010 (Int$)	4,977	6,011	634	32,966
GDP per capita 2015 (Int$)	5,520	5,772	787	24,067
OOP*** 2000 (% of CHE)	45.9	19.6	7.4	82.1
OOP 2005 (% of CHE)	43.2	19.8	6.9	80.2
OOP 2010 (% of CHE)	40.2	19.9	5.0	78.7
OOP 2015 (% of CHE)	37.0	19.4	3.6	77.1

Note. * Health-adjusted life expectancy; ** Current health expenditure per capita; *** Out-of-pocket payment

3.2 Stochastic frontier model outputs

The maximum likelihood estimates of the technical efficiency effects model are presented in Table 2.

Table 2. Model estimation results

Variable	Parameter	Coefficient
Constant	β_0	3.8005*
Current health expenditure per capita Int$	β_1	0.0635*
Constant	δ_0	0.53868*
Mean years of schooling	δ_1	-0.0151
GDP per capita in Int$	δ_2	-0.0469
Share of out-of-pocket payment	δ_3	-0.0003
Sigma squared	σ^2	-0.0217
Gamma	γ	0.9999*
Log-likelihood		166.7

Note. * $p < .05$

The elasticity of current health expenditure per capita demonstrates the right sign and is statistically significant. A 1% change in CHE per capita in Int$ leads to a 0.06% increase in HALE evaluated at the average values of the variables. The coefficients of the inefficiency effect variables are not statistically significant. However, the signs of the variables, mean years of schooling and GDP per capita have negative signs implying that they reduce technical inefficiency. The share of out-of-pocket payment has a negative sign, which is counter to expectation. The value of γ, which is 99%, is high and indicates that much of the variation in the composite error term is due to the inefficiency component.

3.3 Technical efficiency scores

The average efficiency score over the four-time periods was 83.5%. Average technical efficiency increased from 79.3% in 2000 to 88.3% in 2015 – a 9 percentage point increase. Overall, technical efficiency improved progressively as can be seen in Figure 1.

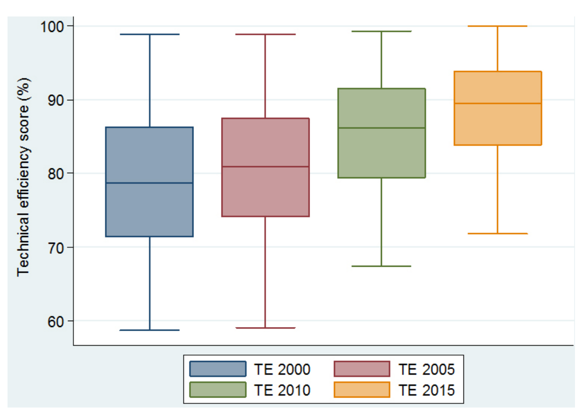

Figure 1. Boxplot of efficiency scores

It can be seen from the figure that the median efficiency score has increased from below 80% to close to 90%, which is a significant improvement.

The means and range of the technical efficiency scores are provided in Table 3.

Table 3. Means and range of technical efficiency scores 2000-2015

Variable	Mean	Min (country)	Max (country)
TE* 2000 (%)	79.3	58.7 (Sierra Leone)	98.9 (Cabo Verde)
TE 2005 (%)	81.0	59.1 (Eswatini)	98.9 (Cabo Verde)
TE 2010 (%)	85.6	67.4 (Eswatini)	99.3 (Cabo Verde)
TE 2015 (%)	88.3	71.8 (Sierra Leone)	99.9 (Cabo Verde)

Note. * Technical efficiency

Over the four periods of time, the country with the highest efficiency score was Cabo Verde. Sierra Leone and Eswatini registered the lowest efficiency scores.

Six countries (12%) registered a marginal drop in technical efficiency. In 16 countries (32%), an increase of more than 10 percentage points was witnessed between 2000 and 2015. Eritrea registered the highest increase of 31.5 percentage points. This saw an increase in technical efficiency from 68.2% in 2000 to 99.7% in 2015. The list of top and bottom 10% of countries in terms of their technical efficiency is presented in Table 4.

Cabo Verde and Morocco were consistently among the top 10% performers over the four periods of time. On the other hand, Eswatini and Sierra Leone were consistently among the lowest performers.

The detailed efficiency scores are depicted in Table 5.

In 2015, Sierra Leone had the lowest efficiency score of 71.8%. This implies the existence of a potential to raise the output (HALE) by close to 30% with the amount of resources that are currently committed.

Table 4. Top and bottom 10% of countries according to level technical efficiency scores 2000-2015

Top 10%				Bottom 10%			
2000	**2005**	**2010**	**2015**	**2000**	**2005**	**2010**	**2015**
Algeria	Algeria	Algeria	Cabo Verde	Botswana	Botswana	Eswatini	Côte d'Ivoire
Cabo Verde	Cabo Verde	Cabo Verde	Eritrea	Eswatini	Eswatini	Lesotho	Eswatini
Mauritius	Mauritius	Eritrea	Ethiopia	Sierra Leone	Lesotho	Nigeria	Lesotho
Morocco	Morocco	Morocco	Morocco	Zambia	Sierra Leone	Sierra Leone	Nigeria
Tunisia	Tunisia	Tunisia	Rwanda	Zimbabwe	Zimbabwe	South Africa	Sierra Leone

4. DISCUSSION AND RECOMMENDATIONS

In line with other studies,[2, 19] the findings indicate that there is a significant scope to improve health outcomes. In 2015, in the lowest-performing country, HALE could potentially be improved by about 30%. Sun et al.[19] using data envelopment analysis found that the average efficiency score in the African region of the WHO was 67% in 2011. In contrast, our findings indicate that the mean efficiency score was 86%. This may partly be attributed to the fact that our study includes countries in the northern part of Africa, which are included in the Eastern Mediterranean region of the WHO and which, in our study, are also found to be among those with high-efficiency scores. Kirigia et al.[2] in their study of 54 continental African countries using data envelopment analysis found average constant returns to scale technical efficiency of 53.5%. Despite the differences in the levels of technical efficiency among different studies, what is clear is that there is a significant scope to improve efficiency.

In a region where health spending is low by global standards and relative to need, technical inefficiency of this magnitude is likely to slow down progress towards universal health coverage and other health system goals. Thus, besides raising more money, attention should be paid to producing more health for the money.

The findings indicate that the majority of the countries in the bottom 10% of technical efficiency scores are in the Southern Africa region. Although this requires in-depth probing, those countries had a high prevalence of HIV among the population in the age group 15-49 years, which may have a significant negative impact on HALE. In 2015, the HIV prevalence rate was 22.1% in Botswana, 28.9% in Eswatini, 11.8% in Zambia, 14% in Zimbabwe, 24.1% in Lesotho, and 19.2% in South Africa. In contrast, among the top 10% high performing countries, the HIV prevalence was very low. Algeria, Morocco, Egypt, and Tunisia had a prevalence rate of less than 0.1%. Cabo Verde, Eritrea and Mauritius respectively had prevalence rates of 0.6%, 0.7% and 1.7%.[27]

One of the objectives of efficiency assessment is learning from peers that have relatively higher performance levels. Under-performing health systems should therefore endeavor to emulate and adapt the processes and functions of the consistently high-performing countries such as Cabo Verde and others as presented in Table 5.

Table 5. Efficiency scores (%) from stochastic frontier model

Country	TE 2000	TE 2005	TE 2010	TE 2015
Algeria	94.9	96.8	95.6	94.0
Angola	71.4	76.6	83.6	88.8
Benin	83.7	85.6	88.0	89.6
Botswana	64.6	68.1	77.5	82.3
Burkina Faso	77.9	80.0	84.0	87.5
Burundi	79.6	82.0	85.1	91.2
Cabo Verde	98.9	98.9	99.3	100.0
Cameroon	72.5	75.7	79.4	81.3
Central African Republic	71.1	71.0	76.7	78.7
Chad	72.5	72.5	76.5	77.9
Comoros	85.7	87.3	90.2	92.8
Congo	80.0	83.3	90.2	89.5
Côte d’Ivoire	70.8	72.5	74.9	77.5
Democratic Republic of the Congo	87.6	86.3	90.9	93.0
Egypt	91.9	91.8	91.5	90.8
Equatorial Guinea	74.6	74.1	76.3	78.0
Eritrea	68.2	89.8	96.8	99.7
Eswatini	65.8	59.1	67.4	74.4
Ethiopia	82.0	88.2	93.3	97.8
Gabon	78.8	79.5	84.1	88.0
Gambia	86.3	87.4	88.1	94.2
Ghana	83.7	83.0	86.9	89.8
Guinea	78.2	81.0	87.5	84.8
Guinea-Bissau	76.0	77.9	81.9	83.9
Kenya	79.2	80.8	90.3	94.5
Lesotho	75.0	67.4	73.3	72.3
Liberia	79.2	81.4	86.6	88.0
Madagascar	88.3	91.1	95.1	97.7
Malawi	71.2	76.4	85.8	92.1
Mali	71.0	76.7	81.6	84.7
Mauritania	87.4	87.5	90.4	90.1
Mauritius	98.1	97.1	95.0	93.6
Morocco	95.9	97.2	97.4	99.3
Mozambique	78.6	77.8	83.5	88.0
Namibia	74.0	69.7	78.1	79.9
Niger	74.4	79.0	85.6	88.8
Nigeria	70.5	70.6	74.6	77.0
Rwanda	73.9	81.7	93.0	97.8
Sao Tome and Principe	88.8	90.4	95.0	97.6
Senegal	85.4	88.8	93.2	95.5
Seychelles	94.8	94.7	93.4	93.3
Sierra Leone	58.7	65.6	72.1	71.8
South Africa	76.6	70.2	73.5	79.3
Sudan	84.6	84.8	85.2	86.4
Togo	86.5	86.4	87.2	89.5
Tunisia	98.3	98.0	97.0	96.5
Uganda	68.5	74.6	81.3	89.6
United Republic of Tanzania	79.3	80.1	87.0	93.8
Zambia	64.5	69.6	82.7	86.8
Zimbabwe	66.1	64.4	75.1	86.7

Given the scarcity of health resources in the majority of these countries, it is imperative to utilize the available resources efficiently to maximize health outcomes and facilitate the road toward universal health coverage. Countries should undertake country-level efficiency assessment of different decision-making units in order to identify the main drivers of inefficiency and institute efficiency-enhancing measures. Finally, Data were obtained from reports of international organizations, which at times may be different from what is reported by countries. The findings, therefore, must be viewed with caution and should not be used to rank countries in terms of technical efficiency.

Conflicts of Interest Disclosure

The authors declare no conflicts of interest.

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