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Technical efficiency and productivity of public district hospitals in KwaZulu-Natal province, South Africa

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Abstract

Background: District hospitals (DHs) constitute a significant proportion of public hospitals and consume a more substantial percentage of the government's total hospital budget. With the level of resources disbursed to DHs, it is essential to ensure efficient allocation and utilization. Hence, this study set out to assess the technical efficiency and productivity of public DHs in KwaZulu-Natal province, South Africa.

Methods: Data envelopment analysis (DEA) and Malmquist total factor productivity (MTFP) were used to assess technical efficiency, identify adjustments required to make inefficient facilities more efficient, and determine overall productivity growth. Input data such as medical personnel and output information such as outpatient visits were retrieved from the databases of the district health information system (DHIS), and personnel salary systems (PERSAL) for three consecutive financial years (2014/15, 2015/16 and 2016/17). A total of 38 district hospitals were included in the study.

Results: The proportion of technically efficient facilities according to constant return to scale (CRS) were 12 (31.6%), 16 (42.1%) and 14 (36.8%) in 2014/15, 2015/16 and 2016/17 respectively while according to the variable return to scale (VRS) technically efficient facilities were 22 (57.9%), 19 (50.0) and 21 (55.2%) respectively for the three consecutive years. On average, the total productivity of DHs increased by 4.8 percent over the three years, which is attributed majorly to technical growth of 6.9 percent.

Conclusion: This study showed that a significant proportion of the district hospitals were technically inefficiency. Also, steps that could enable more efficient use of healthcare resources to yield optimal health service delivery were recommended.

Introduction

The South African health care system is majorly dominated by the public sector, a rapidly growing private and emerging NGO sector. With the high levels of poverty and unemployment among most of the population, that healthcare remains the burden of the state with the national department of health (nDOH) primarily holding overall responsibility for health care provision.[1] Post-apartheid, Government expenditure has significantly increased on all levels of healthcare, including public hospital.[2] The public health sector consumes around 9% of the government's total budget,[1,3] a proportion higher than 5% of GDP recommended by WHO.[4] Despite the high expenditure on health, the country's health outcomes are poor in comparison with most other similar middle-income countries, reflecting among other factors the burden of disease and inequity in access to healthcare in the country.[1] The South African public health sector is responsible for catering for the preventative and curative health care needs of more than 80% of the population.[5] It consists of three healthcare service levels: primary healthcare (PHC) and district hospitals (DHs), secondary or provincial hospitals and the tertiary and specialist hospitals. PHC is strengthened by the district health system, which in turn can make a referral to provincial or tertiary hospitals.[3] The district health system was adopted as the operational vehicle to deliver comprehensive PHC through clinics and district hospitals (DHs).[6] DHs play an essential role in supporting PHC on the one hand and the other as a gateway to more specialist care offered at provincial and tertiary healthcare facilities.[6] They account for 64% of public hospitals in the country and consumed more than half (55%) of the government's total hospital budget.[6-8] Assessing the efficiency of health facilities is critical in optimizing scarce resource utilization and minimizing wastage**.** Such an assessment will allow policy and decision-makers in health care to make better allocative decisions and more effective and efficient use of these scarce resources. A review published by the world health organization (WHO) regional office for Africa has identified six major challenges facing health systems in Africa.[9] These chal-

lenges include poor leadership and governance leading to inefficiency in resource allocation; extreme shortages of health workers worsened by inequities in workforce distribution and brain drain; and extensive corruption in medical products and technologies procurement system. Others are weak health management information systems (HMIS); lack of appropriate healthcare financing policies and strategic plans, and finally, non-effective organization and management of health services.[9] Many of these challenges could be addressed through effective and efficient management of the limited health resources within the continent. Health policymakers need to investigate ways by which health resources could be utilized to ensure equity and subsequently, universal access to quality health care services.

Efficiency in health systems is concerned with how a combination of often fixed resources (such as equipment, staff, drugs, and medical supplies) can lead to the production of the highest output.[10] Aside from the fact that resources within the health sector are limited, inefficient resource utilization poses great concerns for different reasons.[11] Inefficient consumption of resources is an opportunity cost that denies other potential patients access to care.[11] Furthermore, inefficient health resources utilization may jeopardize the best use of such resources elsewhere in the economy;[11] and most importantly, wasting resources may reduce funders' willingness to continue funding the health services.[11] Despite the importance of efficient utilization of resources within the health system, much of the attention of health policymakers and other stakeholders in Africa has been on the mobilization of additional resources with the hope that this will simply rectify inequalities in access to quality health care. As more resources are mobilized, it is essential to continuously evaluate the level at which these resources are being efficiently used. Improved health service delivery through efficient use of resources at the health facility level is key to achieving increased access and eventually, universal health coverage. Reviews of studies on efficiency measurement of health facilities in low and middle-income countries showed that there are relatively few studies conducted in the last three decades.[12,13] Less than one-third of these studies were done in sub-Saharan African (SSA), with the majority carried out more than ten years ago. In Southern Africa, very few studies on the efficiency of health care facilities were conducted in the past two decades.[14] A literature search showed that there were four hospital efficiency studies conducted in South Africa within this period,[15-18] and just like the SSA efficiency studies,[15] majority of these studies are more than a decade ago.[14] Thus, efficiency assessment of South African hospitals and other health facilities have received scant attention in recent times.

The present study was undertaken to measure hospital efficiency with a focus on district hospitals. This study is relevant given the apparent crisis generally in healthcare, shrinking government revenue, and increasing the health care needs of the growing population as well as re-emerging health problems. This study assessed the overall technical efficiency of public DHs in South Africa's second most populated province, KwaZulu-Natal. The specific objectives focused on i) evaluating the technical efficiency of public DHs in the province between 2014/15 to 2016/17 financial years; (ii) estimating the adjustments needed to make inefficient DHs efficient; and iii) evaluating the hospital productivity changes to examine efficiency trend over the three years.

Design and Methods

The health system comprises different components whose primary goal is to promote, restore, and maintain the health and general wellbeing of the people.[19] For the health system to function optimally at the facility level, it needs to combine input resources such as medical personnel and drugs to generate preventive, curative, and rehabilitative health services.

Efficiency within the health system can be divided into two: technical and allocative efficiency. Technical efficiency (TE) refers to the best use of a given inputs resources and existing technology. In contrast, allocative efficiency is related to the optimal allocation of these inputs.[20] However, the focus of this study is to assess the performance of district hospitals through their technical efficiency. There are two prominently reported methodologies for evaluating the TE of health facilities; data envelopment analysis (DEA) and stochastic frontier analysis (SFA). These techniques assumed efficiency as fundamentally a connection between health care inputs and the outputs they produce.[9] They assess how effectively a unit of production or organization, such as hospital, uses its input resources, such as staff and beds, to produce health services, such as patients treated.[9] This study adopted the data envelopment analysis (DEA) approach for assessing the TE of the DHs while Malmquist total factor productivity (MTFP) index was employed in determining their productivity growth for the given period.

Data envelopment analysis

DEA is an econometric frontier approach commonly used for estimating the TE of a set of similar entities called decision-making units (DMUs) by accommodating the use of multiple inputs and output.[21] It is based on a linear programming technique that identifies an efficiency frontier on which only the efficient facilities are located.[21] A facility is said to be technically efficient if it can produce maximum output from a given sets of input.

DEA determines the relative efficiency of a facility by comparing its efficiency to the best performing facility (efficiency frontier) within the same set. Thus, the yardstick against which to compare the TE of a hospital is determined by the group. An efficiency score was assigned to each hospital, reflecting the ratio of its weighted sum of outputs to the weighted sum of inputs.[22] DHs that are technically efficient fall on the efficiency frontier and are assigned a score of "1" while inefficient DHs lie below the frontier and have efficiency scores that are less than "1".

There are two model assumptions for estimating efficiency in DEA; the constant return to scale (CRS) and variable return to scale (VRS). The CRS assumes that any increase in the level of input will lead to a proportional increase in the level of output, and this was first proposed by Charnes, Cooper, and Rhodes (CCR).[23] The other model, VRS, proposed by Banker, Charnes, and Cooper (BCC),[24] assumed any increase in the quantity of input would either increase or decrease the level of output [24]. These model assumptions are represented in the programming equation below:[18,23]

CRS Model assumption

$$Max \ E_0 = \sum_{r=1}^{s} u_r \, y_{r j_0}$$

Subject to:

$$\sum_{i=1}^{m} v_i \, x_{i j_0} = 1$$

$$\sum_{r=1}^{s} u_r \, y_{r j_0} - \sum_{i=1}^{m} v_i \, x_{i j_0} \leq 0 \quad j = 1, \ldots, n$$

$$u_r, v_i \geq 0$$

VRS Model assumption

$$Max\ E_0 = \sum_{r=1}^{s} u_r y_{rj_0} + u_0$$

Subject to:

$$\sum_{i=1}^{m} v_i x_{ij_0} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj_0} - \sum_{i=1}^{m} v_i x_{ij_0} + u_0 \le 0 \quad j = 1,..,n$$

$$u_r, v_i \ge 0$$

where: Y_{rj} = the amount of health services output r (r = 1,…, s) from hospital j; X_{ij} = the amount of health system input j (i = 1, ….., m) in j^{th} hospital; U_r = weight given to health service output r; V_i = weight given to health system input I; n = number of hospitals in the sample; s = number of outputs; m = number of inputs.

VRS model assumption could result in two distinct returns to scale (production scale); increasing returns to scale (IRS) or decreasing returns to scale (DRS). A return to scale refers to the quantitative change in the output of a firm (DMU) resulting from a proportionate increase in all inputs.[25] Increases in output by a greater proportion than the corresponding increase in inputs is termed IRS, while increment in output by a smaller proportion than the corresponding increase in inputs is called DRS.[25] The CRS model is most appropriate when all facilities are assumed to be operating at an optimal scale, which is rarely the case in health systems. As such, we adopted both the CRS technical efficiency and VRS technical efficiency models to estimate the TE of the DHs. In addition to TE, the scale efficiency of the DHs was also determined. The scale efficiency (SE) is an estimation of the extent to which a DMU (DHs in this case) deviates from an optimal operation scale. The scale efficiency is represented by the ratio of the CRS technical efficiency scores to VRS technical efficiency scores.

The DEA models can be computed through two types of orientation: the input or output orientation models. An input orientation indicates how much a firm can decrease its input(s) to yield a given level of output(s),[26] while output orientation determines how much a firm can increase its output using a given level of input.[26] For this study, we utilized the input-oriented DEA model as the focus is on the best use of given health input resources to produce an optimum health service output. This model fits with the context of DHs as the department of health, and hospital management have more control over the health system inputs (such number of doctors and nurses) than the output, such as the number of patients admitted or visited the hospital.

Malmquist total factor productivity index

The Malmquist total factor productivity (MTFP) index was first introduced by Fare (1957) before being further developed within the non-parametric DEA framework using input and output data.[26] It is an estimation of the change in productivity over a given time.[26] The MTFP is a product of efficiency change (EFFCH) also known as 'catching up' effect to best practice frontier and technical change (TECH) also known as 'frontier shift' effect which measures the shift in the frontier of technology or innovation between two adjacent periods.[26] In turn, EFFCH is a product of pure efficiency change (PECH) and scale efficiency change (SECH), *i.e.* MTFPC = EFFCH X TECH = (PECH X SECH) X TECH.

The MTFP index takes a value of more than "1" for productivity growth, a value of "1" for stagnation, and a value of less than "1" for productivity decline. One of the major focus of the MTFP index is to identify the contributions of diffusion and learning (catching up or efficiency change) and innovation (technical change or shifts in the frontier of technology) to productivity changes.[25]

TECH is a measure of the change in hospital production technology; that is, the shift in technology use between two consecutive years.[25] It is greater than "1" when the technological best practice is improving. When equal to "1" it indicates no technological change while less than "1" shows deterioration.[25] On the other hand, EFFCH is the change in the gap between observed production and maximum feasible production (production frontier) between two consecutive years.[25] It is greater than one, equal to or less than one if a hospital is moving closer to, unchanging or diverging from the production frontier.[25] To further identify the main cause of productivity changes, EFFCH could be divided into pure efficiency Change (PEFFCH) and scale efficiency change (SECH).

PEFFCH refers to the efficiency change calculated under VRS. It evaluates whether movements inside the frontier are in the right direction to attain the VRS technical efficiency.[25,27,28] Conversely, SECH refers to productivity change due to scale change that brings a firm (hospital in this case) closer to or further away from the optimal scale under a constant return to scale.[25,27-29] It is expressed as a value of less than, equal to, or greater than "1" if the hospital's scale of production contributes negatively, not at all, or positively to productivity change, respectively.[25]

Description of study area and population

South Africa has an estimated population of 58 million.people of which 19.2% resides in KwaZulu-Natal. With a population of 11.3 million people the province is the second most populated province after Gauteng (15.2 million people).[30] Also, the province comprises an area of 94,361 km^2, which covers approximately 7.7% of the land area of the country, an area roughly the size of Portugal.[31] The majority of South African access health care service through the public sector clinics and hospitals.

Health services at district hospitals are rendered by various clinical and non-clinical generalists that include: medical and dental personnel; nurses; pharmacists, pharmacist assistants, laboratory scientists/technicians and other support personnel. DHs have between 30 to over 300 beds, a 24-hour emergency service and an operating theatre.[6] The range of services delivered are usually informed by the needs of the catchment area served by the DHs. These ranges from outpatient services to inpatient and also laboratory services.

Data collection technique

The study included all the thirty-eight public district hospitals in the province. Data relating to health service inputs and outputs of all the DHs were retrieved from the national district health information system (DHIS) database and personnel salary system (PERSAL) for a three-year consecutive financial period (2014/15, 2015/16 and 2016/17).

Input and output variables

The choice of inputs and outputs used for the efficiency analysis were guided by the district hospital (DH) package of services for South Africa,[4] and reports from previous studies. The District hospitals package of services describes the expected range of services that should be offered at DHs and personnel required to provide them. For the purpose of this study, the input variables deployed include; medical and dental personnel (doctors and dentists), nursing personnel (nurses and midwives), pharmacy personnel (pharmacists and pharmacist assistants), allied personnel (laboratory scientist/technicians, radiographers, physiotherapists, *etc.*),

support/other services personnel (social workers, cleaners, maintenance etc.) and number of beds. On the other hand, the output variables included total inpatient days, total outpatient headcount, total theatre/operation cases, X-rays done, delivery by caesarean and regular delivery. These variables were selected based on data completeness and robustness. Data validity and reliability check was done by randomly visiting some of the DHs for discrepancy check and data confirmation.

Data analysis

The data retrieved from the databases were stored in Microsoft excel and was checked to ensure completeness and correctness. The descriptive statistics of all input and output variables were computed using IBM-SPSS version 26.0. The mean, standard deviation (SD), minimum and maximum values of all input and output variables were determined. The technical efficiency and the MTFP analyses were estimated using performance improvement management software (PIM-DEA) developed by Thanssoulis and Emrouznejad,[32] and data envelopment analysis program (DEAP) by Coelli.[33] The DHs were coded in alphabetical order before importing data into the software. The technical efficiency, scale efficiency scores and slacks (input reduction and/or output increases) were computed. DHs that assume the "best practice frontier"

were assigned an efficiency score of "1" and are said to be technically efficient compared to their peers. The inefficient health facilities are assigned a scores less than "1". MTFP values of more than "1" show productivity growth while values less than one indicate productivity decline.

Results and Discussion

This study utilized a combination of larger and more diversified input and output variables compared to previous hospital and health facility efficiency studies in other LMICs countries.[12,14,34] Also compared to most previous studies, this study utilized a larger sample size (DMUs) which has been demonstrated to reduce estimation bias in data envelopment analysis.[35] The descriptive analysis of the input and output variables deployed in the efficiency analysis of all the included 38 district hospitals are as shown in Table 1.

Technical efficiency

The estimated CRS and VRS technical efficiency score, scale Efficiency score and return to scale for the DHs are presented in Table 2. In 2014/15, 12 (31.6%) and 22 (57.9%) of the DHs were

Table 1. Descriptive statistics of input and output variables.

	Medical and dental personnel	Nursing personnel	Input Pharmacy personnel	Output Allied personnel	Support and other services personnel	No of beds	Inpatient days total	OPD headcount total	Theatre cases total	X-ray done	Delivery by caesarean section	Regular delivery
2014/15												
Mean	28.68	407.29	18.11	22.87	271.32	225.47	51590.26	62833.74	1430.11	12284.74	651.37	1690.97
Sum	1090	15477	688	869	10310	8568	1960430	2387682	54344	466820	24752	64257
Std. Dev.	28.67	181.08	9.47	14.67	89.18	87.50	24416.75	37418,35	1389.51	10057.77	437.75	924.42
Minimum	10	133	7	8	99	52	11452	18440	233	2452	165	406
Maximum	155	812	47	88	485	431	134854	224133	6728	65155	1889	4152
Range	145	679	40	80	386	379	123402	205693	6495	62703	1724	3746
2015/16												
Mean	22.34	355,03	18.42	21.34	249.50	225.45	49485.89	60340.39	1306.18	12217.18	643.50	1599
Sum	849	13491	700	811	9481	8567	1880464	2292935	49635	464253	24453	60762
Std. Dev.	24.88	164,58	9.82	13.43	84.02	86.70	23872.68	36193.29	1340.65	9720.85	427.25	904.70
Minimum	4	116	7	6	98	52	11300	13887	183	2780	130	411
Maximum 3853<Nessuno(a)>	146	791	49	81	431	431	134631	209855	6873	62741	1893	
Range	142	675	42	75	333	379	123331	195968	6690	59961	1763	3442
2016/17												
Mean	21.08	346,47	18.39	21.11	239.66	229.11	45936.84	56545.55	1265.63	11819.63	624.34	1560.79
Sum	801	13166	699	802	9107	8706	1745600	2148731	48094	449146	23725	59310
Std. Dev.	24.53	155,84	8.62	13.57	79.63	114.47	22734.31	35366.38	1279.71	9580.52	400.50	879.44
Minimum	5	125	8	8	96	52	12155	13472	184	2940	134	380
Maximum	140	775	43	79	412	681	129096	200541	6529	59900	1881	3820
Range	135	650	35	71	316	629	116941	187069	6345	56960	1747	3440

CRS technically efficient and VRS technically efficient respectively. In the subsequent year 2015/16, the proportion of CRS technically efficient DHs increased by 10.5% to give 42.1% efficient facilities while the proportion of VRS technically efficient DHs decreased by 7.9% to give 50.0% efficient facilities. For the final year under study (2016/17), the proportion of both CRS technically efficient and VRS technical efficient facilities were 14 (36.8%) and 21 (55.2 %), respectively.

A Venn diagram was constructed to show facilities which were consistently efficient over the three years (Figure 1). Nine DHs were efficient throughout the three-year period as shown at the intersections of the Venn diagram; one DH was efficient in both 2014/15 and 2015/16. Similarly, one DH was efficient in both 2014/15 and 2016/17 while five DHs were efficient in both 2015/16 and 2016/17. Two DHs were efficient in 2015/16 only while one DH was efficient 2014/15 only (Figure 1).

It is difficult to compare the findings of this study with previous studies because the input and output variables were different for each study. In general, there is a range of efficiencies that have been reported across the studies and show that DHs in KwaZulu-Natal are more efficient. A study conducted in East Asia found only 8.8% and 15.8% of the studied hospitals to be CRS and VRS technically efficient, respectively.[36] Another study conducted South-East Asia recorded 29% CRS efficient facilities (29%) and 79% VRS efficient facilities.[37] In Africa, a Ghanaian study reported 24% VRS technically efficient DH;[38] 9.5-14.5% and 24-38% Botswana hospitals were CRS and VRS technically efficient respectively over the period 2006 to 2008;[27] and 18% of studied hospitals in Uganda were CRS technically efficient while 47% were VRS technically efficient.[39] In this study, the mean VRSTE scores for the DHs were 90.7%, 91.8% and 90.0% for the three consecutive years. This shows if all the DHs were running efficiently, they could have produce 9.3% more outputs for 2014/15, 8.2% more outputs for 2015/16 and 10.0 % more output for 2016/17 using the same amount of input. Conversely, the hospitals on the average could reduce their input mix by 9.3%, 8.2% and 10.0% respectively to maintain the same level of output. The high level of technical efficiency has reflected in the mean efficiency scores could be due to high utilization of the hospitals as majority of the DHs in South Africa are public funded, hence, and are relatively affordable.

There were different range of average CRSTE and VRSTE scores reported in previously conducted hospital efficiency studies. A study conducted in Ethiopia reported average CRSTE of 77% and average VRSTE score of 94%.[40] Similarly, a recent study on DHs in Bangladesh also reported a CRSTE average score of 79% but a higher VRSTE average score of 92%.[37] In Africa, an average VRSTE score of 64.8% was reported for Gambian secondary health care facilities,[41] while a Botswana study recorded an average VRSTE of between 70.4-76.3%.[27]

Scale efficiency

The proportion of scale efficient DHs (operating at the required optimal size) for the period under study was similar to the CRSTE findings with 12 (31.6%), 17 (44.7%) and 15 (39.5%) efficient facilities in 2014/15, 2015/16 and 2016/17, respectively (Table 2). The average scale efficiency scores were 93.8%, 95.1% and 91.2% consecutively for the three years signifying that there is a need to increase the hospital outputs slightly by 6.2% in 2014/15, 4.9% in 2015/16 and 8.8%% in 2016/17. This could be achieved through putting policies in place to adjust the scale of production of inefficient hospitals. Reports from previous African studies showed wide range of scale efficient facilities: 86-93% of health

facilities in Ethiopia,[42] 79.2-84.7% of hospitals in Botswana,[27] and 31-46% of the referral hospitals in Uganda.[25]

Based on return to scale, 31.6%, 44.7% and 36.8% of the DHs showed a constant returns to scale (CRS) for the year 2014/15, 2015/16 and 2016/17, respectively. This indicates that doubling the inputs utilized by these facilities within the period leads to doubling of their outputs. This shows that the size of these hospitals do not influence their productivity, they were operating at their optimum production scale. On the other hand, 47.3% of the DHs manifested increasing return to scale (IRS) in 2014/15 while a lower proportion of 36.8% each indicated same scale of production in both 2015/16 and 2016/17. This indicated that these facilities needs to expand their scale of operation in order to operate an optimal level. This could be achieved for instance through introduction of innovative health technologies to enhance the performance of the hospital workers.[27] Like CRS, 23.7% of the facilities exhibited a decrease return to scale (DRS) in 2016/17 while lesser proportions of 18.4% and 21.1% showed DRS in 2015/16 and 2014/15, respectively. This DRS among facilities could be related to challenges of task coordination and poor communication between management and workers.[27] Thus, there is need for these facilities to reduce the size of their production scale for them to be at the optimal production level.

Adjustments to make inefficient facilities efficient

Table 3 shows the total input reduction or output increment needed to make inefficient DHs efficient for the three years. In total, the inefficient DHs combined would need to reduce the number of medical and dental personnel by 63 (9.2% of the total actual value) and on the average by 2 personnel per facility for the year 2014/15. Alternatively, using the same input, the output could also be increased to make inefficient hospital efficient. For instance, increasing the total inpatient days of the inefficient facilities combined by 23,321 (1.9% of the total actual value) or 614 on the average per DH can improve performance and leads to optimal service delivery. Other total and average input reductions or output increases needed to make inefficient DHs efficient for the three years are presented in Table 3.
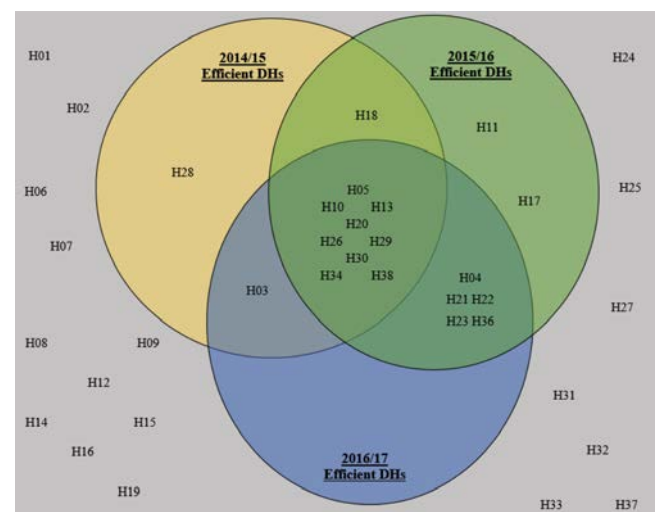

Figure 1. Venn diagram showing efficiency status of district hospitals over the years.

Though the output by these facilities could be increased by different strategies such as improving the accessibility of these facilities,[27] and health promotion through social mobilization, advocacy and awareness creation. However, while health managers and policy makers may not have more direct influence on hospital inputs, the department of health can reshuffle the hospital inputs such as doctors, nurses and no of beds within the DHs in order to make them efficient. Also, the excess inputs could be transferred to other primary health care clinics. Patients could receive a better and quality health service at this level and by so doing reducing burden on the DHs.

Productivity change

The productivity change for the years under study was analysed using Malmquist productivity factor productivity (MTFP) index and the year 2014/15 was taken as reference point. The Malmquist index summary of geometric means is as shown in Table 4. As shown in the last row and column of the table, the productivity of the district hospitals over the three-year period increased by 4.8%. The maximum MTFP was recorded in 2015/16 (1.276). This total factor productivity improvement was mainly due to technical innovation. The hospitals hospital efficiency change decreased by 1.9% while the technical change increased by

Table 2. Technical efficiency scores for the three consecutive years.

DHs	2014/15				2015/16				2016/17			
	CRSTE	VRSTE	Scale EFF.		CRSTE	VRSTE	Scale EFF.		CRSTE	VRSTE	Scale EFF.	
H01	0.711	0.797	0.892	IRS	0.684	0.76	0.9	IRS	0.557	0.79	0.705	IRS
H02	0.892	1	0.892	DRS	0.919	1	0.919	DRS	0.868	1	0.868	DRS
H03	1	1	1	-	0.87	0.902	0.965	IRS	1	1	1	-
H04	0.78	0.874	0.893	IRS	1	1	1	-	1	1	1	-
H05	1	1	1	-	1	1	1	-	1	1	1	-
H06	0.547	0.595	0.919	IRS	0.625	0.635	0.984	IRS	0.378	0.499	0.758	IRS
H07	0.731	0.793	0.921	IRS	0.715	0.755	0.947	IRS	0.639	0.741	0.862	IRS
H08	0.822	0.886	0.928	DRS	0.705	0.914	0.772	DRS	0.85	1	0.85	DRS
H09	0.708	0.72	0.983	DRS	0.833	0.835	0.997	IRS	0.676	0.721	0.938	IRS
H10	1	1	1	-	1	1	1	-	1	1	1	-
H11	0.647	1	0.647	IRS	1	1	1	-	0.759	1	0.759	IRS
H12	0.836	0.845	0.989	IRS	0.753	0.797	0.944	IRS	0.645	0.735	0.877	IRS
H13	1	1	1	-	1	1	1	-	1	1	1	-
H14	0.734	0.752	0.977	DRS	0.785	0.999	0.786	DRS	0.691	0.809	0.854	DRS
H15	0.875	1	0.875	DRS	0.858	0.963	0.89	DRS	0.834	1	0.834	DRS
H16	0.537	0.565	0.951	IRS	0.568	0.571	0.996	IRS	0.559	0.65	0.86	IRS
H17	0.957	1	0.957	DRS	1	1	1	-	0.957	1	0.957	DRS
H18	1	1	1	-	1	1	1	-	0.757	0.861	0.879	IRS
H19	0.645	0.687	0.938	IRS	0.801	0.908	0.882	DRS	0.694	0.832	0.834	DRS
H20	1	1	1	-	1	1	1	-	1	1	1	-
H21	0.928	1	0.928	IRS	1	1	1	-	1	1	1	-
H22	0.696	0.86	0.809	IRS	1	1	1	-	1	1	1	-
H23	0.73	0.761	0.959	IRS	0.631	0.631	1	-	0.644	0.644	1	-
H24	0.881	0.889	0.991	IRS	0.847	0.905	0.936	IRS	0.748	0.898	0.833	IRS
H25	0.879	1	0.879	DRS	0.825	0.914	0.903	DRS	0.853	1	0.853	DRS
H26	1	1	1	-	1	1	1	-	1	1	1	-
H27	0.878	1	0.878	IRS	0.894	0.949	0.942	IRS	0.912	0.916	0.996	DRS
H28	1	1	1	-	0.949	0.968	0.98	IRS	0.69	0.738	0.935	IRS
H29	1	1	1	-	1	1	1	-	1	1	1	-
H30	1	1	1	-	1	1	1	-	1	1	1	-
H31	0.841	0.848	0.992	IRS	0.979	1	0.979	IRS	0.714	0.818	0.873	IRS
H32	0.793	0.794	0.998	IRS	0.721	0.748	0.965	IRS	0.803	0.811	0.99	IRS
H33	0.675	0.818	0.824	IRS	0.68	0.852	0.798	IRS	0.633	0.85	0.745	IRS
H34	1	1	1	-	1	1	1	-	1	1	1	-
H35	0.907	1	0.907	IRS	0.754	0.87	0.867	IRS	0.729	0.903	0.808	IRS
H36	0.84	1	0.84	IRS	1	1	1	-	1	1	1	-
H37	0.857	1	0.857	DRS	0.804	1	0.804	DRS	0.794	1	0.794	DRS
H38	1	1	1	-	1	1	1	-	1	1	1	-
Mean	0.851	0.907	0.938		0.874	0.918	0.951		0.826	0.9	0.912	

6.9%. The cross-section of productivity growth analysis in health facilities by previous studies reported a range of outcomes. For instance, a study of a county hospital conducted in China reported a MTFP average score of 1.078.[36] Also, previous studies in various Africa countries showed different MTFP average scores indicating either growth or deterioration of the facilities under study; Botswana (0.985),[27] Uganda (1.049),[25] Seychelles (1.024),[43] and Ethiopian (0.964).[42]

The summary of the mean annual values of the Malmquist productivity index and its components for each individual district hospital is shown in Table 5. Twenty-four (63.2%) of the DHs had productivity growth over the three year period as indicated by their index values which were greater than one. Conversely, thirteen (34.2%) of hospitals had MPI value less than one signifying deterioration in performance while one DH showed no difference in performance over the three years.

Efficiency and technical change

Efficiency and technical change are the major components of the Malmquist total productivity Index contributing to productivity change over a period of time. Findings from this study showed a 1.9% decrease in efficiency change. Ten (26.3%) of the hospitals indicated increase in efficiency change, eleven (28.9%) displayed no efficiency change while seventeen (44.7%) expressed a decline in efficiency (Table 5).

There was a 6.9% increase in technical change among the DHs over the three years. The breakdown by facilities showed that majority, 31 (81.6%) of the facilities displayed increase in technical innovation (change) with index values greater than "1" while 5 (13.2%) and 2 (5.3%) of them registered a declined and no technical changes respectively 9 (Table 5). Technical changes could be attributed to several factors such as: enhanced communication net-

work between health policy makers and health facility management teams; availability of new and modern health technology; easy access to these technologies; complimentary training to enable health workers acquire skills to take advantage of the new and modern technologies; and finally availability of funds needed to acquire and manage the health technologies.[27,44] Thus, the increased technical change over the period as shown by majority of the hospital could be due to application of improved modern heath technologies in health service delivery. It can also be due to enhanced communication network between different health workforce cadres resulting in improved staff motivation towards service delivery.

Pure and scale efficiency change

The average pure efficiency change of 0.995 showed that there was less than 1 percent in pure efficiency growth over the period (Table 5). Nine (23.7%) of the hospitals exhibited a pure technical efficiency increment with average pure efficiency scores greater than one, 19 (50.0%) of them indicated no change in pure efficiency over the period while 10 (26.3%) of the hospitals registered a decreased in pure technical efficient with average score less than one.

Similarly, there was 1.4% decrease in the scale efficiency of the DHs as shown in the average score of 0.986 (Table 5). Compared to pure efficiency change, a lower proportion of the DHs; 7 (18.4%) recorded an increased scale efficiency change as expressed in their average index scores which were greater than one. Eleven (28.9%) of the facilities had no scale efficiency changes with average scores of "1" over the period while twenty (52.6%) indicated a decline in scale efficiency as shown by their average scores which was less than "1".

Table 3. Total input (reductions) and output (increases) needed to make inefficient DHs efficient.

Input and output	Total actual values	2014/15 Total shortfall/ excess	Average shortfall excess	Total actual values	2015/16 Total shortfall/ excess	Average shortfall excess	Total actual values	2016/17 Total shortfall/ excess	Average shortfall excess
Inputs									
Medical and dental personnel	688	63	2	488	83	2	477	56	1
Nursing personnel	10999	2643	70	9108	2768	73	9527	2383	63
Pharmacy personnel	479	59	2	451	45	1	485	64	2
Allied personnel (therapist and laboratory)	595	123	3	521	108	3	524	78	2
Support and other services personnel	7296	1456	38	6137	1289	34	6406	622	16
No of beds	5547	10	<1	5061	0	0	5505	298	8
Output									
Inpatient days - total	1212451	23321	614	1156113	23446	617	1116776	51915	1366
OPD headcount - total	1337860	0	0	1297207	24046	633	1166766	162636	4280
Theatre cases total	28507	33889	892	26051	53342	1404	25528	44463	1170
X-ray done	251473	67661	1781	254918	78900	2076	246521	64805	1705
Delivery by caesarean section	14539	7290	192	13282	5157	136	13452	11884	313
Regular Delivery	38835	14402	379	32944	19003	500	34061	18562	488

Table 4. Malmquist index summary of annual means.

Year	Efficiency change [A]	Technical change [B]	Pure efficiency change [C]	Scale efficiency change [D = (A/C)]	Total factor productivity change [E = A*B]
2015/16	1.028	1.102	1.012	1.016	1.133
2016/17	0.936	1.036	0.979	0.956	0.970
Mean	**0.981**	**1.069**	**0.995**	**0.986**	**1.048**

Conclusions

Overall, nine (23.7%) of the DHs were operating at optimal scale of service delivery (CRS and VRS technically efficient) throughout the study period. In order to make inefficient facilities efficient two different adjustments could be made; the input reduction and output increments.

This study showed the different input mix of the inefficient DHs could be reduced by different proportion of the actual values

to yield the same output and by so doing making them efficient. These excess inputs (personnel and beds) could be transferred to other health facilities. In line with the Sustainable development goal (SDG), this distribution of health workforce will enhance the country's universal health coverage and accessibility to quality health care. Hence, the rates of child and maternal mortality and other disease burden would be reduce significantly.

From the output adjustment perspective, the inefficient district hospitals can be made efficient through increasing their output

Table 5. Malmquist index summary of firm means.

Year	Efficiency change [A]	Technical change [B]	Pure efficiency change [C]	Scale efficiency change [D = (A/C)]	Total factor productivity change [E = A*B]
H01	0.885	1.123	0.996	0.889	0.994-
H02	0.987	1.116	1	0.987	1.101+
H03	1	1.037	1	1	1.037+
H04	1.132	1.174	1.07	1.058	1.330+
H05	1	1.153	1	1	1.153+
H06	0.832	1.092	0.916	0.908	0.908-
H07	0.935	1.053	0.967	0.967	0.985-
H08	1.017	1.08	1.062	0.957	1.098+
H09	0.977	1.161	1	0.977	1.135+
H10	1	1.055	1	1	1.055+
H11	1.083	1.121	1	1.083	1.214+
H12	0.878	1.028	0.933	0.942	0.903-
H13	1	1	1	1	1
H14	0.97	1.092	1.038	0.935	1.059+
H15	0.976	0.994	1	0.976	0.971-
H16	1.02	1.122	1.073	0.951	1.144+
H17	1	1.005	1	1	1.005+
H18	0.87	1.062	0.928	0.937	0.924-
H19	1.037	1.106	1.1	0.943	1.147+
H20	1	1.026	1	1	1.026+
H21	1.038	1.073	1	1.038	1.114+
H22	1.199	1.037	1.078	1.112	1.243+
H23	0.939	1.099	0.92	1.021	1.032+
H24	0.922	1.081	1.005	0.917	0.996-
H25	0.985	0.995	1	0.985	0.980-
H26	1	0.908	1	1	0.908-
H27	1.019	1.03	0.957	1.065	1.049+
H28	0.831	1.064	0.859	0.967	0.884-
H29	1	0.98	1	1	0.980-
H30	1	0.993	1	1	0.993-
H31	0.921	1	0.982	0.938	0.922-
H32	1.006	1.03	1.01	0.996	1.037+
H33	0.969	1.132	1.019	0.951	1.097+
H34	1	1.073	1	1	1.073+
H35	0.897	1.162	0.95	0.944	1.042+
H36	1.091	1.193	1	1.091	1.302+
H37	0.963	1.093	1	0.963	1.052+
H38	1	1.132	1	1	1.132+
Mean	**0.981**	**1.069**	**0.995**	**0.986**	**1.048+**

+DH with improved performance; -DH with declined performance. All Malmquist index average are geometric means.

using the same input mix. These could be achieved through improved health promotion and awareness towards changing the health seeking behaviour of people, and thereby increasing their utilization of the hospital care services. Also, policymakers could accelerate the plan of introducing innovative system of healthcare financing which will ensure universal health coverage and reduction of healthcare financial burden among the people. These measures aimed at increasing the hospital output using the same amount of input could assist in reducing resource wastage within the health system.

Finally, in order to ensure continuous delivery of quality healthcare service within the country, routine efficiency monitoring of the different health facilities must be undertaken.

Study limitations

Private and other non-profit district hospitals, which also form part of the district health system, were not included in this study. Hence, the results generated gives an overview of the situation in the public sector district hospitals and cannot be generalized for all secondary health facilities constituting the district health system in the province. In addition, data on the severity of cases treated in the hospital and case-mix over the study period were not available. Inputs and outputs of the hospitals were empirically analysed to give an understanding of the technical efficiency and performance changes among the public DHs, which could have an impact on the quality of health care delivery.

References

1. Zwarenstein M. The structure of South Africa's health service. Afr Health 1994;(Spec No):3-4.
2. Hlafa B, Sibanda K, Hompashe DM. The impact of public health expenditure on health outcomes in South Africa. Int J Environ Res Public Health 2019;16:2993.
3. Mahlathi P, Jabu D. Minimum data sets for human resources for health and the surgical workforce in South Africa's health systems: a rapid analysis of stock and migration. African Institute of Health and Leadership Development; 2015.
4. WHO. How much should countries spend on health? Geneva: World Health Organization; 2003.
5. Coovadia H, Jewkes R, Barron P, et al. The health and health system of South Africa: historical roots of current public health challenges. Lancet 2009;374:817-34.
6. Department of Health Pretoria. A district hospital service package for South Africa—a set of norms and standards. Pretoria: Department of Health; 2002.
7. National Treasury Republic of South Africa. The budget review 2017. Pretoria; 2017.
8. Babalola TK, Moodley I. Protocol for investigating the technical efficiency of district hospitals in the public health sector of KwaZulu-Natal, South Africa. JMIR Res Protoc 2019; 8:e12037.
9. Kirigia JM, Barry SP. Health challenges in Africa and the way forward. Int Arch Med 2008;1:27.
10. Kumbhakar SC, Lovell CK. Stochastic Frontier Analysis. Cambrigde University Press; 2003.
11. Cylus J, Papanicolas I, Smith PC. Health system efficiency: how to make measurement matter for policy and management. Copenhagen: European Observatory on Health Systems and Policies; 2016.
12. Hafidz F, Ensor T, Tubeuf S. Efficiency measurement in health facilities: a systematic review in low-and middle-income countries. Appl Health Econ Health Pol 2018;16:465-80.
13. Moshiri H, Aljunid SM, Amin R. Hospital efficiency: Concept, measurement techniques and review of hospital efficiency studies. Malays J Public Health Med 2010;10:35-43.
14. Babalola TK, Moodley I. Assessing the efficiency of healthcare facilities in Sub-Saharan Africa: A systematic review. Health Serv Res Manag Epidemiol 2020. doi: 10.1177/2333392820919604.
15. Kirigia JM, Lambo E, Sambo L. Are public hospitals in Kwazulu-Natal Province of South Africa technically efficient? Afr J Health Sci 2000;7:25-32.
16. Kirigia JM, Sambo LG, Scheel H. Technical efficiency of public clinics in Kwazulu-Natal Province of South Africa. East Afr Med J 2001;78:S1-13.

17. Kibambe JN, Koch SF. Dea applied to a gauteng sample of public hospitals. South Afr J Econ 2007;75:351-68.
18. Zere E, McIntyre D, Addison T. Technical efficiency and productivity of public sector hospitals in three south african provinces. South Afr J Econ 2001;69:336.
19. WHO. Everybody's business--strengthening health systems to improve health outcomes: WHO's framework for action. Geneva: World Health Organization; 2007.
20. Porcelli F. Measurement of technical efficiency. A brief survey on parametric and non-parametric techniques. PhD Thesis, Univrsity of Warwick; 2009.
21. Ozcan YA. Health care benchmarking and performance evaluation. Springer; 2008.
22. Mardani A, Zavadskas EK, Streimikiene D, et al. A comprehensive review of data envelopment analysis (DEA) approach in energy efficiency. Renew Sustaine Ener Rev 2017;70:1298-322.
23. Charnes A, Cooper WW, Lewin AY, Seiford LM. Data envelopment analysis: Theory, methodology, and applications: Springer Science; 2013.
24. Banker RD, Charnes A, Cooper WW. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci 1984;30:1078-92.
25. Mujasi P, Kirigia JM. Productivity and efficiency changes in referral hospitals in Uganda: An application of Malmquist total productivity index. Health Syst Policy Res 2016;3:28.
26. Huguenin JM. Data envelopment analysis (DEA): a pedagogical guide for decision makers in the public sector. Institut de Hautes Études en Administration Publique; 2012.
27. Tlotlego N, Nonvignon J, Sambo LG, et al. Assessment of productivity of hospitals in Botswana: a DEA application. Int Arch Med 2010;3:27.
28. Ma J, Evans DG, Fuller RJ, Stewart DF. Technical efficiency and productivity change of China's iron and steel industry. Int J Prod Econ 2002;76:293-312.
29. Kirigia JM, Asbu EZ, Greene W, Emrouznejad A. Technical efficiency, efficiency change, technical progress and productivity growth in the national health systems of continental African countries. Eastern Africa Social Science Research Review 2007;23:19-40. doi: 10.1353/eas.2007.0008.
30. Statistics South Africa. Mid-year population estimates. Statistics South Africa: Pretoria; 2019.
31. Msemburi W, Pillay-van Wyk V, Dorrington R, et al. Second national burden of disease study for South Africa: Cause-of-death profile for Free State, 1997–2012. 2016. Available from https://www.samrc.ac.za/reports/second-national-burden-disease-study-south-africa-cause-death-profile-report-1997-2012
32. Emrouznejad A, Thanassoulis E. Introduction to performance improvement management software (PIM-DEA). Handbook of research on strategic performance management and measurement using data envelopment analysis: IGI Global; 2014. p. 256-75.
33. Coelli T. A guide to DEAP version 2.1: a data envelopment analysis (computer) program. Centre for Efficiency and Productivity Analysis, University of New England, Australia. 1996.
34. Azreena E, Juni MH, Rosliza AJ, Sciences C. A systematic review of hospital inputs and outputs in measuring technical efficiency using data envelopment analysis. Int J Public Health Clin Sci 2018;5:17-35.
35. Zhang Y, Bartels R. The effect of sample size on the mean efficiency in DEA with an application to electricity distribution in Australia, Sweden and New Zealand. J Product Anal 1998;9:187-204.
36. Cheng Z, Tao H, Cai M, et al. Technical efficiency and productivity of Chinese county hospitals: an exploratory study in Henan province, China. BMJ Open 2015;5:e007267.
37. Ahmed S, Hasan MZ, Laokri S, et al. Technical efficiency of public district hospitals in Bangladesh: a data envelopment analysis. Cost Effect Resour Alloc 2019;17:15.
38. Jehu-Appiah C, Sekidde S, Adjuik M, et al. Ownership and technical efficiency of hospitals: evidence from Ghana using data envelopment analysis Cost Effect Resour Alloc 2014;12:9.
39. Mujasi PN, Asbu EZ, Puig-Junoy J. How efficient are referral hospitals in Uganda? A data envelopment analysis and tobit regression approach. BMC Health Serv Res 2016;16:230.
40. Bobo FT, Woldie M, Wordofa MA, et al. Technical efficiency of public health centers in three districts in Ethiopia: two-stage data envelopment analysis. BMC Res Notes 2018;11:465.
41. Jarjue G, Nor NM, Ghani JA, Jalil SH. Technical efficiency of secondary health care service delivery in the Gambia. Int J Econ Manage 2015;9:25-43.
42. Ali M, Debela M, Bamud T. Technical efficiency of selected hospitals in Eastern Ethiopia. Health Econ Rev 2017;7:24.
43. Kirigia JM, Emrouznejad A, Gama Vaz R, et al. A comparative assessment of performance and productivity of health centres in Seychelles. Int J Product Perform Manage. 2007;57:72-92.
44. Renner A, Kirigia JM, Zere EA, et al. Technical efficiency of peripheral health units in Pujehun district of Sierra Leone: a DEA application. BMC Health Serv Res 2005;5:77.