A non-parametric assessment of efficiency of South African public universities

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Abstract

The aim of this paper is to evaluate the technical efficiency and productivity changes of 23 public universities in South Africa from 2009 to 2015. The study used an output orientation DEA model based on VRS. Given the shrinking funding from government and the rapid rise of student enrolments, the need for universities to use available resources efficiently cannot be overemphasised. The insights generated by this study could inform policy makers and education stakeholders on the efficiency levels of public universities in South Africa and identify performance benchmarks. The performance benchmarks could be used as best practice to be emulated by inefficient institutions and propose potential improvements required to reach a satisfactory level of efficiency.

Keywords: *Data Envelope Analysis; Efficiency; Public Universities.*

JEL Classification: G21, C01, D22, I23

1. Introduction

The Higher Education (HE) system in South Africa has been going through an exercise of transformation in order to redress the educational imbalances of the past. The funding of HE institutions (HEIs) was one of the changes that was used to transform the HE system in South Africa. Funding of HE in South Africa remained the key challenge as the HEIs were characterised by insufficient funding due to a steady decline of funds (Wangenge-Ouma and Cloete, 2008; Akor and Roux, 2006). The transformation agenda of HE led to the expansion of HE which put serious constraint on state funding of HEIs and those from poor backgrounds accessing HE (Allais, 2017). The post-apartheid government established a mechanism of increasing access to HE by providing the National Student Financial Aid Scheme (NSFAS) to poor deserving students (Wangenge-Ouma, 2012). This massification triggered a funding crisis that highlighted the need for better ways of measuring and evaluating efficiencies and understanding of HE funding. The fundamental financial problems faced by HEIs are a worldwide phenomenon, linked to the increasing cost of education per student and the pressure to increase enrolments (Johnstone, 2003). Challenges of declining funds in universities (most public universities in South Africa are funded mainly by government) has sparked protests of students in South Africa demanding that fees must fall. In 2015/2016. The country experienced the rising protests of students demanding free education Protesting students across the country have made it clear that there is something very wrong with the current system of funding of university education in South Africa (Theobald, 2015).

HE is important in driving development in the economy, and measuring the efficiency is important due to government's significant contribution to funding. Evaluating efficiency of HE will be important because if the sector operates efficiently it will free some funds to help in funding many students who enter the system.The measure of efficiency in public institutions is a growing concern due to the expansion of the HE system, therefore it is important for HEIs to cater for the significant growth of the diverse population of students in an efficient manner (Cunha and Rocha, 2012). Moreover, financial constraints have called for more diversification of funding sources, accountability and cost effectiveness by HEIs (Ahmad, Farley and Naidoo, 2012). Evaluation of efficiency in public universities would be an important step in demonstrating how this technique would help HEIs to identify the need to improve their performance and would allow government and all interested stakeholders to evaluate the efficiency of HEIs. Moreover, as a significant sum is received by the HE sector from government funds, it is important to monitor this sector on a regular basis for its performance and productivity (Johnes, 2008).

In measuring the performance of of organisations numerous measures can be adopted including traditional measures such as earnings per share (EPS), dividend per share (DPS), return on equity (ROE) and return on assets (ROA) among others. These ratios have been criticised by several scholars such as Smith (1990), Thanassoulis, Boussofiane and Dyson (1996), Emrouznejad and Cabanda (2015) and Harrison and Rouse (2016). Evaluating performamance using ratios will provide a general indication of efficiency problems, but a further analysis will be required to trace the causes of inefficiencies. Other measurements that could be used to measure performamce are non-parametric and parametric techniques which can calculate an aggregate measure of efficiency and provide information about efficiency improvement possibilities (Koltai and Uzonyi-Kecskés, 2017). Therefore the efficiency measurements are often used as a proxy to best measure performance.

Two methods used in assessing efficiency in HE are Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) (Gromov, 2017). Efficiency is a means for enhancing fiscal return, i.e. reducing waste and generating the best possible fiscal outcomes, and these two approaches measure public sector efficiency. However, there is no general consensus on which of the two models best measures efficiency of HEIs because they adopt different approaches (Barra, Lagravinese and Zotti, 2015). SFA is a parametric approach that was developed by by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The important idea for the SFA model is that the error term is composed of two parts: a random error term and an inefficiency term. The advantage of the SFA model is that when estimating the technical efficiency, it acknowledges that there are random shocks which are beyond the control of the producer that can affect output. Another advantage of the SFA model is the ability to control the stochastic error component in the econometric estimation (Marwa and Aziakpono, 2016). One of the limitation of the SFA model is the possibility of miss-specifying the production function and the unresolved issues of the actual probability distribution of the random component which may cause results to be biased (Marwa and Aziakpono, 2016).

DEA is a non-parametric model developed by Charnes, Cooper and Rhodes (1978). This model is the most widely used non-parametric method that has been applied in the performance evaluation of banks, financial institutions, universities, hospitals and health organisations, manufacturing and service industries (Emrouznejad, Parker and Tavares, 2008). Some advantages of the DEA model are that it is very useful in contexts where there is a multiplicity of inputs used to produce a multiplicity of outputs, and where market prices are absent (Johnes and Tone, 2017). The DEA model is also very useful when the sample size is small. Furthermore, DEA model has been mostly used in public sector where outputs are not sold on the market (Mattsson, Månsson, Andersson and Bonander, 2018). Additionally, it removes the necessity to make random assumptions about the functional form of the frontier and the distributional assumption of the error term. One of the main limitations of the DEA technique is its deterministic nature and therefore this technique is referred as a non-statistical method (Mattsson, Månsson, Andersson and Bonander, 2018). To some extent this can be handled by using resampling methods, such as the bootstrap procedure proposed by Simar and Wilson (1998). Therefore, the DEA approach is seen as the most appropriate to use in evaluating efficiency of HEIs. which is difficult to measure due to the absence of input and output prices (Andersson, Antelius, Månsson, and Sund 2016) and DEA takes care of this deficiency.

Financial constraints have called for more diversification of funding sources, accountability and cost effectiveness by HEIs (Ahmad, Farley and Naidoo, 2012). Evaluation of efficiency in public universities would be an important step in demonstrating how this technique would help HEIs to identify the need to improve their performance and would allow government and all interested stakeholders to evaluate the efficiency of HEIs. Moreover, a significant sum is received by this sector from government funds, making it important to monitor the HE sector on a regular basis for its performance and productivity (Johnes, 2008). Therefore, using available funds efficiently is a serious concern for HE. In the current environment, where public budgets for HE are declining and tuition fees are increasing, there is a sense of urgency to better track the performance of universities in the hope that costs can be contained without compromising quality and accessibility. For universities, improving productivity will be evident in an increasing number of graduates, and amount of learning, research and innovation relative to the inputs used such as enrolment of students, academic and non-academic staff and state funding. Therefore this could be used as the most promising strategy that could be adopted in an effort to keep high quality university education as affordable as possible.

This paper evaluates technical efficiency among twenty-three public South African universities with the aim of allowing policy makers or education stakeholders to know the efficiency levels of universities and determine the target levels for institutions that are inefficient and improvements required to reach a satisfactory level of efficiency. Measuring efficiencies in institutions would be recognised as one of the steps in monitoring and evaluation of public sector universities (Cunha and Rocha, 2012). The next section provides an overview of HE in South Africa, followed by a review of the literature. This will be followed by a discussion of the DEA and bootstrapping DEA scores methods that will be used to evaluate the technical efficiency of public South African universities, and a discussion of the results and observations made.

2. Overview of Higher Education in South Africa

In South Africa HE is divided into public universities, private universities and colleges of further education and training. Public universities and colleges of further education and training are funded by government. According to Statistics South Africa (Census 2011), South Africa has a population of about 51.8 million, 79.2% of whom are Black Africans, followed by Whites and Coloured which each constitute 8.9%, and Indian or Asian constitute only 2.5% of the entire population. In South Africa 62.9% of the population is urban, followed by traditional areas with 31.8% and farms with 5.3%. The apartheid history in South Africa left HE deeply marked by discrimination and authoritarian legacy (Higher Education Transformation Summit, 2015), especially for Black Africans who are the majority in the country. The public universities accept students from poor backgrounds since government supports these students through NSFAS. Therefore, it was important to concentrate on public universities which fall under HE, since they are mainly funded by government. In 1994, the post-apartheid government aimed at transforming HE which during apartheid saw universities separated on a racial basis, and access for students to funding, resources and infrastructure was mainly dependent on racial background (Kotecha, Wilson-Strydom and Fongwa, 2012). The main emphasis on transforming HE in South Africa was to ensure the provision of access for the previously disadvantaged, represented mainly by the Black population. Therefore, HE in South Africa in terms of economic level seeks to redress the skills divide that resulted in fragmented HE.

Post-apartheid, the fragmented and structurally racialised system of 36 public universities were merged into 26 universities which were classified into three broad categories: traditional (University of Pretoria (UP), University of Witwatersrand (Wits), Rhodes University (RU), University of Fort Hare (FH), University of Stellenbosch (SU), University of Cape Town (UCT), University of Western Cape (UWC), University of KwaZulu-Natal (UKZN), University of Free State (FS), University of Limpopo (UL), Sefako Makgatho University (SMU) and North West University (NWU)), comprehensive (University of Johannesburg (UJ), University of South Africa (UNISA), Nelson Mandela Metropolitan University (NMMU), Walter Sisulu University (WSU), University of Zululand (UZ), Central University of Technology (CUT), University of Free State (FS) and University of Venda (UNIVEN)), and universities of technology (Tshwane University of Technology (TUT), Vaal University of Technology (VUT), Cape Peninsula University of Technology (CPUT), Durban University of Technology (DUT), Mangosuthu University of Technology (MUT) and Central University of Technology (CUT)) and 95 private HEIs in 2015 (Higher Education Transformation Summit, 2015). In terms of qualification types, HE is now unified and offers an organised single qualifications framework designed to create clarity with respect to degree and diploma purposes (Council on Higher Education, 2016). There has been a dramatic increase in the number of students entering universities in South Africa, especially Black Africans who were previously denied access. The growth has not been met with sufficient funding so that public HEIs are not able to meet their goals and the increase of funds from government has been negligible (Council on Higher Education, 2016).

Diminishing state funding (in real terms) in the case of South Africa has occurred at a time when the system is in greater need of state financial support as access to HE in South Africa is on the rise (HESA, 2008). There has been a decline in state funding for HE in real terms (1.1% from 2000 to 2012), whereas the percentage of gross domestic product going to HE has remained around 0.7%, which in terms of international standards is low (Langa, Wangenge-Ouma, Jungblut and Cloete, 2016). Most public South African universities are mainly funded by government. In the past two decades, there has been rapid growth of enrolment of students to HEIs in South Africa.

To finance HE the government in South Africa adopted a cost-sharing model between the state and the beneficiaries of consuming HE (Johnstone, 2003). An individual needs to pay more towards their fees due to the fact that more benefits accrue to an individual: but although this is the case, cost sharing is a serious problem in the South African economy due to the high rates of poverty that characterise this economy. It is difficult for many students to attain HE as tuition fees are a major inhibiting factor, and fewer students will be able to attend HE. Therefore the government in SA subsidises the costs of students through financial aid schemes to assist deserving and needy poor students to meet their demands to have access to HE. Evaluating the efficiency of HEIs will be important because if the sector operates efficiently it will free some funds to help fund many students who enter the system. Based on these factors the advantageous universities will attract better students due to better infrastructure and more resources than the disadvantaged universities.

3. Literature review

This section is divided into theoretical and empirical evidence linked to the efficiency evaluation of HEIs.

3.1 Review of theoretical literature

In evaluating the efficiency of HEIs two methods are generally used: the non-parametric method known as Data Envelopment Analysis (DEA), and the parametric method known as Stochastic Frontier Analysis (SFA). The non-parametric technique developed by Charnes, Cooper and Rhodes (1978) was based on linear programming, while the parametric technique developed by Aigner, Lovell and Schmidt (1977) was based along statistical lines (Kosor, 2013). These two approaches provide scholars with the capacity and ease required for modelling the production processes and cost structures of HEIs that are complex. The efficiency measurements involve comparing the actual performance with the optimal performance that is located on the relevant frontier. The frontier is not known and an empirical approximation, known as the "best practice" frontier, is desired.

The production frontier is based on the economic theory of production which is defined as the optimal output produced from given fixed inputs, with the availability of technology that exists to firms involved (Battese, 1992). The economic theory producer behaviour is used in the study as a framework to explain how HEIs transform various inputs into various outputs. Emrouznejad and Cabanda (2015) define production as a process that transforms inputs such as land, labour, capital and entrepreneurship into outputs. Therefore, the underlying issue of efficiency that combines inputs into outputs can be measured by efficiency. The production function that is commonly used is expressed in the functional form:

$$Q = A.L^{\alpha}K^{\beta} \qquad \ldots(3.1)$$

where Q is an output, two inputs L and K represent labour and capital respectively, A represents technology, and α and β represent the output elasticity of labour and capital respectively.

The coefficients α and β can be used to measure returns to scale. If α and $\beta = 1$ and the output remains the same, in terms of efficiency this indicates constant returns to scale (CRS). If α and $\beta < 1$, the output will be less than input and this implies decreasing returns to scale (DRS). If α and $\beta > 1$, the output will be greater than the input and this implies increasing returns to scale (IRS). When combining both the increasing and decreasing efficiency of the firm this will lead to variable returns to scale (VRS).

3.2 Review of empirical literature

The theoretical framework above assisted in understanding the efficiency evaluation framework of HEIs using a non-parametric approach (DEA). The empirical review also proved the reliability of using DEA to measure the efficiency of HEIs. DEA is proposed and adopted for this study. The DEA model has been used since the 1980s to assess the efficiency of different sectors of the economy (Wolszczak-Derlacz, 2014). The literature shows that studies using DEA models were mostly conducted internationally and very few studies have been carried out in Africa.

On the empirical framework, pioneers who worked on the DEA methodology after it was developed by Farrell (1957) and Charnes, Cooper and Rhodes (1978) were Johnes and Johnes (1993) who employed a non-parametric method for the academic year 1989 in economics departments in 36 universities in the UK. They were followed by Coelli (1996b), who employed a DEA model using VRS to 36 Australian universities in calculating both technical and scale efficiencies of universities. A third paper, by Madden, Savage and Kemp (1997), investigated the economics departments of 24 Australian universities for the period 1987 to 1991.

The fundamentals of the literature in HE are formed by the three papers and proved that DEA contributes positively in development of performance indicators in university. Therefore, HEIs analysis of efficiency was built on the theoretical and methodological framework developed by Johnes and Johnes (1993), Coelli (1996a) and Madden, Savage and Kemp (1997).

There has been a growing trend concerning efficiency of HEIs but research has been concentrated on Europe (United Kindom (UK), Germany, Italy, Poland, Switzerland and Portugal) and the United States (US). Veiderpass and McKelvey (2016), Wolszczak-Derlacz (2014) and Wolszczak-Derlacz and Parteka (2011) looked at 17 European countries, ten European countries and the US, and European public HEIs respectively. Cunha and Rocha (2012) and Kempkes and Pohl (2010) looked at Portugal and Germany respectively. Rosenmayer (2014) looked at Canada, Australia, Great Britain, Germany and Spain. The literature about African countries is very scant. Bangi and Sahay (2014) and Al-Bagoury (2013) looked at Tanzanian universities and 15 African countries respectively. To the best of our knowledge, only two papers looked at the relative economic efficiency of South African universities: Taylor and Harris (2004) evaluated economic efficiency of a sample of 10 out of 23 public universities in South Africa using a non-parametric approach and trend analysis. Marire (2017) evaluated economic efficiency of 22 public South African universities using a parametric approach and also finding the determinants of efficiency. This study differs from the approaches used by Harris and Taylor (2004) and Marire (2017) in that it evaluates technical efficiency for public South African universities using a DEA approach and bootstrapped the technical efficiency scores to correct for biasness. The paper also uses different combinations of inputs and outputs in estimating technical efficiency.

Numerous studies in the literature used the DEA model for evaluating the efficiency of HEIs. Several studies have looked at countries' HEIs efficiency using the DEA model in recent years: Anderson, Antelius, Månsson and Sund (2016) in Sweden, Gromov (2017) in Russia, Duan and Deng (2016) in Australia, Moradi-Motlagh, Jubb and Houghton (2016) in Australia, Erkoç (2016) in Turkey, Selim and Bursalıoğlu (2015) in Turkey, Liu and Tsai (2014) in US, Sav (2013) in US, Bangi and Sahay (2014) in Tanzania, Agasisti and Bonomi (2014) in Italy, Srairi (2014) in Tunisia, Nazarko and Šaparauskas (2014) in Poland, Cunha and Rocha (2012) in Portugal, and Taylor and Harris (2004) in South Africa.

In applying DEA successfully when estimating the efficiency frontier, measurement of inputs and outputs is needed. There are differing views on how to measure and quantify inputs and outputs since many of these variables do not have market prices (Srairi, 2014). Moreover, establishing a direct relationship between inputs and outputs is difficult when measuring education efficiency (Bangi and Sahay, 2014). When determining efficiency of HEIs a proximal relationship is applied, for example total enrolment of students cannot be the only variable that leads to graduation in HE, there are numerous contributing factors. Therefore, according to Srairi (2014), selection of outputs does not have definite standards to follow. The objectives of universities, according to international logic, is to teach and research, therefore the number of graduated students and number of published papers are quantified as results (Adamu, Soon and Ahmad, 2016).

Literature which discusses outputs as number of graduates and published papers for evaluating efficiency of universities includes Anderson, Antelius, Månsson and Sund (2017), Marire (2017), Duan and Deng (2016), Erkoç (2016), Bangi and Sahay (2014), Wolszczak-Derlacz (2014), Al-Bagoury (2013) and Agasisti and Johnes (2010).

Input variables of HE are considered less controversial over how they should be quantified (Srairi, 2014). Input variables of HEIs are generally agreed as human and physical capital (for example academic and non-academic staff, number of students, library buildings, computers etc.). Literature that discussed inputs as number of students enrolled includes Anderson, Antelius, Månsson and Sund (2017), Liu and Tsai (2014), Bangi and Sahay (2014); Agasisti and Bonomi (2014); Srairi (2014); Wolszczak-Derlacz (2014); Sav (2013); Al-Bagoury (2013), Daghbashyan (2011) and Franta and Konecny (2009). Numbers of academic and non-academic staff were used by Anderson, Antelius, Månsson and Sund (2017), Gromov (2017), Pietrzak, Pietrzak and Baran (2016), Erkoç (2016), Bangi and Sahay (2014), Srairi (2014) and Wolszczak-Derlacz (2014).

Total income or financial resources for HE is disaggregated into state funding, student fees and private income. Therefore, the income variable has mixed results in the literature: some studies classify total income as output while others classify income as input. Some studies look at disaggregated income while others look at total income. Studies looking at total income or income as disaggregated output variables include Deng and Duan (2016), Pietrzak, Pietrzak and Baran (2016), Erkoç (2016), Srairi (2014), Nazarko and Šaparauskas (2014), Agasisiti and Johnes (2010) and Johnes and Johnes (2008). Studies classifying total income or income as disaggregated input variables include Anderson, Antelius, Masson and Sund (2017), Selim and Bursalıoğlu (2015), Liu and Tsai (2014), Nazarko and Šaparauskas (2014), Wolsczak-Derlacz (2014), Sav (2013) and Cunha and Rocha (2012). For this study income for universities is disaggregated into three: state funding, student fees and private income. State funding has been classified as an input while the other two forms of income for universities, private income and student fees, were classified as ouput.

The next section presents the non-parametric DEA model that was used to evaluate technical efficiency in public South African univerisites and bootstrapping the DEA scores to correct for bias for South African public universities. The efficiency scores can be bias-corrected, as proposed by Simar and Wilson (1998).

4. Methodology

4.1 Analytical Technique

DEA is a non-parametric approach that is derived from the work of Farrell (1957) and Charnes, Cooper and Rhodes (1978). It uses mathematical programming techniques or linear programming techniques that estimate the production possibility frontier and asses the technical efficiency of each decision-making unit (DMU) in relation to the frontier (Johnes and Johnes, 1993). Therefore, the DEA model generally is an operationalised non-parametric model that is either input-output orientated: an input-orientated approach evaluates the ability to minimise inputs while keeping output fixed, while an output-orientated approach evaluates the ability to optimise outputs of the DMU assuming fixed inputs (Selim and Bursalıoğlu, 2015). The main characteristic of the DEA approach is to transform multiple input-output DMUs into a single input-output value for all DMUs. The DEA model is appropriate in assessing the efficiency of a university because it is able to handle inputs and outputs simultaneously (Duan and Deng, 2016). DEA calculates the maximum efficiency measure for each DMU in relation to other DMUs, therefore the technical efficiency measure provided is the ratio of output to input. The DMUs that do not lie on the frontier are said to be inefficient and these are measured against those that lie on the frontier. It is important to note that the aim of DEA analysis is not only to determine efficiency but also to find the target values for input and output for inefficient units. In order to understand the DEA model, let us consider the case of public South African universities which uses input vector $x = (x_1, \dots, x_N) \in R_+^N$ to produce output vector $= (y_1, \dots, y_M) \in R_+^M$. Therefore, the production possibility set is presented by the production set:

$$T = \{(x, y) : \in R_+^{M+N} \ x \ can \ produce \ y\} \qquad \dots(4.1)$$

We assume that outputs will be proportionally increased while the input proportions remain unchanged. For this study the output orientation DEA model based on Variable Reurns to Scale (VRS) proposed by Banker, Charnes and Cooper (BBC model) will be adopted as this requires all DMUs to operate optimally (Duan and Deng, 2016). The output orientation model will be appropriate for HE since the principle of cost minimisation is not applied according to market conditions (Adamu, Soon and Ahmad, 2016). In applying the DEA model the choice of assumption between CRS and VRS needs to be made. In the real world, chosing CRS assumption might lead to misleading results of technical efficiency due to different circumstance faced by universities such as contraints on finances, imperfect competition, etc. (Yuangyai, 2017).

Therefore, the output orientation BBC model will be specified as follows:

$$\max_{\theta_k, \lambda} \theta_k$$

Subject to:

$$\sum_{k=1}^{s} Y \lambda_k \geq \theta y_{ik}, \qquad i = 1, \dots, m \qquad \dots(4.2)$$
$$\sum_{k=1}^{s} X \lambda_k \leq x_{jk}, \qquad j = 1, \dots, n$$
$$\sum_{k=1}^{s} \lambda_k = 1 \qquad \lambda \geq 0$$

The $\max_{\theta_k, \lambda} \theta_k$ represents relative efficiency of universities to be maximised, which yields an efficiency rating that measures the distance to the efficiency frontier. The objective $\sum_{k=1}^{s} Y \lambda_k \geq \theta y_{ik}$ represents maximising output while $\sum_{k=1}^{s} X \lambda_k \leq x_{jk}$ represents a constraint of using given resources. The expression θ_k will be the maximised efficiency and the expression x_{jk} defines the amount of j^{th} input that will be used by the k^{th} university. The outputs are given by y_{ik} for i^{th} output of the k^{th} university where K = 1,…,23 represents universities.

$1 \leq \theta_k \leq \infty$, and θ is the proportional increase in output that may be achieved by the k^{th} university, when holding input constant. Therefore, the technical efficiency score can be defined by $1/\theta$ which varies between zero and one.

4.2 Bootstrapping DEA score

One of the disadvantges of non-parametric DEA model is the lack of statistical inference and bias which can be overcomed by using a bootstrapping procedure (Wolszczak-Derlacz, 2014). Bootstrapping of DEA scores was introduced by Simar and Wilson (1998), allowing the extraction of the sensitivity of efficiency scores which results from the distribution of (in)efficiency in the sample. Bootstrapping allows for construction of confidence intervals for DEA efficiency scores, which relies on smoothing the empirical distribution. The rationale behind the bootstrapping method is to simulate a true sampling distribution by mimicking a data generating process, which are DEA scores. The bootstrapping approach simulates the data generating process multiple times by resampling from the data and applying the original estimator to each simulated sample. Repeating the approach many times allows us to achieve a good approximation of the true distribution of the sampling (Balcombe, Davidova and Latruffe, 2008). According to Ohene-Asare, Turkson and Afful-Dadzie (2017), the aim of bootsrapping is to get the statistical properties of the efficiency scores. The underlying principle of bootstrapping is to approximate the sampling distribution of the the true unknown scores ($\hat{\theta}_k$) of the original scores(θ_k) through a Data Generating Process (DGP) in obtaining bootstrapped estimates (θ_k^*). The difference between the original estimated scores and the true unknown scores of the sample can be approximated by the difference between bootstrapped estimates and the original estimated scores. Following Simar and Wilson (1998), the first computation is a set of bootstrap estimates for the technical efficiency score for each university which is θ_k^* for $b = 1, \dots B$ is the total number of replications performed with pseudosamples drawn from the 'original' (non-bootstrapped) dataset. Then, the bootstrap bias estimate for the non-bootstrapped estimator is calculated as follows:

$$\widehat{bais}_k(\theta_k) = 1 / B \sum_{b=1}^{B} \theta_k^* - \theta_k \qquad \dots(4.3)$$

From the above Eq (4.3) the bias corrected estimator of the technical efficiency scores can be estimated as follows:

$$\hat{\theta}_k^* = \theta_k - \widehat{bais}_k(\theta_k) \qquad \dots(4.4)$$

$$= 2\theta_k - 1 / B \sum_{b=1}^{B} \theta_k^*$$

Where B is the number of bootstrapped samples, Simar and Wilson (2007) suggest using 2,000 bootrapped samples: this study adopted the Simar and Wilson (1998) procedure of bootstrapping DEA scores for creating an inference that is meaningful in a statistical sense and correct for bias from the original estimated scores.

Data

In evaluating the efficiency of public South African universities, the data used in the study is sourced from the Centre of Higher Education and Trust over the period 2009 to 2015. The study looks at public South African universities after the universities merged with technikons during 2001–2007, and the number of public HEIs were reduced from 36 to 23 public universities and categorised into eleven traditional universities, six universities of technology (formerly technikons) and six comprehensive universities (which offer both technikon and university type programmes) (Arnolds, Lillah and Stofile, 2013). In 2015, Mpumalanga and the Northern Cape provinces having just acquired their own institutions, the number of universities was 26. The study looks at the universities that have existed for more than five years. In all, four inputs and four outputs are selected based on frontier efficiency literature in HEIs and availability of data. Table 1 below provides input and output variables for the evaluation of technical efficiency for public South African universities for this study.

Table 1: Input and output variables for evaluating technical efficiency

Input Variables	**Output Variables**
• % state funding ($\boldsymbol{STATE\_FUND}$) • number of students enrolled ($\boldsymbol{STUD\_ENR}$) • number of academic staff ($\boldsymbol{STAFF\_AC}$) • number of non-academic staff ($\boldsymbol{STAFF\_NON}$)	• weighted graduates *($\boldsymbol{GRAD}$)* • research outputs (published journals, books, masters, doctoral and post-doctoral dissertations) • % fees paid by students ($STUD\_FEES$) • % Private income ($INC\_PRIVATE$)

5. Results and discussion

Table 2 below shows the descriptive statistics of the input and output variables for each of the 23 public universities in South Africa that are considered in the study. It is evident that a large proportion of funding for South African public universities comes from government: on average state funding for universities is 44.3% of the total income received by universities from government. The maximum amount of funds to universities is 66.0% and the minimum is 24.0%. The share of private income for universities is very low: on average private income for universities is 22.8% of the total income. The maximum funds for universities from private sources is 56.6% and minimum is 1.1%. This is of concern because some universities struggle to raise funds from private sources. The F-statistics of a one way Anova test conducted to check for difference of variables across time showed no significant differences for all other variables in the dataset except for student fees. Student fees across time showed a significant difference: over the seven years fees have changed significantly. If fees increase, the cost of consuming HE for students increases. The literature shows that HEIs in South Africa have raised funds by increasing student fees above the rate of inflation in order to perform their mandate (HESA, 2008). The F-statistics of the one way Anova test, conducted to check for difference of vatiables across categories, showed significant diffences in the dataset for categories of universities. This shows that university categories are an important factor as they can affect results.

Table 2: Summary statistics of variables used (Pooled)

		GRAD	RESEARCH	STUD_FEES	PVT_ INC	*STATE_FUND*	*STUD_ENROL*	*STAFF_AC*	STAFF_NON
		Number	Number	%	%	%	Number	Number	Number
		y1	y2	y3	y4	x1	x2	x3	x4
Pooled	Mean	6572.6	845.6	33.0	22.8	44.3	40707.3	1023.8	1078.4
	Median	5282.0	549.6	32.1	21.4	45.0	26119.0	894.0	886.0
	Max	34604.0	3193.0	51.0	56.6	66.0	355240.0	4129.5	3527.9
	Min	1258.0	4.1	18.3	1.1	24.0	7012.0	170.1	250.2
	SD	5187.2	797.4	6.5	11.9	8.9	61952.3	657.2	654.6
	N	161	161	161	161	161	161	161	161
Time	F-Stat	0.773	0.217	0.0375 *	0.921	0.92	1	0.98	1
Category	F-Stat	0.0083 **	2e-16 ***	1.83e-10 ***	2e-16 ***	5.24e-16 ***	0.000116 ***	3.36e-05 ***	5.8e-07 ***

Source: Authors' computation using R-studio software (Version 1.2.1335)

Y=Output X=Inputs
'*' $p < 0.05$.
'**' $p < 0.01$.
'***' $p < 0.001$.

Table 3: South African universities by category and province

DMUs	University Name	University	Category	Province
DMU1	Cape Peninsula University of Technology	CPUT	University of Technology	Western Cape
DMU2	Central University of Technology	CUT	University of Technology	Free State
DMU3	Durban University of Technology	DUT	University of Technology	KwaZulu-Natal
DMU4	University of Free State	FS	Traditional Univeristy	Free State
DMU5	University of KwaZulu-Natal	UKZN	Traditional University	KwaZulu-Natal
DMU6	Mangosuthu University of Technology	MUT	University of Technology	KwaZulu-Natal
DMU7	Nelson Mandela Metropolitan University	NMU	Comprehensive University	Eastern Cape
DMU8	North West University	NWU	Traditional University	North West
DMU9	Rhodes University	RU	Traditional University	Eastern Cape
DMU10	University of Stellenbosch	SU	Traditional University	Western Cape
DMU11	Tshwane University of Technology	TUT	University of Technology	Gauteng
DMU12	University of Cape Town	UCT	Traditional University	Western Cape
DMU13	University of Fort Hare	UFH	Traditional University	Eastern Cape
DMU14	University of Johannesburg	UJ	Comprehensive University	Gauteng
DMU15	University of Limpopo	UL	Traditional University	Limpopo
DMU16	University of South Africa	UNISA	Comprehensive University	Gauteng
DMU17	University of Venda	UNIVEN	Comprehensive University	Limpopo
DMU18	University of Pretoria	UP	Traditional University	Gauteng
DMU19	University of Western Cape	UWC	Traditional University	Western Cape
DMU20	University of Zululand	UZ	Comprehensive University	KwaZulu-Natal
DMU21	Vaal University of Technology	VUT	University of Technology	Gauteng
DMU22	University of Witwatersrand	WITS	Traditional University	Gauteng
DMU23	Walter Sisulu University	WSU	Comprehensive University	Eastern Cape

The application of the DEA model for 23 public South African universities for the academic years 2009 to 2015, the technical efficiency using output-oriented approached results are summarised in Table 4. Relative technical efficiency was estimated using the FEAR software (Wilson, 2013) where public South African universities are randomly used and represented by DMU_1 to DMU_{23}. The DEA model indicated that of the 23 public South African universities, thirteen universities (CPUT, CUT, DUT, MUT, NWU, RU, SU, TUT, UCT, UFH, UJ, UNISA and UP) were found to be lying on the efficient frontier for the academic years 2009 to 2015, which indicated that these universities fully use their resources efficiently in fulfilling the objective of teaching and research and are more efficient than the others. The limitation of the DEA model is in explaining why differences occur. Taylor and Harris (2004) explain this using the contingency theory, which says that organisations are influenced by the environment, history, and factors such as size of the organisation, stability of the environment, the personalities involved at all levels of operations, leadership of the entity and the competitiveness of the market. There can be some differences which make some universities more successful and relatively more efficient than others. However, those that were never efficient during the seven years of academic observation were FS and VUT. The average technical efficiency for the seven academic years has declined from 0.978 in 2009 to 0.945 in 2010, increasing in 2011 to 2012, then remained constant in the following year and continued to increase afterwards. The average efficiency scores for the seven academic years are 0.978, 0.945, 0.957, 0.966, 0.966, 0.978, and 0.983. The results for NWU (previously known as Potchefstroom University (PCH)) and UJ (previously known as the Rand Afrikaans University (RAU) indicates that the two universities were efficient. These findings are consistent with Taylor and Harris (2004) who obtained similar results. Taylor and Harris (2004) explain that the diffence in efficiency of these universities is attributed to high graduation numbers and the quality of academic staff. The high graduation numbers for RAU provided a substantial decrease in expenditure per graduate which has a positive effect on efficiency. The quality of academic staff with doctorates were above average at PCH and RAU, so the high graduation numbers was attributed to high quality academic staff appointed to these universities which is positively correlated to efficiency.

When comparing the results of efficiency by categories of university (traditional, comprehensive and universities of technology), of eleven traditional universities, six universities achieved an efficiency score of 1 for the seven academic years observed: NWU, RU, SU, UCT, UFH and UP. Of six universities of technology, five universities achieved an efficiency score of 1: CPUT, CUT, DUT, MUT and TUT, while only one university was inefficient. When comparing efficiency of the comprehensive universities, only two universities were efficient (UNISA and UJ), whereas the other four universities were inefficient. Based on the results, it is concluded that the universities of technology are more efficient than both comprehensive and traditional universities, with average mean efficiency scores of 0.991, 0.968 and 0.955 respectively. Therefore, universities that are not efficient can improve their efficiency score through increasing output or decreasing input and the information that will be provided by DEA will indicate which improvements are needed.

Table 4: Relative VRS Technical Efficiency (TE) of public South African universities, 2009–2015

DMU_s	University	2009	2010	2011	2012	2013	2014	2015	Mean
DMU_1	CPUT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_2	CUT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_3	DUT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_4	FS	0.869	0.744	0.757	0.771	0.760	0.833	0.793	0.790
DMU_5	KZN	0.949	0.919	0.915	0.961	0.981	1.000	1.000	0.961
DMU_6	MUT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_7	NMU	0.991	0.915	1.000	1.000	1.000	1.000	1.000	0.987
DMU_8	NWU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_9	RU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{10}	SU	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{11}	TUT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{12}	UCT	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{13}	UFH	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{14}	UJ	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{15}	UL	0.738	0.761	0.754	1.000	1.000	1.000	1.000	0.893
DMU_{16}	UNISA	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{17}	UNIVEN	1.000	1.000	0.990	1.000	1.000	1.000	1.000	0.999
DMU_{18}	UP	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
DMU_{19}	UWC	1.000	0.834	0.856	0.826	0.756	0.879	0.915	0.867

DMU_{20}	UZ	1.000	0.975	0.782	1.000	1.000	1.000	1.000	0.965
DMU_{21}	VUT	0.945	0.870	0.962	0.936	0.940	0.965	1.000	0.945
DMU_{22}	WITS	1.000	1.000	1.000	1.000	1.000	1.000	0.967	0.995
DMU_{23}	WSU	1.000	0.721	1.000	0.725	0.786	0.818	0.942	0.856
		0.978	0.945	0.957	0.966	0.966	0.978	0.983	0.968

Table 5 shows a summary of average original technical efficiency scores and the bias-corrected efficiency scores using bootstrapping excerise for $B = 2000$. The estimated original technical efficiency scores are headed "b.eff" and the bias-corrected efficiency scores based on bootstrapping are headed "b.eff.bc". Columns 3 and 4 give the original DEA technical efficiency score and the bias-corrected technical efficiency scores respectively. The last two columns provide 97.5% confidence interval for the bias-corrected efficiency estimates. The results reveal that there are marginal changes to technical efficiency scores when bootstrapping was employed to the original technical efficiency scores. The bias-corrected technical efficiency scores became less than the original technical efficiency. Therefore, the results indicate that one should be careful in making relative comparisons of the performances among universities based on the original DEA technical efficiency scores. These results are consistent with literature where DEA scores were boostrapped to correct for bias: the bias-corrected measure, which is the difference beween original efficiency score and bias-corrected efficiency, was less dramatic but still substantial (Simar and Wilson, 1998). When the original technical scores were corrected for bias by bootstrapping non of the univerties were efficient for the period under investigation.

Table 5: Original and bias-corrected efficiency scores

DMU_s	**University**	**b.eff**	**b.eff.bc**	**b.bias**	**Lower Bound (2.5%)**	**Upper Bound (97.5%)**
					Bias corrected	
DMU_1	CPUT	1.000	0.942	0.058	0.834	0.998
DMU_2	CUT	1.000	0.942	0.058	0.815	0.998
DMU_3	DUT	1.000	0.943	0.057	0.827	0.998
DMU_4	FS	0.790	0.766	0.024	0.731	0.788
DMU_5	KZN	0.961	0.925	0.035	0.856	0.959
DMU_6	MUT	1.000	0.936	0.064	0.770	0.998
DMU_7	NMU	0.987	0.941	0.046	0.856	0.985
DMU_8	NWU	1.000	0.948	0.052	0.861	0.998
DMU_9	RU	1.000	0.934	0.066	0.770	0.998
DMU_{10}	SU	1.000	0.935	0.065	0.782	0.998
DMU_{11}	TUT	1.000	0.943	0.057	0.822	0.998
DMU_{12}	UCT	1.000	0.940	0.060	0.806	0.998
DMU_{13}	UFH	1.000	0.935	0.065	0.782	0.998
DMU_{14}	UJ	1.000	0.941	0.059	0.805	0.998
DMU_{15}	UL	0.893	0.858	0.035	0.792	0.892
DMU_{16}	UNISA	1.000	0.934	0.066	0.771	0.998
DMU_{17}	UNIVEN	0.999	0.941	0.057	0.796	0.997
DMU_{18}	UP	1.000	0.935	0.065	0.772	0.998
DMU_{19}	UWC	0.867	0.837	0.029	0.783	0.865
DMU_{20}	UZ	0.965	0.916	0.049	0.788	0.964

DMU_{21}	VUT	0.945	0.918	0.028	0.880	0.944
DMU_{22}	WITS	0.995	0.931	0.065	0.782	0.993
DMU_{23}	WSU	0.856	0.825	0.031	0.770	0.854

6. Conclusion

In South Africa most universities are government-funded. The share of governemt funding for universities has been declining although enrolment rates have been on the rise since the end of apartheid. The post-apartheid government transformed HE so that previously disadvantaged Black Africans and deserving students could gain access to HE. Therefore, it was important to assess the efficiency of public South African universities. The DEA output oriented model based on variable returns to scale was used to assess the efficiency of South African HEIs since the principle of cost minimisation is not applied according to market conditions. The empirical investigation of technical efficiency of public South African universities used 23 public universities in South Africa, only thirteen of which were efficient through out the period under investigation. Therefore, universities will want to improve performance and be the best and this will create favourable competition among universities.

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