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Estimating Wasted Resources in South African Public Schools - A DEA Approach

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Estimating Wasted Resources in South African Public Schools - A DEA Approach[1]

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ABSTRACT

In South Africa, 12 230 191 or 95 per cent of learners are registered in primary and secondary public schools presided over by the nine provinces. The provincial education spending annually constitutes approximately 40 per cent of total provincial expenditure but the general quality of education spending and outcomes remain poor. This points to the existence of inefficiencies in the education sector, warranting a scientific investigation. The present study uses Data Envelopment Analysis (DEA) to determine the technical efficiency/inefficiency of the macro role-players (the nine provinces) in the public education sector in South Africa. A DEA model mathematically identifies the most efficient decision-making unit (DMU) which forms the efficiency frontier (benchmark) against which the model estimates for all the other inefficient units (below the frontier), relative inefficiency scores. The firms with scores of 100 per cent are technically efficient and those with scores lower than 100 per cent are technically inefficient. The 2017/18 total education expenditure (TEE) and the learner-to-educator ratio (LER) are the inputs and the selected output variable is the number of public secondary schools attaining the national senior certificate (NSC) pass rate of 60 per cent or more. The mean technical efficiency score for all nine provinces was 97.9 per cent, implying a potential improvement in the use of inputs by 2.1 per cent. KwaZulu-Natal, Limpopo and Northern Cape were efficient and the other six provinces were inefficient. The six inefficient provinces had potential to improve education expenditure spending efficiency by R24.7 billion to be used for training existing and appointing additional 9 684 teachers. This could result in smaller class sizes and improve educational outcomes.

Keywords: Expenditure, Data Envelopment Analysis, Education, Inefficiency, Technical Efficiency

JEL Classification: C6, D2, I22.

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1. Introduction

According to the South African National Treasury (2018), education expenditure accounted for 40 per cent of annual provincial budgets in the 2017/18 budget cycle. Despite the fact that spending this high proportion of provincial budgets on education, South Africa consistently underperforms with respect to the quality of the National Senior Certificate (NSC) examination results, according to authors such as Bernstein (2011). The majority of learners who passed the NSC exams did not meet the minimum requirements to enrol for a bachelor's degree. According to Modisaotsile (2012) and Donohue and Bornman (2014), the general quality of public sector education was poor with many signs of a crisis, most notably high dropout and low completion rates. Statistics South Africa (2016) states that the upper secondary school completion rate was 55.1 per cent in 2016. In public schools, which account for 95 per cent of learners, the learner-to-education ratio (LER) is 31:1 and in private schools is 15:1 (Department of Basic Education, 2018). The poor educational outcomes are mainly prevalent in public schools, with far less resources than the private schools as can be seen from the LER above. Therefore the focus of this study is only on public sector schools.

Each province has its own unique educational characteristics based on differences in various environmental factors including culture, belief systems, political and social surrounding. If we are then to evaluate a public education system for efficiency (or inefficiency), we need to be able to identify the best performers in the system (within one country) and use that as a benchmark against which we can evaluate the relative performance of the others. In this study, we opt to do this at the aggregate level, in other words we evaluate each of South Africa's nine provinces for the efficiency with which they used the resources at their disposal to achieve educational outcomes. We do this in the belief that at the macro level, even though education policy is centralised, different levels of efficiency may be attributed to efficacy of management/execution at the provincial level which are the responsibility of Provincial Government. We make use of a non-parametric tool (Data Envelopment Analysis - DEA), designed to 'mathematically' identify the best performers and compare them with the technical efficiency deviations of the non-optimal performers. We found that the KwaZulu-Natal, Limpopo and the Northern Cape defined the technical efficiency frontier. The other six provinces were found to be relatively inefficient. The analysis shows that inefficient provinces have the potential to improve the efficiency of education expenditure by R24.7 billion and appoint an additional 9 684 teachers relative to the benchmark while maintaining the same educational outcomes.

The rest of the paper is organised as follows: In section 2, a review of literature using DEA to assess the technical efficiency of primary and secondary education is conducted. In section 3, the methodology and data are outlined, section 4 discusses the efficiency results and section 5 summarises the findings of the study and its recommendations.

2. Literature Review

In terms of the antecedent DEA literature, Arias Ciro and Torres Garcia (2018) assessed the technical efficiency of secondary education in 37 countries between 2012 and 2015. In the first model, 9 per cent of the analysed countries emerged as efficient, while the inefficient countries needed to improve the enrolment rates by 21 per cent. In Model 2, eight countries were efficient and the inefficient Decision-Making Units (DMUs) needed to increase the enrolment rates by 22 per cent, while maintaining the same input levels. Halkiotis et al. (2018) used DEA methodology to evaluate the efficiency of 23 high schools in Greece with data from 2015. The sample mean technical efficiency score was 79.9 per cent. In another study, Gavurova et al. (2017) measured the technical efficiency of secondary education in 31 European (EU) countries for 2015. The VRS efficiency results showed an average technical efficiency score of 95.5 per cent. In 2016, two additional studies by Lauro et al. (2016) and Yuan and Shan (2016) respectively assessed the technical efficiency of the education sectors in Brazil and China. The former study adopted a two-stage DEA model considering 465 elementary Rio de Janeiro schools as DMUs using 2011 data. It found that 30 schools achieved technical efficiency under constant returns to scale (CRS), 65 under the VRS and 30 were scale efficient. Yuan and Shan (2016) used a four single-stage DEA models to determine the efficiency of 17 Shanghai districts. The mean efficiency scores for these models were 84.8, 84.8, 87.5 and 93.1 per cent respectively.

Huguenin (2015) used DEA to analyse the technical efficiency of 90 primary schools in Switzerland from 2010 to 2011. The study found that on average, each school could improve the use of inputs by 7 per cent while maintaining the same quality of pupil performance. The research by Hussain et al. (2015) used DEA to assess the technical efficiency of six rural and six urban schools for a period of 20 years. The study observed an average efficiency score of 84.2 per cent under the CRS. The average pure technical efficiency score was 91.5 per cent under the VRS. Lavado and Domingo (2015) sampled 38 Asian countries for a period of seven years. The inefficient countries overspent by 27 per cent at prevailing output levels and could raise their outputs by 6 per cent using the same levels of expenditure. Baciu and Bolezat (2014) used DEA to gauge the efficiency of public expenditure in 27 EU member states from 2000 to 2009. The average efficiency rate was 67 per cent, calling for an improvement in the use of education expenditure by 33 per cent. Salazar-Cuéllar (2014) appraised the technical efficiency of public spending in 15 Latin American countries using cross-country data between 2000 and 2009. The output-maximisation oriented results showed that inefficient countries could increase primary education output indicators by 3 to 4 per cent while input-minimisation results reflected that inefficient countries wasted between 37 and 45 percent of resources. In terms of secondary education, the inefficient countries could, on average, increase the secondary school enrolment and its quality by 6 and 10 per cent and pertaining to inputs, inefficient countries were wasting between 32 and 44 per cent.

A study by Yawe (2014) analysed the technical efficiency of 500 schools in Uganda from 1995 to 2005. The CRS and VRS technical efficiency scores were 85.6 and 94.4 per cent respectively. In 2013, a study by Prasetyo and Zuhdi (2013) sampled 81 countries, including South Africa, to evaluate the technical efficiency of their education systems from 2006 to 2010. The authors deduced that 16 DMUs, excluding South Africa were always efficient during the study period. In 2011, Aristovnik (2011) assessed the technical efficiency of 37 EU countries from 1999 to 2007. The study presented varying results for primary and secondary education. The average efficiency scores for primary and secondary education were 95 and 91.8 per cent respectively with possible output-expansions of 5 and 8.2 per cent by the inefficient DMUs.

3. Methodology and Data[5]

This paper uses a DEA to determine technical efficiency. Cooper et al. (2007) and McWilliams et al. (2005) state that DEA tightly envelops the production technology to generate ideal efficiency frontiers. According to Taylor and Harris (2004), DEA enables relative public institutions operating in the same environment to compute technical efficiency. This study uses the Banker, Charnes and Cooper (BCC) model (variable returns to scale - VRS model) described by Gavurova et al. (2017) to determine efficiency. The reason for selecting the VRS model is because, according to Fried et al. (2008), the efficiency results calculated through the VRS model is always superior to the CRS-based results as the former more tightly encloses the production technology. According to Aristovnik (2012) and Martić

[5] The datasets used for the study are available from the corresponding author on reasonable request. This particularly relates to the DEA model inputs and results. Most of data sources are listed in the reference list.

et al. (2009), depending on the objectives of a particular study, the VRS model can be categorised into an input-minimisation and output-maximisation orientation. The former computes efficiency scores by determining the extent of improvement in the use of inputs to reach the efficiency frontier while holding the level of outputs constant. The latter is the exact opposite. It is purported by Wang and Alvi (2011), that DEA is study-specific; it only uses information derived from a particular study without considering exogenous factors. Therefore, the efficiency results are dependent on the appropriate selection of the analytical variables.

Under the VRS model, suppose there are M different number of inputs and P different number of outputs for N DMUs. These quantities are represented by column vectors xij (i = 1, 2, 3, …M, j = 1,2,3 …N) and qrj (r = 1, 2, 3, …P, j = 1,2,3 …N) The $M\ x\ N$ input matrix, X and $P\ x\ N$ output matrix, Q represents the production technology for all the N number of DMUs. For each DMU, the ratio of all the output variables over all the input variables is represented by u'qrj/v'xi. Where u $= P\ x\ 1$ vector output weights and v $= M\ x\ 1$ vector input weights. The optimal weights or the efficiency estimates are obtained by solving a mathematical problem. In the context of the CRS, an efficient DMU operates at most productive scale size (MPSS) or technically optimal production scale (TOPS). Hence, the optimal weights or efficiency estimates are obtained by solving a mathematical problem that is reflected in equation 1.

$$\begin{aligned} &\text{Tops} = \max_{u,v} (u'q_{rj}/v'x_{ij}) \\ &St. \\ &u'q_{rj}/v'x_{ij} \le 1 \qquad (1) \\ &u, v \ge 0 \end{aligned}$$

Equation 1 shows the original linear programme, called the primal. It aims to maximise the efficiency score, which is represented by the ratio of all the weights of outputs to inputs, subject to the efficiency score not exceeding 1, with all inputs and outputs being positive. Equation 1, has an infinite number of solutions, if (u,v) is a solution, so is αv,αv. To avoid this, one can impose a constraint v'xij =1, which produces equation 2.

$$\begin{aligned} &\text{maxu,v} (u'q_{rj}) \\ &St. \\ &v'x_{ij} = 1 \qquad (2) \\ &u'q_{rj} - v'x_{ij} \le 0 \end{aligned}$$

u, v ≥ 0

An equivalent envelopment problem can be developed for the problem in equation 2, using duality in linear programming. The dual for $\max_{u,v}$ (u'qrj) is $min\theta, \lambda\theta$. The value of θ is the efficiency score; it satisfies the condition $\theta \leq 1$; it is the scalar measure. Lauro et al. (2016) report that λ is an $NX1$ vector of all constants representing intensity variables indicating necessary combinations of efficient entities or reference units (peers) for every inefficient DMU, it limits the efficiency of each DMU to be greater than 1. This results in equation 3, which represents the VRS model with an input minimisation orientation. Gannon (2005) advises that the VRS should be used if it is likely that the size of a DMU will have a bearing on efficiency.

$$Min\theta, \lambda\theta$$

St.

$$-\mathrm{q}rj + Q\lambda \geq 0 \quad (3)$$

$$\theta \mathrm{x}ij - X\lambda \geq 0$$

$$N1'\lambda = 1$$

$$\lambda \geq 0$$

As the model of this study considers slack and radial movements for the inefficient provinces, these are accounted for in equation 4. Coelli et al. (2005) define slacks as input excesses and output shortfalls that are required over and above the radial movements to push DMUs to efficiency levels. Both the slack and radial movements are characterised only with inefficient DMUs. The radial movements are initial input contractions or output expansions that are required for a firm to become efficient. The efficient DMUs with any slacks movements depict weak efficiency and require further radial movements. In equation 4, Si^{+} and Si^{-} are output and input slacks respectively to be calculated with θ, and λn. ε, is the non-Archimedean constant.

$$\text{Min } \theta, \lambda j, Sr^{+}, Si^{-}$$

$$\theta - \varepsilon \left[\sum_{i=1}^{M} Si^{-} + \sum_{r=1}^{P} Si^{+} \right]$$

$$St.$$

$$\theta \mathrm{x}i_0 - \textstyle\sum_{j=1}^{N} \mathrm{x}ij\, \lambda j - Si^{-} = 0, \quad (4)$$

$$\theta \mathrm{q}r_0 = \textstyle\sum_{j=1}^{N} \mathrm{qr}j\, \lambda j - Sr^{+} = 0,$$

$$\sum_{j=1}^{N} \lambda j = 1$$

$\lambda j, Sr^{+}, Si^{-}$

In this paper, we use a single BCC model with an input-minimisation objective to analyse provincial technical efficiency in the provision of primary and secondary education for the 2017/18 financial year. The model considers TEE and the LER as inputs and the PSNSC with a pass rate ≥ 60 per cent as an output variable. The education efficiency literature (see literature review), shows that human resource variables such as the number of teachers and/or students are commonly used input variables in this setting. The same applies to using education results as an output. The sample consists of nine provinces of South Africa and Table 1 summarises the efficiency data.

Table 1: Input and Output Variables

Provinces	Education inputs		Education output
	x1 (TEE)	*x2 (LER)*	*y1(SNSC)*
Eastern Cape	33 344 643	30	523
Free State	13 534 735	30	312
Gauteng	41 786 542	30	835
KwaZulu-Natal	48 286 416	31	1243
Limpopo	29 255 925	32	814
Mpumalanga	19 535 077	30	445
Northern Cape	6 069 346	28	114
North West	15 107 481	31	364
Western Cape	20 722 693	30	413
Observations	9	9	9
Mean	25 293 651	30	563
Minimum	6 069 346	28	114
Maximum	48 286 416	32	1 243
Median	20 722 693	30	445
Standard deviation	13 110 046	1	323

Notes: TEE is actual expenditure measured in R'000. LER is the ratio of total leaners to educators in a particular school. PSNSC with a pass rate ≥ 60 refers to public secondary schools with NSC results ≥ 60 per cent.

Sources: Department of Basic Education (2018), Department of Education of Province of KwaZulu-Natal (2018), Department of Education of Province of Mpumalanga (2018), Eastern Cape Education (2018), Free State Department of Education (2018), Gauteng Department of Education (2018), Limpopo Department of Education (2018), Northern Cape Department of Education (2018), North West Department of Education (2018).

4. Efficiency Results

Table 2 shows that the nine DMUs (provinces) have an average technical efficiency score of 97.9 per cent. That is, six DMUs were inefficient while three (KwaZulu-Natal, Limpopo and the Northern Cape) were efficient. The six inefficient DMUs could improve efficiency by 2.1

per cent. The average scale efficiency score was 83.1 per cent. Only KwaZulu-Natal and Limpopo were scale efficient. This implies that the other six DMUs were not operating at optimal scale. They needed to improve relative to scale efficient DMU to operate at an optimal scale.

Table 2: Efficiency Scores

Province	Efficiency results	Scale Efficiency	
Eastern Cape	0,970	0,602	IRS
Free State	0,969	0,882	IRS
Gauteng	0,997	0,776	IRS
KwaZulu-Natal	1,000	1,000	-
Limpopo	1,000	1,000	-
Mpumalanga	0,963	0,866	IRS
Northern Cape	1,000	0,677	IRS
North West	0,949	0,911	IRS
Western Cape	0,960	0,766	IRS
Mean	0,979	0,831	

Source: Authors

Table 3: Education Statistics

Province	Learners	LER	Educators	Educator requirements
Eastern Cape	1 775 602	29,1	61 017	1 693
Free State	688 976	29,1	23 676	1 036
Gauteng	2 109 890	29,9	70 565	1 385
KwaZulu-Natal	2 773 823	30,7	90 353	-
Limpopo	1 659 635	32,1	51 640	-
Mpumalanga	1 026 151	28,9	35 507	1 826
Northern Cape	291 461	28,5	10 227	-
North West	820 545	29,4	27 910	1 782
Western Cape	1 084 111	28,8	37 643	1 962
Total	12 230 194	29,9	408 537	9 684

Source: Department of Basic Education (2018b).

Tables 3 and 4 indicate the radial and slack movements associated with the efficiency results that are in Table 2. The inefficiency rate of 3 per cent for the Eastern Cape implies an improvement in the use of TEE by R11.8 billion and a 0.9 per cent improvement in the LER (1 693 additional teachers) to reach the efficiency frontier. The efficiency score of the Free State Province of 96.9 per cent translates into an inefficiency score of 3.1 per cent, equivalent to improving spending by R404 million and the LER by 0.9 per cent (1 036 more teachers). The Gauteng Province recorded an efficiency score of 99.7 per cent. To reach the efficiency frontier, it could improve expenditure efficiency by R8.2 billion and the LER by 0.1 per cent (1 385 more teachers).

The Mpumalanga Province realised an efficiency score of 96.3 per cent, needing to improve efficiency by 3.7 per cent. To be relatively efficient, it needed to improve education spending efficiency by R702 million and improve the LER by 1.1 per cent (1 826 extra teachers). The North West Province had a score of 94.9 per cent, needing to improve efficiency by 5.1 per cent; equivalent to spending R14.2 billion less on education and appointing 1 782 additional teachers or improving the LER by 1.6 per cent. The Western Cape's inefficiency rate of 4 per cent implies improving spending efficiency by R2.9 billion and the LER by 1.2 per cent (1 962 teachers).

Table 4: Total Education Expenditure and Learner-to-Educator Ratio Radial and Slack Movements: VRS

Provinces	Eastern Cape	Free State	Gauteng	KwaZulu-Natal	Limpopo	Mpumalanga	Northern Cape	North West	Western Cape	Total
TEE original input	33 000 000	13 000 000	41 000 000	48 000 000	29 000 000	19 000 000	6 000 000	15 000 000	20 000 000	224 000 000
TEE radial movement	(1 005 000)	(404 000)	(115 000)	-	-	(702 000)	-	(767 000)	(804 000)	(3 797 000)
TEE slack movement	(10 780 000)	-	(8 063 000)	-	-	-	-	-	(2 073 000)	(20 916 000)
TEE target	21 215 000	12 596 000	32 822 000	48 000 000	29 000 000	18 298 000	6 000 000	14 233 000	17 123 000	199 287 000
LER original input	30	30	30	31	32	30	28	31	30	272
LER radial movement	(0,9)	(0,9)	(0,1)	0,0	0,0	(1,1)	0,0	(1,6)	(1,2)	(5,8)
LER slack movement	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
LER target	29,1	29,1	29,9	31,0	32,0	28,9	28,0	29,4	28,8	266,2
Original output	523	312	835	1 243	814	445	114	364	413	5 063
Output radial movement	-	-	-	-	-	-	-	-	-	-
Output target	523	312	835	1 243	814	445	114	364	413	5 063
DMU peers	4;7	4;5;7	4;7	4	5	4;5;7	7	4;5;7	4;7	

Notes: TEE = Total education expenditure. LER = Learner-to-educator ratio and TEE is in R'000.

Source: Authors, based on efficiency results.

5. Conclusions

This study determined the average technical and scale efficiency rates of provincial education in South Africa using a non-parametric approach called DEA. This model identifies the most efficient performer(s) (DMU), which forms the efficiency frontier. All other DMUs (provinces) below the frontier are inefficient and the model estimates the magnitude of the deviation from the efficient frontier (benchmark), which is also indicative of wasted resources. We found that only KwaZulu-Natal, Limpopo and Northern Cape were efficient in the use of total resources (education expenditure and learner-to-educator ratio) – in other words, these three provinces were on the efficiency frontier. The other six provinces were inefficient. Relative to efficient DMUs, they could improve spending on education by R24.7 billion to reach the efficiency frontier. In other words, if these six inefficient provinces can improve their efficiency up to the benchmark, they would save R24.7 billion (in 2017/18) that can be allocated to improvements in educational outcomes in South Africa. For example, this saving or re-allocation of resources could be applied to hiring more teachers (9 684) or re-train existing teachers to improve the quality of education by delivering higher NSC pass rates and improved quality of pass rates (more learners with mathematics and science).

In conclusion, one important qualification should be made. In South Africa, which spends a higher proportion of its total budget on education than most other developing and emerging market economies, the quality of educational outcomes is one of the lowest. This may mean that even the efficient provinces set a very low benchmark relative to peers. This suggests that resource wastage may be underestimated in this study and potential gains from efficiency improvements may be far larger than expected.

In terms of limitations, this study only determines the inefficiency levels of TEE and the LER without explaining the factors resulting in these inefficiencies. As a result, it is difficult to understand why such inefficiencies or efficiencies exist.

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Appendix 1

Selected Primary and Secondary Education Efficiency Studies and Data

Author(s)	Factors of production	Outputs
Arias Ciro and Torres García (2018)	2 inputs (financial and non-financial) Teacher-to-pupil ratio Government and private expenditure per secondary student % of GDP	4 outputs Enrolment rates PISA reading score PISA Maths score PISA science literacy
Halkiotis, et al. (2018)	3 inputs (financial and non-financial) Teacher-to- student ratio Average number of students per class Average annual expenditure per pupil	4 outputs Percentage of students admitted to university Percentage of students admitted to higher education technological institutes Percentage of students with excellent performance to university entrance between 18 and 20 The number of graduates not admitted in Higher Education
Gavurova, et al. 2017	1 input (financial) Government expenditure on secondary education % of GDP	3 outputs PISA maths score PISA reading score PISA science score
Lauro, et al. (2016)	4 inputs (non-financial) Number of employed teachers Number of school staff Number of computers Number of classrooms	3 outputs Number of students served by the school Average pass rate from grade 1 to 5 Average grade 5 standardised Prova Brasil score
Yuan and Shan (2016)	3 inputs (financial and non-financial) Total budget per capita Equipment budget per capita Teacher-to-pupil ratio	3 outputs Quota per class Quota per school Student density per Km2
Huguenin (2015)	3 inputs (financial and non-financial) Number of full-time equivalent teaching staff Number of full-time equivalent administrative and technical staff School budget	3 outputs Grade 2 results in French and mathematics Grade 4 results in French, German and mathematics Grade 6 results in French, German and mathematics
Hussain, et al. (2015)	3 inputs (non-financial) Number of employed teachers Number of institutes Infrastructure	2 outputs Enrolment rate Student-teacher ratio
Lavado and Domingo (2015)	1 input (financial) Education expenditure per capita	2 outputs Percentage of pupils completed primary education Percentage of pupils completed secondary education
Baciu and Bolezat (2014)	1 input (financial) Actual education expenditure	2 outputs Secondary school enrolment Quality of education results: mathematics and science
Salazar Cuéllar (2014)	2 inputs (financial and non-financial) Public education expenditure per student Percentage of teachers per student	3 outputs Youth literacy rate Net enrolment rate Completion rate
Yawe (2014)	5 inputs (non-financial) Total number of teachers in a given primary school Total number of pupils in a primary school Total number of classrooms in a primary school Total number of toilets in a primary school Average class size	4 outputs Pass rates: number of pupils who passed examinations with 4–12 aggregates Pass rates: number of pupils who passed examinations with 13–23 aggregates Pass rates: number of pupils who passed examinations with 24–29 aggregates Pass rates: number of pupils who passed examinations with 30 –34 aggregates
Prasetyo and Zuhdi (2013)	3 inputs (financial) Government expenditure per capita Education subsidies Other educational transfers	2 outputs HDI: years of schooling of adults aged 25 years HDI: years of schooling of children of school entering age
Aristovnik (2011)	1 input (financial) % GDP per capita secondary school expenditure per student	3 outputs Primary school enrolment Primary school teacher-pupil ratio Primary school completion rate
Houck, Rolle and He (2010)	1 input (financial) Expenditure per pupil	5 outputs AP tests passed per 1,000 students District average SAT test score Percent passing the math section of the Georgia high school exit exam Percent of students passing the math portion of the Georgia high school graduation test State-calculated graduation rate

Source: The authors