



<http://www.eab.org.tr>

Educational Research Association
The International Journal of Research in Teacher Education
2019, 10(1): 31-40
ISSN: 1308-951X



<http://ijrte.eab.org.tr>

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

Iddrisu Sulemana¹,
Mohammed Abubakari Sadick^{2*},
Oswin Aganda Anaba³,
Hira Salah Ud Din Khan⁴

Abstract

As efficiency plays a pivotal role in the realization of quality education and teacher training institutions are the lifeblood of quality teachers, the present study presents the results of an efficiency study of some selected Ghanaian public universities colleges of education in the three Northern Regions of Ghana from 2012-2017. Through the use of Slack Based Model of Data Envelope Analysis and a model of CCR, our results indicate that Tamale College of Education and Tumu were the only efficient colleges out of the four selected colleges in the study domain. While Bagabaga College of Education and St. John BOSCO were the inefficient colleges during the study period of 2012 – 2017. The results also suggested that by adopting best managerial practices, the Colleges can, on an average, reduce their inputs by at least 2.2% and still produce at the same level of outputs. According to the slack-based results, only two Colleges that is, Bagabaga College of Education and St. John BOSCO were inefficient and needed adjustment in inputs and outputs to become efficient.

Keywords: collages of education; data envelope analysis; slack-based model; efficiency

¹Tamale College of Education, email: sulesakabu@yahoo.com

²School of Management, Department of Marketing, Jiangsu University, email: 5103160205@stmail.ujs.edu.cn, hirasbk1@gmail.com

³Bolgatanga Polytechnic, Department of Liberal Studies, email: oswinaganda@yahoo.com

⁴*Corresponding author: Mohammed Abubakari Sadick, email: 5103160205@stmail.ujs.edu.cn

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

Introduction

It is worthy of note to appreciate that motivated and well trained teachers will play an indispensable role towards the realization of Sustainable Development Goal (SDG 4) for 2030 (UN, 2016; Unwin, 2005). As argued by Unwin (2005), unhappy and dejected teachers will find it difficult to inject into twenty first century students the expected knowledge and skills needed to achieve the full benefits of SDGS in particular, quality education as enshrine in SDG goal 4. Drawing on this logic, quality education serves as a vehicle and a tool to addressing community and global difficulties (UN, 2016). Given the significance of teacher training institutions in the promotion of socio-economic health of global communities, successive and present governments in Ghana have invested enormously in the sector with the ultimate goal for achieving literate population. For instance, the total budget allocated to the Ministry of Education in 2017 was 11.6% of GHS 9.12 billion, whilst in 2018 the designated spending was GHS 10.18 billion (Ministry of Finance, 2019).

In spite of this generous investment in the sector, the Ghanaian teacher training colleges now University Colleges of Education system in recent times been called into question by some scholars on the basis that, quality of teachers being churn out from these institutions failed to meet the standards' of the profession and more importantly lack focus on the practical demand on actual teaching (Akyeampong, 2003). This scenario of professional incompetence of the teacher trainees demonstrates inefficiency on the teacher training institutions for producing quality teachers. Thus, it defeats the mission and core mandate of the institutions for churning out quality teachers to meet the need of quality education. The government of Ghana through the Ministry of Education had established National Council for Tertiary Education (NCTE) among other responsibilities aim at training quality teachers to feed in the public schools in Ghana to boost quality education. Even though the current study supports the premise of efficient and quality trained teachers in part, we seek to emphasize that the analysis of efficiency that we have pursued is limited to only four Public University Colleges of Education (PUCE) in some selected colleges in the three Northern Regions of Ghana, thus excluding other PUCE. Thus, the analysis is limited to only four colleges not the entire colleges in the country.

In summary, the objective of this study is to assess the efficiencies of the four selected PUCE in the three northern regions of Ghana via data envelope analysis (DEA) and to determine the slack variables contributing to inefficiency of the selected colleges.

Theoretical Backgrounds

Literature on DEA concedes that is predominantly used as a tool in analysing performance across government and private sectors of similar production components with several resources. In addition, it proffers new insights into activities evaluated by other methods (Copper, Seiford, & Tone, 2007) and use to calculate efficiency in varied areas, such as economic sector (Kwon & Lee, 2015; Tao, Liu, & Chen, 2013; Tsolas & Charles, 2015; Wanke & Barros, 2014) security force performance, assets allocation, ecological efficiency or energy sector (Aristovnik, Seljak, & Mencinger, 2014; Azadeh, Haghghi, Zarrin, & Khaefi, 2015; Du, Cook, Liang, & Zhu, 2014; Fang & Li, 2015; Lozano, 2015; Omrani, Beiragh, & Kaleibari, 2015; Woo, Chung, Chun, Seo, & Hong, 2015). Moreover, application of DEA is not limited to only industries but can be applied in service institutions such as the education sector. As pointed out by scholars, DEA is a potent tool that can be used to assess the performance of teachers, university colleges, academic programs and primary education institutions (Souza & Gomes, 2015; Escorcía Caballero, Visbal Cadavid, & Agudelo Toloza, 2015; Grosskopf, Hayes, & Taylor, 2014; Huguenin, 2015; Visbal-Cadavid, Martínez-Gómez, & Guijarro, 2017).

Supply Chain Management in Education (SCME)

The SCME epitomizes the integration of supply chain management ideals that are fused into the educational system. It is a novel model that businesses and firms apply to enhance and boost

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

educational management tasks. Extant study has observed that supply chain management (SCM) is predominantly used by profit orientated entities but it is argued that it can equally apply in the services sectors such as education (Gopalakrishnan, 2015). Linking this assumption of supply chain in the context of PUCE, the fundamental suppliers of process input is the students who offer their minds, brains, body and information to depict inputs to the service process (Lau, 2007). As the focal lens of PUCE is on teaching along the research work of tutors, SCME denotes the process converting inputs which in this context are the teacher trainees and research of tutors via the educational procedure to achieve outputs (student teachers outcomes).

The processing of the PUCE embodies the academic staff, non-academic staff, and infrastructure. The teacher trainees are the supply output and the quality of research results of tutors that have achieved value by means of the process through scrutiny (Jauhar, Pant, & Nagar, 2016).

The Teaching Supply Chain

It is indicated that, the success of students' academic achievement largely depends on the teaching supply chain and it depicts the supply chain network for students (Jauhar et al., 2016). Students are considered the raw materials in the context of 'Teaching' supply chain; and are processed through various services which includes, lectures and course work, non-academic training, social events, sports and counselling services, practical training, final year project works, end of semester exams, and internships and recruitment training. Thus, the end results /products of the teaching supply chain are the graduates (student teachers who completed successfully).

The Research Supply Chain

Research plays a pivotal role in the success of PUCE and it entails generation of research idea, development of instrument, data collection, analysis, findings, and suggestion of future research. The individuals who constitute in research activities are the researchers, academic and non-academic staff as well as industries. It forms the basis in the PUCE activity process whereby the supply chain idea is regarded as the raw material in the research supply chain and the end result is the research outcome.

Sustainability in educational SCM

Sustainable SCME manages supplied input/output process along teaching and research in supply chain in simultaneous consideration of environmental variables. Similarly, sustainable SCM is about managing environmental, social, and economic indicators that spur good governance practices in the lifecycles of goods and services with the aim of generating, safeguarding and ensuring long-term growth of environmental, social, and economic values (Izadikhah & Saen, 2018).

Methodology

Studies on DEA recognized Charnes, Cooper and Rhodes as scholars who proposed it as a methodological tool following the concept introduced by Farrel in 1957 (Charnes, Cooper, & Rhodes, 1978). More often, the technique involved in DEA as a methodological tool uses linear programming to compare production units that handle the similar resource and produce similar group of products, producing an efficient frontier and related efficiency indicators within the population of production units under studied. In this regard, selected PUCE in the three northern regions of Ghana (TUMU, TATCO, BATCO and St. John BOSCO) form the DMUs can be considered as series of firms that convert resources into products. The objective behind DEA is premise to identify the DMUs that yield the maximum output levels by using the least input levels. A DMU attains 100% (1) potency only if none of the inputs or outputs can be enhanced without deteriorating some of its other inputs or outputs.

Considering this, PUCes are critical and significant educational pipeline in Ghana's educational

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

agenda as far as nurturing and training of teachers are concern. Ghana has ten regions and each region has one or two PUCes that train teachers to teach in the public schools. In this study, data is obtained from Ministry of Education under the teachers' division unit. According to National Council of Tertiary Education (NCTE), Ghana currently has 46 PUCes. Out of this number, the current study investigated 4 in some selected colleges in the three northern regions of the country. The aim of this is to assess the effect of teaching and research efficiency of the selected 4 PUCes for a period of six years (2012-2017) with the use of suitable inputs and outputs.

Data and Variables

Data-The current study explores efficiency differences of some selected PUCE in the three Northern Regions of Ghana – Northern Region, Upper East Region and Upper West Region. Data are collected from TUMU Training College (TUMU), Tamale Training College (TATCO), Bagabaga Training College (BATCO), St. John Bosco Training College (BOSCO) and Ghana Education Service under the teachers' division.

Variables- several studies have been conducted in the educational sector through DEA but, study on it in the PUCE is scanty and again, little is seen about the nature of the educational production function (Koshal, Koshal, & Gupta, 2013) and criteria set aside in the selection of inputs and outputs is rare thus, choice of educational analysis is a pressing factor. Literature on school related variables are seen as; classrooms, number of students, disbursement, qualification, and academic staff, non- academic staff as inputs variables and publications and graduants as output variables (Tyagi, Yadav, & Singh, 2008).

Table 1: Definition of Variables

Category	Variables	Descriptions
Inputs	Number of Students	Total Number of students from year 1-3
	Number of non-academic Staff	Total number of employees not directly involved in teaching
	Number of academic Staff	Total number of employees directly involved teaching
	Qualifications	Teaching staff who attain M.edu, M.phil, M.Sc., PhD, etc.
	Disbursements	Allowances given by government to students to support their educational needs
	Number of Classrooms	Number of classrooms use for teaching and learning
Outputs	Publications	Number of research papers published by teachers and students yearly
	Graduants	Total number of students graduating from the collages

Slack Based Model DEA

Tone (2002) developed a Slacks Based Measure (SBM), an additive model which takes into consideration the scalar measure of efficiency that takes into account the input surplus and output deficits concurrently time with the goal of maximizing both the input and the output. The model depicts constant and a uniform decreasing with respect to input excesses and output deficit. Similarly, the potency of a DMU evaluated should be determined by conferring its location set unaffected by data information set and returns effectiveness scores between 0 and 1, as in the spiral DEA model. The following index p

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

$$p = \frac{1 - 1/m \sum_{i=1}^m s_i^- / x_{i_o}}{1 + 1/s \sum_{r=1}^s s_r^+ / y_{r_o}} \quad \text{eq (1)}$$

$$s.t \quad \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{i_o}, i = 1, \dots, m \quad \text{eq (2)}$$

$$\sum_{j=1}^n \lambda_j y_{rj} + s_r^+ = y_{r_o}, r = 1, \dots, s$$

$$\lambda_j \geq 0, j = 1, \dots, n, \quad s_i^- \geq 0, i = 1, \dots, m, \quad s_r^+ \geq 0, r = 1, \dots, s.$$

Where:

λ_j = are the dual variables

s^- = vector containing the input surplus values of each DMU

s^+ = vector containing the output shortage values of each DMU

y_{rj} = amount of outputs produced by j

x_{ij} = amount of inputs used by j

The SBM potency score is less than CCR effective score, and CCR inept DMU failed to meet SBM efficient. The SBM efficiency score is stabilized between zero and one, and is achieved if, $p^* = 1$, then it depicts efficient, because $p^* = 1$ means slacks are zero and the DMU position on the efficient limit. The SBM score is components' invariant.

Results

Table 2 depicts the summarised form of the slack-based efficiency scores, where efficiency scores of some selected University Colleges of Education in the three Northern Regions of Ghana and their years are reported. The results show an average overall score efficiency of 0.98 or 98% over the 6-year period. The five-input and two-output model from Table 2 indicate two colleges (TUMU and TATCO) of the four selected college of education in the Northern regions are efficient. From the overall score for each sampled college, BATCO and BOSCO were the inefficient colleges during the study period of 2012 – 2017. In addition, the mean observation from the various years suggest that apart from 2012 which was the only efficient year, the rest of the years (2013-2017) in the study period were inefficient. The general performance of all the colleges clearly shows how prudent they are when it comes to their inputs and output resources respectively.

Table 2: The slack-based efficiency results of Public Universities Colleges of Education in Ghana from 2012 to 2017

DMUs/Years	TUMU	TATCO	BATCO	BOSCO	Mean	Rank
2012	1	1	1	1	1	1
2013	1	1	0.973	0.836	0.952	6
2014	1	1	0.861	1	0.965	4
2015	1	1	1	0.965	0.991	3
2016	1	1	1	0.827	0.957	5
2017	1	1	1	0.999	0.999	2
Mean	1	1	0.972	0.938	0.978	

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

Rank 1 1 3 4

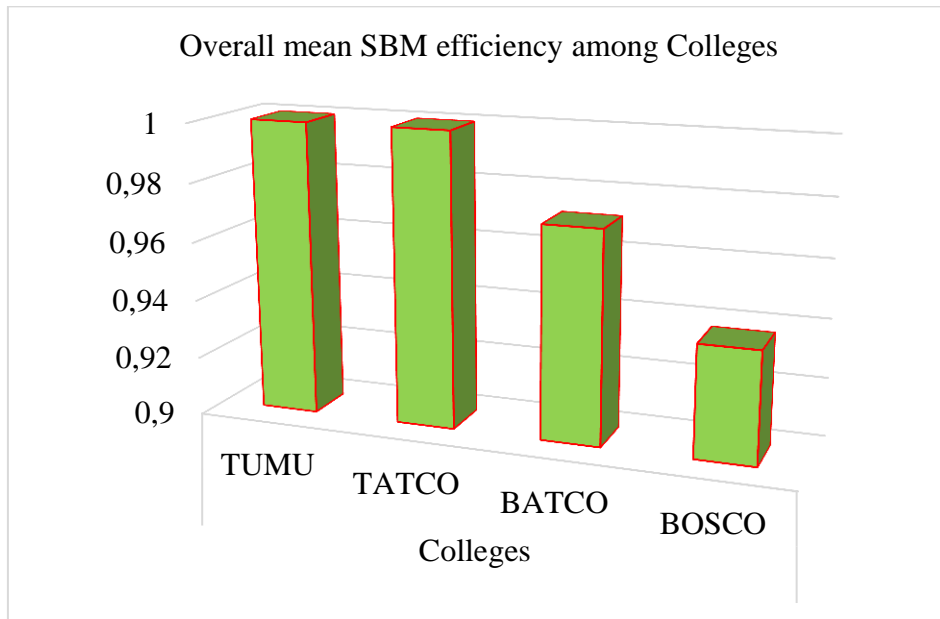


Figure 1: Trend of overall mean slack-based efficiency among the colleges of education

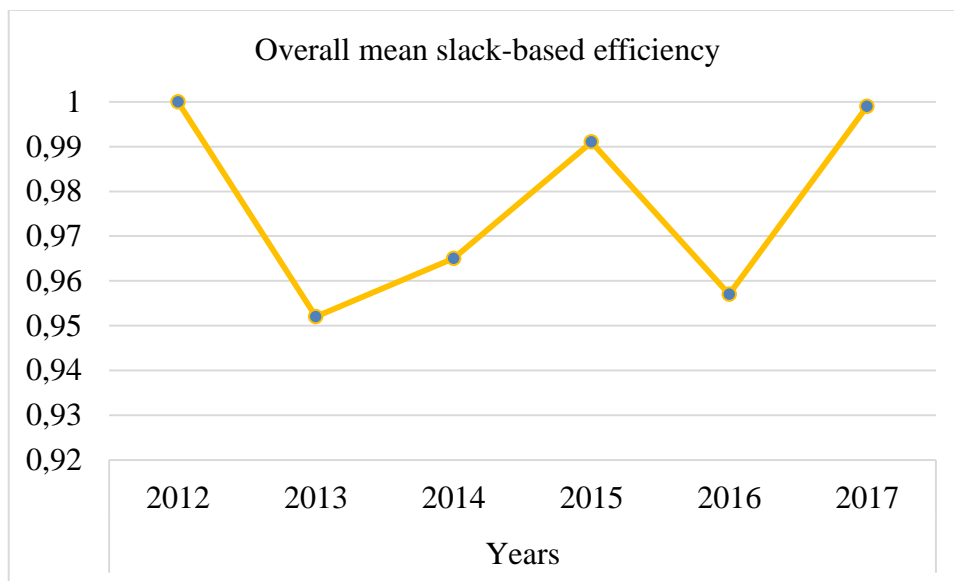


Figure 2: Trend of overall mean slack-based efficiency among the years

As observed in Table 2, BATCO (in 2013, 2014) and BOSCO (in 2013, 2015, 2016, 2017) were the inefficient DMUs for the study period, thus, to augment BATCO's inefficiency in 2013, it needs to reduce the number of non-teaching staff by 11, decrease the number of academic staff by 9, reduce staff qualification by 0.44 and reduce the number of classrooms by 5 to be at the efficiency frontier (efficient). For 2014, BATCO needs to reduce the number of students by 10, decrease the number of academic staffs by 8 and cut the number of classrooms by 5 to be at the efficiency frontier in 2014. On the other hand, to augment BOSCO's inefficiencies in 2013, it must reduce the number of students by 40; decrease the number of academic staffs by 21 and the number of classrooms by 3 to be on the efficiency frontier (efficient). For 2015, BOSCO

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

should decrease the number of students by 16, reduce the number of academic staffs by 12 and increase the number of publications by 1. Also, in 2016 BOSCO must decrease the number of academic staffs by 9, staff qualifications by 1 and increase publication by 2. Lastly, for BOSCO to be considered efficient, they should reduce the number of students by 39, the number of academic staffs by 19, the number of staff qualification by 10 and increase yet again the number of publications by 1 to be at the efficiency frontier (efficient). Below in Table 3 are the slack-based results for the inefficient DMUs.

Table 3: Slack-based results

Slack variables/years	BATCO			BOSCO		
	2013	2014	2013	2015	2016	2017
Inputs variables						
Number of students	0	9.87	40.41	10.16		38.99
Number of non-teaching staff	11.13	0	0	0		
Number of academic staff	8.92	7.97	20.73	11.66	8.76	18.36
Staff qualifications	0.44	0	0		1.06	9.99
Number of classrooms	5.01	4.48	3.30			
Output variables						
Number of Graduants						
Number of publications				0.12	1.57	0.49

Discussions

In this section, the input-oriented slack-based efficiency scores attained from the CCR model have been discussed. This paper tries to measure the efficiency of Public University Colleges of Education in Ghana through DEA-SBM.

Table 2 presents the results of the 4 selected Public University Colleges along with their years. The results indicate that the 4 selected Colleges in the 3 Northern regions of Ghana has an overall good efficiency results with just a few inefficiencies. The mean efficiency score for the 4 Colleges for the study period turned out to be 0.978. This indicates that an average College, if producing its outputs on the efficiency frontier instead of its simulated location, would only need 97.8% of its inputs currently being utilized. This shows that, by adopting best managerial practices, the Colleges can, on an average, reduce their inputs by at least 2.2% and still produce at the same level of outputs. However, the likely decrease in inputs from implementing best managerial practices differs from College to College. As stated earlier, a College with efficiency score equal to 1 is efficient and an efficiency score less than 1 is inefficient, the results from the 4 Colleges suggest that only 2 out of the 4 Colleges were seen to be efficient throughout the study period. The results of the 2 inefficient Colleges mean that resource usage in these Colleges is not effective, thus, there exist some input wastages. The results also suggest a slight nonconformity from the best managerial practices. These inefficient Colleges can improve their

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

efficiency by reducing their inputs (Number of students, number of non-teaching staff, number of academic staff, staff qualifications and number of classrooms). The efficiency scores (0.827 to 0.999) among the inefficient Colleges can possibly decrease their current inputs levels by 17.3% to 0.1%, while leaving their output levels unaffected.

Turning to the slack-based results in Table 3, it was found out that only two Colleges (BATCO and BOSCO) were inefficient and needed adjustment in inputs and outputs to become efficient. The figures suggest that for the inefficient Colleges to become efficient they need to reduce their inputs (see Table 3) and increase their outputs (see Table 3) to become efficient.

Conclusions

In this study, we have demonstrated the merits entailed in the application of DEA-SBM in the study context, where the evaluation context is constructed taking the non-zero slack value into account. The introduction of slack-based measure is a slight change in the attractiveness score, but the benchmark target is appropriately provided. The results show that 2 out of the 4 Colleges employed in the study do not present any kind of inefficiency (50%); i.e., they are efficient overall. The 2 PUCes that have some form of inefficiency are managerial inefficient. Two PUCes, BOSCO and BATCO, are overall inefficient. The findings show an average overall score efficiency of 0.98 or 98% over the study period. In addition, the mean observation from the various years demonstrates that apart from 2012 which was the only efficient year, the rest of the years (2013-2017) in the study period were inefficient. For the inefficient PUCes that is BATCO and BOSCO to augment their inefficiencies then, it need to reduce their inputs by at least 2.2%.

It is imperative to indicate that, the present study has some limitations which present opportunities for future studies, should be taken into account. First, the empirical results are not generalizable because only four selected colleges were captured out of the forty six colleges in the country. For this reason, the implications for managerial practise may only be applicable to the four selected university colleges in the three Northern Regions of Ghana, thus, future research should broaden the scope to cover the other regions.

The second limitation stems from the use of the model (DEA), although is considered to be a tool use to determine efficiency among DMUs of firms, it embodies several components but the present study employs only the CCR and slack-based model but failed to consider super-efficiency and cross-efficiency evaluation models. Therefore, we recommend that future researchers should consider supper and cross-efficiency evaluation models in the context of university colleges of education.

Finally, this study failed to consider the dynamism of factors such as average students' qualifications (CGPA) and departments operating costs as input variables. In addition, average graduates' result and Graduates' employment rate that is, number of trained teachers absorb into the teaching field by government as output variables. Thus, future research should consider them.

References

- Akyeampong, A. (2003). *Teacher Training in Ghana-Does It Count? Multi-Site Teacher Education Project (MUSTER): Country Report One*. DfID.
- Aristovnik, A., Seljak, J., & Mencinger, J. (2014). Performance measurement of police forces at the local level: A non-parametric mathematical programming approach. *Expert Systems with Applications*, 41(4), 1647–1653.
- Azadeh, A., Haghghi, S. M., Zarrin, M., & Khaefi, S. (2015). Performance evaluation of Iranian electricity distribution units by using stochastic data envelopment analysis. *International Journal of Electrical Power & Energy Systems*, 73, 919–931.

***Assessing the Efficiency of Public Universities Colleges of Education in the
promotion of Quality Education in Ghana through DEA-SBM***

- Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444.
- Du, J., Cook, W. D., Liang, L., & Zhu, J. (2014). Fixed cost and resource allocation based on DEA cross-efficiency. *European Journal of Operational Research*, 235(1), 206–214.
- Souza, G. da S., & Gomes, E. G. (2015). Management of agricultural research centers in Brazil: A DEA application using a dynamic GMM approach. *European Journal of Operational Research*, 240(3), 819–824.
- Escorcía Caballero, R., Visbal Cadavid, D., & Agudelo Toloza, J. M. (2015). Eficiencia en las instituciones educativas públicas de la ciudad de Santa Marta (Colombia) mediante "Análisis Envoltante de Datos". *Ingeniare. Revista Chilena de Ingeniería*, 23(4), 579–593.
- Fang, L., & Li, H. (2015). Centralized resource allocation based on the cost–revenue analysis. *Computers & Industrial Engineering*, 85, 395–401.
- Gopalakrishnan, G. (2015). How to apply academic supply chain management: The case of an international university. *Management: Journal of Contemporary Management Issues*, 20(1), 207–221.
- Grosskopf, S., Hayes, K. J., & Taylor, L. L. (2014). Applied efficiency analysis in education. *Economics and Business Letters*, 3(1), 19–26.
- Huguenin, J.-M. (2015). Determinants of school efficiency: The case of primary schools in the State of Geneva, Switzerland. *International Journal of Educational Management*, 29(5), 539–562.
- Izadikhah, M., & Saen, R. F. (2018). Assessing sustainability of supply chains by chance-constrained two-stage DEA model in the presence of undesirable factors. *Computers & Operations Research*, 100, 343–367.
- Jauhar, S. K., Pant, M., & Nagar, A. K. (2016). Sustainable educational supply chain performance measurement through DEA and Differential Evolution : a case on Indian HEI. *Journal of Computational Science*. <https://doi.org/10.1016/j.jocs.2016.10.007>
- Koshal, R. K., Koshal, M., & Gupta, A. K. (2013). Students' Mathematics Academic Performance: An Interaction of Inputs from the Students, Schools, and Voters. *Perspectives on Global Development and Technology*, 12(5–6), 680–698.
- Kwon, H.-B., & Lee, J. (2015). Two-stage production modeling of large US banks: A DEA-neural network approach. *Expert Systems with Applications*, 42(19), 6758–6766.
- Lozano, S. (2015). A joint-inputs Network DEA approach to production and pollution-generating technologies. *Expert Systems with Applications*, 42(21), 7960–7968.
- Ministry of Finance, G. (2019). The Budget Statement and Economic policy of The Government of Ghana, (November).
- Omran, H., Beiragh, R. G., & Kaleibari, S. S. (2015). Performance assessment of Iranian electricity distribution companies by an integrated cooperative game data envelopment analysis principal component analysis approach. *International Journal of Electrical Power & Energy Systems*, 64, 617–625.
- Tao, L., Liu, X., & Chen, Y. (2013). Online banking performance evaluation using data envelopment analysis and axiomatic fuzzy set clustering. *Quality & Quantity*, 47(2), 1259–1273.
- Tone, K. (2002). A slack-based measure of super -efficiency in data envelopment analysis. *European Journal of Operational Research*, 130(3), 498–509.
- Tsolas, I. E., & Charles, V. (2015). Incorporating risk into bank efficiency: A satisficing DEA

Assessing the Efficiency of Public Universities Colleges of Education in the promotion of Quality Education in Ghana through DEA-SBM

approach to assess the Greek banking crisis. *Expert Systems with Applications*, 42(7), 3491–3500.

- Tyagi, P., Yadav, S. P., & Singh, S. P. (2008). Efficiency analysis of schools using DEA: a case study of Uttar Pradesh state in India. *Department of Mathematics, IIT, Roorkee. India*.
- UN. (2016). *The Sustainable Development Goals Report 2017*. United Nations Statistics Division Sustainable Development Goals website at <https://unstats.un.org/sdgs>. <https://doi.org/10.18356/4d038e1e-en>
- Unwin, T. (2005). Towards a framework for the use of ICT in teacher training in Africa. *Open Learning*, 20(2), 113–129. <https://doi.org/10.1080/02680510500094124>
- Visbal-Cadavid, D., Martínez-Gómez, M., & Guijarro, F. (2017). Assessing the Efficiency of Public Universities through DEA. A Case Study. *Sustainability*, 9(8), 1416.
- Wanke, P., & Barros, C. (2014). Two-stage DEA: An application to major Brazilian banks. *Expert Systems with Applications*, 41(5), 2337–2344.
- William W. Cooper, Lawrence, M. S. and K. T. (2007). *DATA ENVELOPMENT ANALYSIS A Comprehensive Text with Models , Applications , References Second Edition*.
- Woo, C., Chung, Y., Chun, D., Seo, H., & Hong, S. (2015). The static and dynamic environmental efficiency of renewable energy: A Malmquist index analysis of OECD countries. *Renewable and Sustainable Energy Reviews*, 47, 367–376.