Business, Management and Economics Engineering
ISSN: 2669-2481 / eISSN: 2669-249X
2024 Volume 22 Issue 01

ESTIMATING THE EFFICIENCY OF RESEARCH PERFORMANCE AND THE DETERMINANTS OF INEFFICIENCY IN SAUDI UNIVERSITIES: USING THE STOCHASTIC FRONTIER ANALYSIS METHOD.

Hanan Hamoud M. Alharbi
PhD candidate of higher education administration, Department of Educational Administration, King Saud University, Riyadh, Saudi Arabia
442204525@student.ksu.edu.sa; hhmharbi2015@gmail.com
https://orcid.org/0009-0001-2686-5008
Web of Science Researcher ID IQU-0311-2023

Prof. Sarah Abdullah Bin- Mengash
Professor of higher education administration, Department of Educational Administration, King Saud University, Riyadh, Saudi Arabia, sarahm@ksu.edu.sa

This article estimates the efficiency of the research performance of Saudi universities using the stochastic frontier analysis (SFA) method using an output number of published research and two inputs are the number of researchers from faculty and the total number of research and technical centers, and the Study of the impact of external interpretative factors represented in the budget allocated incentive and financial support system, infrastructure and supporting equipment. The results showed that the average efficiency of research performance of Saudi universities was 0.49 and was concluded that there is a direct impact of external factors on the inefficiency.

Keywords: efficiency; production function; high education; Parametric statistics

Introduction

The topic of efficiency has received increasing attention recently with the increasing economic view of educational systems, as interest in education has entered a new phase among economists, and planning for education has become an economic process whose effects are evident in increasing interest in the efficiency of educational systems and increasing their productivity through rationalizing spending making good use of its sources, and avoiding waste. In educational systems, the term efficiency is used in the education economics literature to indicate a broad concept, which is the ratio of outputs to inputs. The word efficiency can be considered a designation for a large field of research, which is the field that is concerned with studying the impact of educational resources on its outcomes (Jones & Tone, 2016) & or studies of the distribution of educational resources assuming certain desired levels of outcomes (Sav, 2012) or studies that focus On the outputs to evaluate performance according to econometric methods assuming the scarcity of resources and the necessity of preserving them (Johnes, 2008).

The recent history of efficiency measurement began with Farrell (1957) which demonstrated efficiency in three types of technical efficiency, representing the enterprise's ability to obtain the largest amount of outputs with available inputs or reduce the amount of inputs to obtain a certain amount of outputs; allocative efficiency, the enterprise's ability to optimize input recruitment to achieve desired outputs and productive efficiency, achieved through both technical efficiency and customization.

The application of Farrell's method of estimating the efficiency of the industrial and commercial sectors has been easy. In education, measurement of efficiency has been complex for several reasons, including the diversity of education outputs and the difficulty of measuring them (Kumbhakar & Lovell, 2000), the multiplicity of education inputs and the difficulty of assessing their impact in the light of the lack of clarity of the education process, i.e., how the learning process takes place, or - in economic language- the lack of clarity of production functions itself (Johnes, 2006a), as well as the challenges of measurement inaccuracy and statistical estimates (Schwartz & Zabel, 2005).

After the groundbreaking studies of Farrell, sophisticated analytical methods have been applied since the late 1970s, most notably data envelopment analysis (DEA) (Charnes, Cooper, Golany, Seiford & Stutz, 1985) and stochastic frontier analysis (SFA) (Aigner, Lovell, & Schmidt, 1977); The two methods are based on economic concepts of efficiency and production (Johnes, 2006b) But the analysis of the non-parametric data envelope is based on written programming. Random border analysis is a parametric statistic that considers the estimate error (Johnes, 2004) In terms of the simplest of the two inclusive methods, both are appreciated after the unity of decision-making. (Universities, for example) from the ideal level of efficiency, but random boundary analysis separates two components of a degree of dimension, a component of inefficiency and a component of measurement and estimation errors. Analysis of the data envelope neglects random error and calculates it within the component of inefficiency.

Economists have used the stochastic frontier analysis (SFA) method to estimate potential maximum output production in decision-making units or the minimum cost used when producing outputs (Agasisti & Gralka, 2019). In addition to forming a model that explains relationships and determinants of inefficiency at one stagestochastic frontier analysis (SFA) has been applied using various analytical units such as Universities (Daghbashyan,2012), Schools (Franta & Knecny, 2009) and States (Coelho, 2009). At the Arab level, research efforts are scarce, despite the continued emphasis on adopting different quantitative strategies and entry points to measure institutions' efficiency and improve outputs.

Despite its benefits, research on the application of (SFA) in education is a minority compared to (DEA) (Witte and Torres 2017) of research using SFA in education that can be mentioned as follows. Agasisti, & Gralka (2019) estimated the provisional and continuous efficiency of Italian and German universities; Minaya & Agasisti (2019) assessed the stability of school performance in the Italian context; Agasisti, & Belfield (2017) measured efficiency in community colleges. Vanesa D 'elia, Gustavo Ferro conducted a study to measure the technical competence of university teaching activity at national (public) universities in Argentina. Randomized Boundary Analysis (SFA), this study attempted to measure the efficiency of the research performance of Saudi universities by applying (SFA) to achieve the study's goal.

Higher education in the Kingdom of Saudi Arabia accounts for considerable resources and an increasing pattern of expenditure. This is confirmed when addressing the research system. The

Kingdom of Saudi Arabia has announced the approval of the R&D support program budget in the amount of 6 billion Saudi riyals, within the current fiscal year budget. 1443/1444 A.D. (Ministry of Education, 2019) recognizing the importance of scientific research and innovation in the progress of nations, and the prosperity of societies, which makes an efficient study of its most important components _ research _ important for the purpose of detecting sources of waste in resources, and how to increase the level of exploitation and orientation of society's vast resources; However, the research effort in this regard is not hoped for. Research production still lacks a standard analytical study of its components, which may contribute to the interpretation of its outputs, supporting the development of its operational processes and supporting its inputs to an advanced level of knowledge output; This calls for an assessment of the efficiency of the research performance of Saudi universities, and an examination of the external explanatory factors affecting the universities' inefficiency in maximizing research performance, using the quantitative methods and methods represented in the random boundary analysis (SFA) as the standard analysis method, we formulated the following problem: What is the impact of explanatory external determinants on the inefficiency of the research performance of Saudi government universities according to the method of indiscriminate border analysis?

Study hypotheses.

To answer questions on the subject, the following hypotheses may be formulated:

(1) The Saudi government universities in question have different degrees of competence.

(2) The Saudi government universities in question do not operate with close efficiency.

(3) Found a direct and different impact of external interpretative factors on the inefficient research performance of the Saudi universities in question.

Methodology:

Identification of the study model:

We will characterize the stochastic frontier analysis model (SFA) in the SFA method according to the model of Coelli & Battese (model2,1995) (Battese & Coelli, 1995) which presupposes many additional interpretative variables in which the inefficiency variable follows the normal cut or amputated distribution, as the μ_i inefficiency variant can be defined as follows:

$$\mu_i = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 z_4$$

According to the special model (model2, Battese & Coelli, 1995) and applying the method of greatest possible indiscriminate effect (MLE) (Maximum Likelihood Estimator), we estimate the boundary production function, and the indiscriminate production limit function includes an error limit for a group of enterprises i = 1,..., N and take the following written formulation (Eagan & Titus, 2016, p. 458)

$$\ln y_{it} = \beta_0 + \sum_{n=1}^{i} \beta_n \ln x_{it} + (v_{it} - \mu_{it})$$

Where they represent:

$\boldsymbol{y_i}$: The outputs are the number of research published in universities i.

$\boldsymbol{x_i}$: A vector $(k \times 1)$ of inputs used by universities i^{emo} presented by the number of researchers and the number of research centers and institutions.

$\boldsymbol{\beta_0}$: A vector $(k \times 1)$ of parameters of the estimated model, which represents the elasticities of the inputs x_i (Chaudhuri, 2016, p553)

$\boldsymbol{\mu_{it}}$: it is a random variable, representing the value of universities' inefficiencies, which are always positive and follow a unilateral distribution, as previous studies have shown that μ_i track semi-normal distribution by an average of zero and variation of σ_μ^2 or a truncated normal distribution with mean m and variance σ_μ^2 , Distribution assumptions of technical inefficiency (μ_{it}) are necessary to stochastic frontier analysis (SFA) (Yang, Lin, Kennedy, Ruth, 2011, p393).

Technical efficiency (TE) can be calculated as follows $TE_{it} = \exp(-\mu_{it})$

$\boldsymbol{v_{it}}$ represents the preview error as it always follows normal distribution by a mean 0 and variation σ_v^2 N(m, σ_v^2)

$\boldsymbol{\sigma_\mu^2}$ **:** variance of inefficiency.

$\boldsymbol{\sigma_v^2}$: variance of measurement errors.

$\boldsymbol{\sigma^2}$: Total variations of the error limit.

$$\gamma = \frac{\sigma_\mu^2}{(\sigma_\mu^2 + \sigma_v^2)} = \frac{\sigma_\mu^2}{\sigma^2}$$

γ whereas γ " gamma " If the value of gamma ends at zero, then the deviations as a whole are due to measurement errors. If the value ends at one, the deviations are due to technical inefficiency (Liu, 2010, p60).

Study variables

Output y: The outputs of the study consisted of a single output represented by the budget allocated, the university's type of origin, incentive and financial support system, infrastructure, and supporting equipment.

Inputs X: The study's inputs were:

X1: Number of researchers from faculty and postgraduate students.

X2: Total number of research and technical centres and institutions and scientific chairs

The explanatory external variables z_{it} affecting the inefficiency variable z_{it}:

External interpretative variables are the variables affecting inefficiency in Saudi universities' border production function model. We selected the following explanatory external factors as variables that can affect the maximization of the research performance of Saudi universities. The following explanatory external variables have been identified.

The budget allocated $\mathbf{z_{1t}}$: The University's institutional income rate represents the number of researchers.

University Type z_{2t}: According to this variable, universities were classified into emerging universities and old universities, and we gave weight 1 to old universities and weight 2 to emerging universities.

Incentive and financial support system for research z_{3t}: estimate a sliding heptometer below 1 when support is lacking, and above 7 when support is very high

Infrastructure and Supporting Equipment z_{4t}: estimate a sliding heptometer below 1 when support is lacking, and above 7 when support is very high.

Results and discussion:

In this part we will first assess the stochastic frontier analysis (SFA) of Saudi State universities using the random border analysis method and apply the method of maximum likelihood of indiscriminate effect (MLE); Then study the impact of explanatory external variables on the inefficiency of these universities, using the (Frontier) program, as well as estimate the efficiency of these universities.

(1): Estimate the the stochastic frontier model of the production function of Saudi State Universities:

Using (Frontier 4.1), we estimated the stochastic frontier analysis (SFA) model by estimating the maximum probability of indiscriminate boundary production function parameters using the Maximum Likelihood method of Saudi government universities and assessing the root causes of inefficiency by analyzing the impact of external interpretative variables on the inefficiency variable, the results of which were as follows, as shown in table (1) below.

Table (1) Results of estimating the parameters of the random frontier model for Saudi universities using the Maximum Likelihood method.

variable	Coefficient	Standard- errer	T-ratio
Beta 0	- 0.11	**0.10**	**0.65**
Beta 1	0.66	**0.21**	**-0.55**
beta 2	- 0.16	**0.10**	**- 0.16**
Model Inefficiency			
Delta 0	0.24	0.11	**0.21**
Delta 1	-0.82	0.19	**- 0.41**
Delta 2	0.16	0.15	**0.10**
Delta 3	- 0.22	0.28	**- 0.77**
Delta 4	-0.16	0.10	**-0.15**
Variance Parameters			
sigma-squared	0.14	0.68	**0.60**
Gamma	0.97	0.37	**0.26**
LR test value			**0.6163**
LikelihoodRatio			**- 0.94**
Degree of freedom of			**6**

Through the results of estimating model parameters through to stochastic frontier analysis (SFA) method we find that:

We note that the value of gamma (γ) moral, because the t-tratio value of gamma (γ) was 26.19, which is greater than the 12.59 tabular value at the approved statistical indicator level of 0.05 and the level of freedom score of 6, and since the value of gamma (γ) 0.97 can be said to be 97% deviations due to inefficiency, and the rest deviations are due to measurement errors.

It is further evident that the LR test value was 61.63 which is greater than the 12.59 = t tabular value at the approved statistical indicator level of 0.05 and the freedom score level of 6, and therefore we accept the alternative hypothesis that there is an impact relationship between the external interpretative variables (Budget allocated, university type in terms of origin, incentive and financial support system, infrastructure and supporting equipment) The technical

incompetence of Saudi universities. Consequently, the indiscriminate boundary production function model can be assessed as follows:

$$\ln y_{it} = 0.06 - 0.11x_{1t} - 0.16x_{2t} + v_{it} - \mu_{it}$$

We note from the results of the random model estimation of the indiscriminate boundary production function of Saudi universities that the lower the rate of researchers (That is, if the number of researchers per year increases by 10%, the rate of published research increases by 1.1%, the lower the rate of research centers and institutions per year by 10%, the higher the rate of published research by 1.6%) The availability of qualitative and qualitative qualified researchers effectively contributes to the increase in the rate and quality of knowledge production and its reflection in the rate of contribution to the implementation of development plans - indicating the importance of the research industry and investing its capabilities in areas and disciplines that serve the community and this is its confirmation (Jamali, Samara, G. & Meho, 2023) Research centres and chairs also have a distinctive role to play in making and moving knowledge to achieve research excellence and this is study also the finding of the (Wang, Zeng, Zhong, & Si, 2023).

(2): Study of the impact of external interpretative variables on inefficient research performance in Saudi universities

To determine whether there are underlying reasons for inefficiency in the outputs of Saudi universities, we have studied the explanatory external variables of inefficiency, and therefore through the results of the assessment of the impact of these variables through Table (1) shown above, we note that the values of the external variables interpreted for inefficiency have reached $(\delta 1, \delta_2, \delta_3, \delta_4)(-0.16, -0.22, 0.16, -0{,}82)$ respectively, since the negative signal indicates the adverse effect on inefficiency, the relationship between the additional variables and inefficiency can therefore be derived as follows:

$$\mu = 0.24 - 0.82_{Z1} + 0.16_{Z2} - 0.22_{Z3} - 0.16_{Z4}$$

Through the equation we note the following:

The inverse relationship between the University's budget and the inefficiency, as the higher the proportion of the University's budget, the less inefficient the universities in increasing the rate of research performance, as represented by the number of published research, It can therefore be said that there is a positive impact of the high proportion of the University's budget on the increase in the number of published research An increase of 10% will reduce inefficiency by 8.2%. The budget is the key to enhancing the efficiency of research performance and is consistent with the outcome of the study (Jamali, Samara, G. & Meho, 2023) by targeting increased R&D expenditure under appropriate funding allocation associated with the design of strategic plans supporting investment in knowledge production, and that research and innovation without appropriate funding will be low.

The greater the incompetence of Saudi universities in increasing the rate of research performance. Therefore, it can be said that emerging universities have a negative impact on increasing the rate of research performance, which will reduce incompetence by 1.6%. It is a logical consequence that these ancient universities have completed their infrastructure and digital construction highly

The inverse relationship between incentive and financial support system and inefficiency, as the more incentive and financial support system decreases the inefficiency of Saudi universities in maximizing the number of published research; Therefore, the incentive and financial support

system has a positive impact on increasing the efficiency of research performance, which will reduce inefficiency by 2.2% High levels of competition for support and incentives motivate researchers to invest their best, Providing material and moral incentives to faculty members is a factor in advancing scientific research to meet the requirements of economic development and Saudi Arabia's Vision 2030, and this result is consistent with the study (Rhaiem, 2017) where the study emphasized the importance of providing incentives to faculty members involved in research with market value, a study has revealed (Johnes & Johnes,2019) Poor stimulation of innovators and poor financing of innovative ideas are causes of poor efficiency. An incentive system should be developed to increase the efficiency of research performance.
An inverse relationship between infrastructure and supporting equipment and inefficiency. The higher the quality of infrastructure and supporting equipment, the less inefficient the Saudi universities. Therefore, it can be said that infrastructure and supporting equipment have a positive impact on the increased efficiency of Saudi universities' research performance; This result seems logical, and the availability of the infrastructure and technical environment enhances the efficiency of research performance.

(3): Competency Rating Results Research Performance of Saudi Universities

Table (2) Results of proficiency assessment of research performance For Saudi universities for the year 2023

the university	Efficiency index	the university	Efficiency index
Umm Al Qura University	0.67	**Al-Jouf University**	**0.32**
Islamic University	0.29	**Tabouk university**	**0.36**
Imam Muhammad Bin Saud Islamic University	0.70	**Al Baha university**	**0.32**
King Saud University	0.84	**Najran university**	**0.63**
King Abdulaziz University	0.81	**Princess Nora bint AbdulRahman University**	0.45
King Fahd University of Petroleum and Minerals	0.84	**Northern Border University**	0.27
King Faisal University	0.75	**Shaqra University**	0.49
King Khalid University	0.48	**Prince Sattam bin Abdulaziz University**	0.55
Al Qussaim university	0.39	**Imam Abdul Rahman bin Faisal University**	0.61
Taibah University	0.37	**University collected**	0. 26
Taif University	0.39	**the Saudi electronic university**	0.38
King Saud University for Health Sciences	0.80	**University of Jeddah**	0.62
Gazan University	0.67	**Bisha University**	0.10
Hael University	0.13	**University of Hafar Al-Batin**	0.10
mean efficiency = 0.49			

We note through the results of the technical proficiency assessment of Saudi government universities that there is a difference in the research performance of Saudi universities As the lowest value was recorded at the Islamic University and Imam Mohammed bin Saud Islamic University, King Saud University and King Fahd Petroleum and Minerals University had the highest efficiency rate. It was further found that 13 universities had obtained an efficiency index below 0.40 and that 15 universities had obtained an efficiency index greater than 0.60.
Thus, in general, Saudi public universities still have the possibility of improving research production as represented by the number of research published under current inputs and current external interpretative variables by the difference between the full efficiency index 1 and the current indicator achieved at each university; by pursuing policies that improve the efficiency of research performance; Such as integrating research into regional economic development, expanding its autonomy and enhancing intellectual property protection, there is a need for a system to assess the efficiency of scientific research. The efficiency of research performance can only be improved through full utilization of universities' technical advantages, enhanced awareness of development and enhanced economic cooperation with surrounding areas.
Through the results of the random border analysis, the gap between Saudi universities in the efficiency of research performance is relatively large and can be reduced by promoting information exchange and enhancing the flow of research talent across different universities.

Conclusion

The indiscriminate border analysis method is one of the modern quantitative methods of estimating the indiscriminate boundary production function of the decision unit group and distinguishes between indiscriminate error resulting from miscalculation, The error caused by inefficiency, which is considered to have been created in the context of this analysis and applying this method to the 28 Saudi public universities to assess the competence and external interpretative factors of incompetence, The estimate of the indiscriminate boundary production function model was found to be random by virtue of the morale of the value of gamma (7) That is, 97% of deviations are due to inefficiency, and the results have also shown that there is an influence of external interpretative factors on inefficiency and the determinants of inefficiency are: (Budget allocated, university type in terms of origin, incentive and financial support system, infrastructure and supporting equipment) affecting the inefficiency of Saudi universities. As universities inflate outputs at available cost (production functions) or achieve required outputs at the lowest cost (cost rates), and in either approach, cost functions are bilateral with production functions, and can be used in subsequent studies to assess the efficiency of research performance.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and was approved by the King Saud University's Ethics Committee (KSU-HU-24-087 on 26/ 02/ 2023).
Informed Consent Statement: Participants completed written consent forms prior to their participa- tion in the study.
Acknowledgments:The authors would like to thank Deanship of scientific research in King Saud University for funding and supporting this research through the initiative of DSR Graduate Students Research Support (GSR).

Conflicts of Interest: The authors declare no conflict of interest.

References

Agasisti, T., & Belfield, C. (2017). Efficiency in the community college sector: stochastic frontier analysis. *Tertiary Education and Management*, 23(3), 237–259. https://doi-org.sdl.idm.oclc.org/10.1080/13583883.2016.1238956

Agasisti, T., & Gralka, S. (2019). The transient and persistent efficiency of Italian and German universities: a stochastic frontier analysis. *Applied Economics*, 51(46), 5012–5030. https://doi-org.sdl.idm.oclc.org/10.1080/00036846.2019.1606409

Aigner, D. J., Lovel, C.A.K. and Schmidt, P. (1977). Formulation and Estimation of Stochastic Frontier Production Function Models. *Journal of Econometrics*, 6(1), 21-37. https://doi.org/10.1016/0304-4076(77)90052-5

Battese, G.E. and Coelli, T.J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(6),325-332. https://doi.org/10.1007/BF01205442

Charnes, A., Cooper, W. W., Golany, B., Seiford, L., & Stutz, J. (1985). Foundations of data envelopment analysis for Pareto- Koopmans efficient empirical production functions. *Journal of Econometrics*, 30(1), 91-107

Chaudhuri, D. D. (2016). Impact of Economic Liberalization on Technical Efficiency of Firms: Evidence from India's Electronics Industry. *Theoretical Economics Letters*, 23(6), 549-560

Coelho, MC .(2009). The Effect of Organizational Structure on Education Efficiency: Public-Private Provision and Decentralization. Institute of Local Government Studies, School of Public Policy, The University of Birmingham, United Kingdom.

D'Elia, V., & Ferro, G. (2021). Efficiency In Public Higher Education: A Stochastic Frontier Analysis Considering Heterogeneity. *Economic Analysis Review*, *36*(2), 21-51. Retrieved from https://www.rae-ear.org/index.php/rae/article/view/704

Daghbashyan, Z. (2012). The Economic Efficiency of Swedish Higher Education Institutions Royal Institute of Technology, Centre of Excellence for Science and Innovation Studies. CESIS Electronic Working Paper Series. Paper No. 245.

Eagan, K. and Titus M.A. (2016). *Examining Production Efficiency in Higher Education: The Utility of Stochastic Frontier Analysis*. In Higher Education: Handbook of Theory and Research. New York, NY: Springer

Farrell, M.J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society, 20(3), 253-281.*

Franta, M., & Konecny, T. (2009). Stochastic frontier analysis of the efficiency of Czech grammar schools. *Czech Sociological Review*, 45(6), 1265-1282

Gustavo Ferro, & Vanesa D'Elia. (2020). Higher Education Efficiency Frontier Analysis: A Review of Variables to Consider. *Journal on Efficiency and Responsibility in Education and Science*, 13(3), 140–153. https://doi-org.sdl.idm.oclc.org/10.7160/eriesj.2020.130304

Jamali, D., Samara, G. & Meho, L.I. (2023). Determinants of research productivity and efficiency among the Arab world's accredited business schools. *Manag Rev Q* (2023). https://doi.org/10.1007/s11301-023-00365-1

Johnes, G. and Tone, K. (2016). The Efficiency of Higher Education Institutions in England Revisited: Comparing Alternative Measures. *Tertiary Education and Management,* 23(3), 191-205. https://doi.org/10.1080/13583883.2016.1203457

Johnes, G., & Johnes, J. (2009). Higher education institutions costs and efficiency: Taking the decomposition a further step. *Economics of Education Review, 28*(1), 107–113.

Johnes, J. (2004). Efficiency Measurement. in Geraint J. and Johnes J. (eds.) International Handbook on the Economics of Education, Northampton, MA: Edgar Elgar Publishing.

Johnes, J. (2006a). Data Envelopment Analysis and its Application to the Measurement of Efficiency in Higher Education. Economics of Education Review, 25(3) 273-288. https://doi.org/10.1016/j.econedurev.2005.02.005

Johnes, J. (2006b). Measuring Teaching Efficiency in Higher Education: An Application of Data Envelopment Analysis to Economics Graduates from UK Universities 1993. *European Journal of Operational Research*,174(1)443-456. https://doi.org/10.1016/j.ejor.2005.02.044

Johnes, J. (2008). Efficiency and Productivity Change in the English Higher Education Sector from 1996/97 to 2004/05. *The Manchester School*, 76(6),653-674. https://doi.org/10.1111/j.1467-9957.2008.01087.x

Kumbhakar, S. C., & Lovell, C. A. (2000). *Stochastic frontier analysis*. Cambridge: Cambridge University Press.

Liu, Q. (2010). *Efficiency analysis of container ports and terminals. Doctoral thesis*. University College London

Minaya, V., & Agasisti, T. (2019). Evaluating the Stability of School Performance Estimates over Time. *Fiscal Studies*, 40(3), 401-425–425. https://doi-org.sdl.idm.oclc.org/10.1111/1475-5890.12201

Rhaiem, M.(2017). Measurement and determinants of academic research efficiency: a systematic review of the evidence. *Scientometrics* 110, 581–615 https://doi.org/10.1007/s11192-016-2173-1

Sav, G.T. (2012). Stochastic Cost Frontier and Inefficiency Estimates of Public and Private Universities: Does Government Matter?. *International Advances in Economic Research,* 18(2),187–198. https://dx.doi.org/10.1007/s11294-012-9353-4

Schwartz, A., & Zabel, J. (2005). The good, the bad and the ugly: measuring school efficiency using school production functions. In: L. Stiefel, A. E. Schwartz, R. Rubenstein & J. Zabel (eds.) Measuring school performance and efficiency: Implications for practice and research, (pp. 37-66). Larchmont, NY: Eye on Education.

Titus, M. A., & Eagan, K. (2016). Examining production efficiency in higher education: The utility of stochastic frontier analysis. In M. B. Paulsen, Higher education: Handbook of theory and research (vol 31, pp. 441-512). New York: Springer, Cham. https://doi.org/10.1007/978-3-319-26829-3_9

Wang, C., Zeng, J., Zhong, H., & Si, W. (2023). Scientific research input and output efficiency evaluation of universities in Chengdu–Chongqing economic circle based on data envelopment analysis. *PLoS One, 18*(7) doi: https://doi.org/10.1371/journal.pone.0287692

Witte, K. D., & López-Torres, L. (2017). Efficiency in education: a review of literature and a way forward. *Journal of the Operational Research Society*, 68(4), 339–363. https://doi-org.sdl.idm.oclc.org/10.1057/jors.2015.92

Yang, H., Lin, K., Kennedy, O. R., & Ruth, B. (2011). Sea-Port Operational Efficiency: An Evaluation of Five Asian Ports Using Stochastic Frontier Production Function Model. *Journal of Service Science and Management*, 4(3), 391-399.