JMTPR
Journal of Management Theory and Practices Research
ISSN: 2718-1006

Journal of Management Theory and Practices Research
Cilt/Volume: 6
Sayı/Issue: 1
Haziran/June 2025

Makale İlk Gönderim Tarihi / Recieved (First): 03.12.2024
Makale Kabul Tarihi / Accepted: 27.12.2024

Citation / Atıf: Sözen, M., Sözen, Ç., (2025). Quality And Efficiency in Higher Education: Assessing The Performance Of Selected Turkish Universities Using The Slack-Based Measure Data Envelopment Analysis. *Journal of Management Theory and Practices Research*, 6(1), 175–186. https://doi.org/10.71284/jmtpr.

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

QUALITY AND EFFICIENCY IN HIGHER EDUCATION: ASSESSING THE PERFORMANCE OF SELECTED TURKISH UNIVERSITIES USING THE SLACK-BASED MEASURE DATA ENVELOPMENT ANALYSIS*

YÜKSEKÖĞRETİMDE KALİTE VE ETKİNLİK: SEÇİLMİŞ TÜRK ÜNİVERSİTELERİNİN PERFORMANSININ SBM-VZA İLE DEĞERLENDİRMESİ

Mervenur Sözen [1] **Çağlar Sözen** [2]

Abstract

This study aims to evaluate the efficiency performance of Turkey's most prestigious universities on a global scale by assessing their resource management, academic output, and strategic effectiveness. The analysis focuses on 16 universities that ranked within the top 1000 globally between 2020 and 2023, including Ankara University, Atatürk University, Atılım University, Bilkent University, Boğaziçi University, Ege University, Gazi University, Gebze Technical University, Hacettepe University, Istanbul Medipol University, Istanbul Technical University, Istanbul University, Koç University, Middle East Technical University, Sabancı University, and TOBB University. The study employs Data Envelopment Analysis (DEA) using the Slack-Based Measure (SBM) model to measure university efficiency. Input variables include the number of professors, associate professors, and assistant professors, while output variables are the number of publications and projects. An output-oriented model with variable returns to scale was adopted to emphasize scientific output. In the second phase, the study investigates additional structural and functional factors that may influence university efficiency, such as the number of lecturers (x1), research assistants (x2), administrative staff (x3), undergraduate (x4), master's (x5), and doctoral (x6) students. These variables were tested using panel data analysis. Model selection was guided by the Lagrange Multiplier Test, F-Test, and Hausman Test to assess the significance of individual and temporal effects. The findings indicate that academic and administrative staff composition and student profiles significantly affect institutional efficiency. This research provides valuable insights to inform strategic decision-making processes in Turkish higher education institutions. It offers practical recommendations for enhancing resource utilization, boosting academic performance, and formulating policies to improve the sustainability and global competitiveness of Turkey's higher education system.

Keywords: Academic Performance, Data Envelopment Analysis, SBM-DEA, Panel Data Analysis, Higher Education Quality

JEL Kodları: E52, C51, M52

[1] Dr., Türkiye, e-mail: mervenur.pala1@gmail.com
[2] Dr. Öğretim Üyesi, Giresun Üniversitesi, Görele Uygulamalı Bilimler Yüksekokulu, Finans ve Bankacılık Bölümü, Türkiye, e-mail: caglar.sozen@giresun.edu.tr

* This corrigendum is issued to correct a layout error in the published version of the above-mentioned article.
In the original publication, the English abstract was mistakenly placed under the heading "Özet" (which is reserved for the Turkish summary), and the Turkish summary appeared under the heading "Abstract". This is a typesetting error. We apologize to our readers for any confusion caused by this error. The correction has been made accordingly and is hereby documented.

Özet

Bu çalışma, Türkiye'nin en prestijli üniversitelerinin etkinlik performanslarını küresel ölçekte inceleyerek, kaynak yönetimi, akademik çıktı üretimi ve stratejik verimlilik düzeylerini değerlendirip belirlemeyi amaçlamaktadır. 2020-2023 yılları arasında dünya sıralamasında ilk 1000'e giren Ankara Üniversitesi, Atatürk Üniversitesi, Atılım Üniversitesi, Bilkent Üniversitesi, Boğaziçi Üniversitesi, Ege Üniversitesi, Gazi Üniversitesi, Gebze Teknik Üniversitesi, Hacettepe Üniversitesi, İstanbul Medipol Üniversitesi, İstanbul Teknik Üniversitesi, İstanbul Üniversitesi, Koç Üniversitesi, Orta Doğu Teknik Üniversitesi, Sabancı Üniversitesi ve TOBB olmak üzere toplam 16 üniversiteye odaklanılmıştır. Çalışmada, Slack-Based Measure (SBM) modeli aracılığıyla Veri Zarflama Analizi (DEA) kullanılarak üniversitelerin etkinlik performansları ölçülmüştür. Girdi değişkenleri olarak profesör, doçent ve doktor öğretim üyesi sayısı; çıktı değişkenleri olarak ise yayın ve proje sayısı kullanılmıştır. Bu analizde çıktı yönelimli ve değişken getiriye sahip bir model tercih edilerek, üniversitelerin bilimsel çıktıları esas alınmıştır.

Çalışmanın ikinci aşamasında, üniversitelerin etkinlik düzeyini etkileyebilecek diğer yapısal ve işlevsel faktörler incelenmiştir. Bu faktörler arasında öğretim görevlisi sayısı (x_1), araştırma görevlisi sayısı (x_2), idari personel sayısı (x_3), lisans (x_4), yüksek lisans (x_5) ve doktora (x_6) öğrenci sayıları bulunmaktadır. Bu değişkenlerin, üniversitelerin etkinlik düzeyi üzerindeki etkisi panel veri analizi ile test edilmiş olup, model seçiminde Lagrange Çarpanı Testi, F-Test ve Hausman Testi kullanılarak, üniversitelerin bireysel ve zamansal etkilerinin anlamlılık düzeyleri incelenmiştir. Elde edilen bulgular, üniversitelerin etkinlik düzeylerinin belirlenmesinde akademik ve idari personel yapısının ve öğrenci profili bileşenlerinin önemli olduğunu göstermektedir.

Bu çalışma, Türk üniversitelerinin uluslararası rekabet düzeylerini artırmalarına katkı sağlamak amacıyla yapılmış olup, üniversitelerin stratejik karar alma süreçlerine yön verecek değerli sonuçlar sunmaktadır. Analiz sonuçları, Türk yükseköğretim sisteminin verimliliğini artırmaya yönelik politika geliştirilmesine, kaynakların etkili kullanımına ve akademik performansın güçlendirilmesine dair somut öneriler sunarak, yükseköğretim kalitesinin sürdürülebilir bir şekilde artırılması için önemli bilgiler sağlamaktadır.

Anahtar Kelimeler: Akademik Performans, Veri Zarflama Analizi, SBM-DEA, Panel Veri Analizi, Yükseköğretim Kalitesi

JEL Codes: E52, C51, M52

1. INTRODUCTION

In today's knowledge economy, universities have evolved beyond their traditional role of simply generating knowledge; they now play a crucial part in societal development through research, innovation, and education. In countries like Turkey, where the higher education landscape is continuously evolving, it is essential to understand and enhance university efficiency. This improvement is vital not only for enhancing educational quality but also for bolstering the nation's competitive position on the global stage (Altbach, 2011; Marginson, 2016).

The performance of universities is often assessed through their rankings in global lists, with key factors such as research output, publication frequency, involvement in projects, and international collaborations being significant (Hazelkorn, 2015). Institutions that rank within the global top 1000 are recognized for their academic excellence, effective resource utilization, strategic management, and capacity to produce a skilled workforce. For Turkish universities that achieved a top 1000 ranking between 2020 and 2023, evaluating their operational efficiency is critical for maintaining and enhancing their competitive status.

This study utilizes the Data Envelopment Analysis (DEA) method, particularly the Slack-Based Measure (SBM) model, to assess efficiency across 16 prominent Turkish universities. The SBM model is a non-parametric approach tailored for evaluating systems with multiple inputs and outputs, making it effective for identifying inefficiencies in resource usage (Charnes, 1978; Cooper et al., 2011). In the initial phase of the study, input variables include the counts of professors, associate professors, and assistant

professors, while output variables focus on the number of publications and projects. The model is designed to be output-oriented and assumes variable returns to scale, aiming to evaluate scientific productivity as a key performance indicator.

The second phase broadens the analysis to examine structural and functional factors potentially affecting university efficiency. Structural variables include numbers of lecturers, research assistants, administrative staff, and students across educational levels (undergraduate, master's, and doctoral). Panel data analysis is employed to assess the impact of these variables on efficiency, using tests like the Lagrange Multiplier, F-Test, and Hausman Test to determine the most appropriate model (pooled, fixed effects, or random effects) (Baltagi and Baltagi, 2008). Findings reveal that staff composition, student demographics, and other structural factors significantly influence university efficiency.

This study provides insights to improve resource management, productivity in academic output, and efficiency within Turkey's higher education sector. As Turkish higher education strives to remain globally competitive, the emphasis must shift not only towards increasing resources but also towards utilizing them efficiently. The findings offer guidance for university management and policymakers, highlighting strategies that can support informed decision-making and strategic planning. An efficiency- centered approach, as this research suggests, will help strengthen Turkey's standing in global rankings and enhance the quality of its higher education system.

2. LITERATURE REVIEW

The application of Data Envelopment Analysis (DEA) for evaluating university efficiency has been well-documented in Turkey. Many studies have explored Turkish universities' educational and research efficiencies through various DEA models. Ulucan (2011) examined university efficiency through standard and measurement-specific DEA models, providing benchmarks for less efficient institutions. Selim and Bursalioğlu (2013) analyzed Turkish universities from 2006-2010 using a two-stage DEA model, observing that efficiency was positively impacted by the student-to-academic staff ratio. Cinar (2013, 2016) applied the Multiple Activity Data Envelopment Analysis (MA-DEA) model, which supports efficient resource use across research and educational activities, emphasizing how prioritization in these areas can impact total efficiency. Kadilar and Kadilar (2017) studied foundation universities through DEA and super-efficiency analyses, identifying Sabanci University as super-efficient and Ozyegin University as less efficient, while also noting an overall lack of technical efficiency in foundation universities. Maral (2023) focused on research efficiency in Turkey's research universities, finding only eight of these institutions to be efficient and suggesting that universities must take further steps to boost their efficiency.

3. MATERIALS AND METHODS

3.1. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a non-parametric technique used to assess the relative efficiency of decision-making units (DMUs) that operate with multiple inputs and outputs. The core aim of DEA is to evaluate how effectively these units utilize their resources (inputs) to generate desired results (outputs) (Charnes et al., 1978). In DEA, each unit's efficiency is assessed relative to a reference group; fully efficient units are given a score of 1, while inefficient units receive a score below 1. Due to its ability to handle multiple inputs and outputs, DEA is widely applied across sectors such as education, healthcare, and manufacturing, where it supports meaningful analysis of complex systems.

The DEA model used in this study is based on the Slack-Based Measure (SBM) approach. Unlike other DEA models, SBM-DEA directly considers inefficiency slack and generates an efficiency score for each unit by minimising these slacks (Tone, 2001).

The DEA model can be used in two basic forms:

1. Input-oriented model: The objective is to minimise inputs to achieve a given level of output.

2. Output-oriented model: The objective is to maximise output at a given input level. Since the study focuses on the academic outputs (publications and projects) of universities, the output-oriented model is preferred.

The output-oriented DEA model can be formulated as follows:

$$\text{Max}\,\theta = \frac{\Sigma_{r=1}^{s} u_r y_{rj}}{\Sigma_{i=1}^{m} v_i x_{ij}} \quad (1)$$

Where:

θ = Efficiency score,

u_r = Weights of outputs (number of publications, number of projects, etc.),

y_{rj} = Output number r of the decision unit

v_i = Weights of inputs (number of professors, associate professors, doctoral lecturers, etc.),

x_{ij}= Input i of the decision-making unit

is defined as.

3.2. Slack Based Measurement (SBM)-DEA Model

SBM-DEA is a method used to minimise inefficiency. In the SBM model, the differences between inputs and outputs are directly added to the model and slack is calculated. The mathematical representation of the SBM model is as follows (Tone, 2001):

$$\min \rho = \frac{1-\frac{1}{m}\Sigma_{i=1}^{m} s_i^- / x_i}{1-\frac{1}{s}\Sigma_{r=1}^{s} s_r^+ / y_r} \quad (2)$$

Where:

ϱ = SBM-DEA efficiency score,

s_i^- = Input inefficiency slack (overused input),

s_r^+ = Output inefficiency slack (underproduced output),

x_i = i-th input of the decision unit,

y_r = r-th output of the decision unit

is defined as.

This model is a measure of efficiency that shows how universities' inputs (academic staff) can be used more effectively and how their outputs (publications, projects) can be increased.

3.3. Panel Data Analysis

Panel data analysis is an econometric method that enables the analysis of data obtained from the same units at different time periods (Baltagi and Baltagi, 2008). This method of analysis allows time-dependent variables and differences between individuals to be evaluated together. Panel data sets consist of both cross-sectional data (differences between different units in a time period) and time series data (how a unit changes in different time periods).

Panel data analysis is used in this study to examine the factors affecting the efficiency levels of universities. Structural variables of universities such as the number of lecturers, number of research assistants, number of administrative staff, number of undergraduate students, number of master's students and number of doctoral students were tested with the panel data model.

The Pooled Model treats the entire data set as a single group and does not take individual differences into account (Baltagi and Baltagi, 2008). The equation of the model

$$Y_{it} = \alpha + \beta X_{it} + \varepsilon_{it} \quad (3)$$

is of the form.

Where Y_{it} is the value of the dependent variable (efficiency score) for the i-th unit at time t; X_{it} denotes the independent variables. α, is the constant term, β is the coefficient and, ϵ_{it} is the error term.

The Fixed Effects Model assumes that the specific characteristics of each unit are constant and do not change over time (Baltagi and Baltagi, 2008). The model equation

$$Y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it} \quad (4)$$

is of the form.

Where α_i denotes the unique fixed effect of each unit. The fixed effects model fixes heterogeneity across individuals and analyzes changes over time.

The Random Effects Model assumes that individual differences are randomly distributed and is added to the model as an error term (Wooldridge, 2010). The model equation

$$Y_{it} = \alpha + \beta X_{it} + u_i + \varepsilon_{it} \quad (5)$$

is of the form.

Where u_i represents individual fixed effects and is assumed to be randomly distributed.

The Lagrange multiplier (LM) test is a test of whether the pooled model is appropriate. If the result of the LM test is significant, then the pooled model is not appropriate and either the fixed or random effects model should be preferred (Breusch and Pagan, 1980). The F-test tests whether the fixed effects model is more appropriate than the pooled model. If the F-test is significant, the fixed effects model should be preferred (Baltagi and Baltagi, 2008). The Hausman test allows to choose between fixed and random effects models. If the fixed effects model is preferred as a result of the Hausman test, the differences between individuals should be considered fixed; in the random effects model, the differences are considered random (Hausman, 1978).

4. FINDINGS AND DISCUSSION

Table 1 evaluates the efficiency performance of the leading universities in Turkey between 2020 and 2023 using the SBM-DEA method. The SBM-DEA method is an effective approach to identify inefficiency slack and in this study, an output-oriented model with variable return to scale is used. This approach assesses how effectively universities use their inputs (academic staff) to produce academic outputs (publications and projects). In other words, universities are compared in terms of efficiency according to the extent to which they produce outputs with specific inputs.

Universities such as Bilkent University, Gebze Technical University, Hacettepe University, Middle East Technical University, Sabancı University and TOBB ETU have consistently demonstrated high perfor-

mance by achieving the full efficiency score (1) every year. These universities have been efficient in their academic outputs by using their resources effectively. As the SBM-DEA analysis shows, these universities have managed their resources optimally and managed to remain in a strong position in international competition through their success in research activities and projects. On the other hand, some universities, such as Ege University and Istanbul University, stand out with low efficiency scores over four years. Ege University's efficiency score increased from 0,29 in 2020 to 0,34 in 2023, but still remains low. Istanbul University also achieved a very low efficiency score of 0,14 in 2023. These low efficiency ratios indicate that resource management, academic staff and research outputs are not used efficiently. These universities are unable to effectively transform their inputs into outputs and the SBM-DEA model reveals this inefficiency. Some universities, such as Gazi University and Bogazici University, show significant declines over time. For example, while Gazi University was fully efficient between 2020 and 2022, this score dropped to 0,19 in 2023. Boğaziçi University's full efficiency score was 1 in 2021, but dropped to 0,28 in 2023. Such declines indicate that universities do not have a sustainable strategy for resource management. The use of the variable return to scale model is an important approach that reveals the efficiency losses in resource utilization of these universities in different periods. Universities such as Atatürk University and Atilim University show a fluctuating performance. While Atatürk University was fully efficient in 2022, its efficiency score declined to 0,19 in 2023. Similarly, while Atılım University was fully efficient in 2020 and 2021, its efficiency scores declined in 2022 and 2023. This suggests that these universities are unable to ensure continuity in resource utilization and are experiencing managerial difficulties.

Table 1. Universities' Efficiencies according to SBM-DEA

DMU	2020	2021	2022	2023
Ankara University	0,59	1	1	1
Ataturk University	0,39	0,49	1	0,19
Atilim University	1	1	0,69	0,52
Bilkent University	1	1	1	1
Bogazici University	0,59	1	0,41	0,28
Ege University	0,29	0,32	0,38	0,34
Gazi University	1	1	1	0,19
Gebze Technical University	1	1	1	1
Hacettepe University	1	1	1	1
Istanbul Medipol University	0,56	0,55	0,51	1
Istanbul Technical University	1	1	1	1
Istanbul University	0,82	0,50	1	0,14
Koç University	0,86	1	1	1
Middle East Technical University	1	1	1	1
Sabancı University	1	1	1	1
TOBB ETU	1	1	1	1

Table 2 shows the slack values of elite universities in Turkey between 2020 and 2023, i.e. the efficiency slacks between the number of academic staff (professors, associate professors, doctoral faculty members) and academic outputs (number of publications and projects). These gaps mean that universities are not reaching their potential and are not utilizing their resources to their full capacity. The main objective of the analysis is to identify these slack areas and provide guidance on how universities can improve their resource management and academic output.

Bilkent University, Gebze Technical University, Middle East Technical University (METU), Sabancı University and TOBB ETU achieved full efficiency scores for four years by using all their inputs in the

most efficient way. These universities do not have any slack values, i.e. they have achieved full capacity utilization in the number of professors, associate professors and doctoral faculty members, as well as in the number of projects and publications. This shows that these universities have implemented an effective resource management strategy, successfully transformed their inputs into outputs and achieved sustainable success in their research activities. As a result, it can be recommended that these universities continue with the current strategy and increase international collaborations.

Some universities, which are particularly notable in the Slack data, appear to have significant efficiency problems. In order to improve the performance of these universities, resources should be better managed and inefficient areas should be reduced. Ankara University has significant slack values in 2020. Especially with a slack value of 693 professors and 168 associate professors, it is seen that resources are not fully utilized. However, since 2021, the level of efficiency has increased and slack values have been zeroed. In order to sustain this situation, Ankara University needs to continue its effective resource management strategies and make long-term plans in academic staff management. Ataturk University, 154 doctoral faculty members and 327 project slack values in 2023 indicate that the university is experiencing significant inefficiencies. The fact that this university, which is fully effective in 2022, cannot provide continuity in resource management points to managerial and structural deficiencies. The recommended solution is more effective coordination of projects and the development of strategies to increase the motivation of academic staff. For Atilim University, there is a significant inefficiency in 2023, especially in the number of doctoral faculty members and publications. With a publication slack value of 218, it is understood that the university has experienced a serious performance decline in academic outputs. In order to solve this problem, research projects should be planned better, academic staff should be encouraged to research, and national/international funds should be utilized more. Bogazici University's 147 project slack value and 82 publication slack value in 2023 indicate that the university has not achieved the expected performance in project production and academic publications. To address these challenges, research processes at universities need restructuring, along with a reallocation of resources to boost academic output. Strengthening the engagement of academic staff in projects and enhancing their motivation is also crucial. For instance, Ege University has consistently displayed low activity levels, recording a slack of 254 professors and 291 projects in 2023. This data indicates that the university is not fully utilizing its academic staff or project opportunities. To enhance performance, Ege University should reform its resource management practices, improve project planning processes, and implement incentives for academic staff to increase their outputs. Gazi University faced a significant drop in efficiency, reflected by a slack value of 492 professors in 2023, having maintained full efficiency until 2022. To reverse this decline, the university must reconsider its academic staffing structure and allocate additional resources to research projects. Istanbul University also reported one of the lowest efficiency scores in 2023, with slack figures of 29 professors, 137 associate professors, and 362 projects. This suggests inefficiencies in resource utilization. To remedy this situation, the university needs to adopt a more strategic approach to its research processes and enhance the management of projects and publications. By implementing these reforms and strategies, these universities can improve their efficiency and better contribute to academic excellence and societal development.

Table 2. Slack (Inefficiency) Values of Universities between 2020-2023

DMU	Year	Slack Input: Number of Professors	Slack Input: Number of Associate Professors	Slack Input: Number of Assistant Professors	Slack Output: Number of Projects	Slack Output: Number of Publications
Ankara University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	693,74	168,71	0	175,61	229,31
Ataturk University	2023	0	142,56	154,87	327,54	641,72
	2022	0	0	0	0	0
	2021	0	83,14	197,79	255,23	49,40
	2020	0	121,67	203,16	269,99	150,26
Atilim University	2023	0	0	5,13	38,25	218,69
	2022	0	0	32,71	31,93	49,59
	2021	0	0	0	0	0
	2020	0	0	0	0	0
Bilkent University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0
Boğaziçi University	2023	0	10,28	19,61	147,70	82,19
	2022	0	15,26	7,67	125,81	62,08
	2021	0	0	0	0	0
	2020	0	16,91	0	70,40	0
Ege University	2023	254,28	134,47	0	291,83	96,48
	2022	354,94	138,44	0	279,35	17
	2021	311,07	125,52	0	302,62	0
	2020	274,77	123,53	0	292,19	0
Gazi University	2023	492,49	138,23	0	322,44	448,33
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0
Gebze Technical University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0
Hacettepe University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0

İstanbul Medipol University	2023	0	0	0	0	0
	2022	0	21,50	298,04	125,36	0
	2021	0	28,85	257,73	81,78	0
	2020	0	22,33	235,41	80,07	0
İstanbul Technical University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0
İstanbul University	2023	29	137	51	362	923
	2022	0	0	0	0	0
	2021	0	81,79	259,63	135,22	0
	2020	380	149	297	42	0
Koç University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	38,92	0	0	30,58	0
Middle East Technical University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0
Sabancı University	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0
TOBB ETU	2023	0	0	0	0	0
	2022	0	0	0	0	0
	2021	0	0	0	0	0
	2020	0	0	0	0	0

Table 3 presents the outcomes of three primary tests conducted within the framework of panel data analysis. The Lagrange Multiplier Test indicates that the pooled model is not suitable, as both individual and time effects are significant. This finding emphasizes the need to use either fixed or random effects models for a more precise analysis of university efficiency.

The F-Test further supports this, showing that the fixed effects model is a better fit compared to the pooled model. This suggests that factors influencing university efficiency extend beyond mere time or individual variations and should be considered within the model.

Additionally, the results of the Hausman Test confirm that while the random effects model is consistent, the fixed effects model is ultimately more appropriate. This underscores the value of employing fixed effects, as it provides a more nuanced understanding of efficiency variations that are influenced by the unique characteristics of each university.

Table 3. Model Selection Criteria for Panel Data Analysis

Test/Estimation Results	Test statistics	p	Conclusion
Lagrange Multiplier Test	3,4166	0,000317	Pooled model not appropriate; individual and time effects are important. Fixed or random effect models should be preferred.
F-Test	3,8399	0,0002864	Fixed effect model is more appropriate than pooled model. Fixed effects are important.
Hausman Test	7,4259	0,2832	Random effect model is consistent and usable. However, fixed effect model is more appropriate.

Table 4 showcases the results from the Oneway (Individual) Effect Random Effect Model, which analyzes factors affecting the efficiency of 16 universities over 64 observations across a 4-year period. The model's results indicate a constant term (intercept) value of 0,90941, which is highly significant ($p < 0.001$), reflecting a strong baseline efficiency.

The analysis reveals that the number of lecturers (X_1) does not significantly impact efficiency, with an estimated coefficient of 0,00012891 and a non-significant p-value of 0,806. Similarly, the number of research assistants (X_2) shows an estimated value of -0,00025115 and an insignificant p-value of 0,354. These findings suggest that simply increasing the numbers of lecturers and research assistants may not effectively enhance efficiency.

In contrast, the number of administrative staff (X_3) has an estimated coefficient of -0,00008319 and a significant p-value of 0,032, indicating a negative effect on efficiency. This points to a potential need to re-evaluate current administrative processes to improve their overall effectiveness.

Regarding undergraduate students (X_4), the estimated value is -0,0000024885, with a non-significant p-value of 0.830, indicating that undergraduate enrollment does not have a clear impact on university efficiency. However, the coefficient for graduate students (X_5) is -0,000085873, significant at a p-value of 0,035, suggesting that an increase in the number of graduate students may actually lower efficiency. This finding points to potential areas for improvement in managing or designing master's programs. Conversely, the estimated coefficient for doctoral students (X_6) is 0,00028236, with a significant p-value of 0,009, showing a positive contribution to university efficiency, suggesting that expanding doctoral programs could improve overall effectiveness. Improving administrative personnel management, reviewing master's programs and investing more in doctoral programs are strategies that can help universities increase their efficiency levels. In addition, it is important to continuously monitor and evaluate the variables that affect efficiency levels. Such regular analysis will allow universities to improve their performance over time.

Table 4. Oneway (Individual) Effect Random Effect Model Results

Variable (X)	Estimate	Std. Error	z-value	p	Conlusion
Intercept	0,90941	0.1235	7.3638	1.787E-13	Significant
Lecturer	0,00012891	0.00052561	0.2453	0.806257	Not significant
Research Assistant	-0,00025115	0.0002708	-0.9274	0.353701	Not significant
Number of Administrative Staff	-0,00008319	0.00003879	-2.1449	0.031963	significant
Number of undergraduate Students	-2,4885E-06	0.0000116	-0.2146	0.830102	Not significant
Number of Masters Students	-0,000085873	0.00004065	-2.1124	0.03465	Significant
Number of PhD Students	0,00028236	0.00010896	2.5914	0.009559	Significant

5. CONCLUSIONS

This study evaluates the efficiency levels of Turkey's 16 world-ranked elite universities between 2020 and 2023 using the SBM-DEA method. The SBM-DEA model analyzed the extent to which inputs (the number of professors, associate professors and doctoral faculty members) are converted into outputs (the number of publications and projects) by revealing the inefficiency slack in resource utilization of universities. The study also analyzed the structural factors affecting the efficiency levels of universities using panel data analysis.

The findings show that universities such as Bilkent University, Gebze Technical University, Hacettepe University, Middle East Technical University, Sabancı University and TOBB ETU achieved full efficiency scores (1) and exhibited high performance for four years. By utilizing their resources effectively, these universities have achieved a sustained level of efficiency and maintained their international competitiveness. Sabancı University, in particular, was among the super-efficient universities, as also noted in other studies (Kadilar and Kadilar, 2017). Certain universities, such as Ege University and Istanbul University, demonstrate notably low efficiency scores. While Ege University has seen a slight improvement in its efficiency score from 0,29 in 2020 to 0,34 in 2023, it still remains at a low level. In contrast, Istanbul University's efficiency score of 0,14 in 2023 highlights significant inefficiencies in its resource management practices. To tackle these challenges, Istanbul University could greatly benefit from strategic planning initiatives aimed at optimizing resource utilization and enhancing academic output.

The panel data analysis reveals that a higher number of doctoral students positively impacts efficiency, underscoring the importance of investing in doctoral programs. Conversely, an increase in master's student enrollment is associated with lower efficiency, suggesting that the structure and management of master's programs need reevaluation. Additionally, the negative influence of administrative staff numbers on efficiency indicates a potential need for streamlining administrative processes to boost overall performance.

In summary, this study evaluates resource usage efficiency across Turkish universities and provides actionable recommendations for improvement. To ensure sustained progress, universities should focus on enhancing academic output through strengthened doctoral programs, implement sustainable resource management practices by refining administrative workflows, and redesign master's programs to improve their effectiveness. By executing these strategic measures, Turkish universities can maintain their global competitiveness and enhance their contributions to international scientific advancement.

REFERENCES

Altbach, P. G. (2011). The road to academic excellence: The making of world-class research universities.

The World Bank.

Baltagi, B. H., & Baltagi, B. H. (2008). Econometric analysis of panel data (Vol. 4, pp. 135-145).

Chichester: Wiley.

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. The review of economic studies, 47(1), 239-253.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units.

European Journal of Operational Research, 2(6), 429-444.

Cinar, Y. (2013). Türkiye'de Kamu Üniversitelerinin Eğitim-Araştırma Etkinlikleri ve Etkinlik Artışında Stratejik Önceliklerin Rolü: Çok-Aktiviteli VZA Uygulaması. Ankara Üniversitesi SBF Dergisi, 68(02), 27-62.

Cinar, Y. (2016). Research and teaching efficiencies of Turkish Universities with heterogeneity considerations: application of multi-activity DEA and DEA by sequential exclusion of alternatives methods. arXiv preprint arXiv:1701.07318.

Cooper, W. W., Seiford, L. M., & Zhu, J. (2011). Data envelopment analysis: History, models, and interpretations. Handbook on data envelopment analysis, 1-39.

Hausman, J. A. (1978). Specification tests in econometrics. Econometrica: Journal of the econometric society, 1251-1271.

Hazelkorn, E. (2015). Rankings and the reshaping of higher education: The battle for world-class excellence. Springer.

Kadilar, G. O., & Kadilar, C. (2017). Statistical analysis of the foundation universities in Turkey.

Maral, M. (2023). Examination of research efficiency of research universities in Türkiye by data envelopment analysis. International Journal of Educational Management, 37(6/7), 1162-1176.

Marginson, S. (2016). Higher education and the common good. Melbourne Univ. Publishing.

Selim, S., & Bursalioglu, S. A. (2013). Analysis of the determinants of universities efficiency in turkey: Application of the data envelopment analysis and panel Tobit model. Procedia-Social and Behavioral Sciences, 89, 895-900.

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. European journal of operational research, 130(3), 498-509.

Ulucan, A. (2011). Measuring the efficiency of Turkish universities using measure-specific data envelopment analysis. Sosyoekonomi, 14(14).

Wooldridge, J. M. (2010). Econometric analysis of cross section and panel data. MIT press.