sciendo

Exploring the Heterogeneity among Higher Education Institutions in Europe

Andreea-Monica MUNTEANU*
Bucharest University of Economic Studies, Bucharest, Romania
**Corresponding author, monica.munteanu@csie.ase.ro*

Abstract. *Measuring the performance of tertiary educational systems begins with the appropriate selection of inputs and outputs illustrating the most important educational processes achieved in Higher Education Institutions (HEIs). European HEIs use a multiple input-output production framework. It is widely known that HEIs use distinct human, financial and physical resources to offer educational services, quantified by qualitative and quantitative outcomes. Assessing the efficiency of teaching and research activities performed by HEIs is widely investigated nowadays. This study explores the heterogeneity of 363 European HEIs in their teaching and research processes. Firstly, the reduction dimension technique proposed by Mouchart and Simar is used to construct aggregated input and output. Secondly, the cluster analysis is performed on the aggregated indicators to identify different associations of universities based on their similarities. The Mahalanobis distance is applied as reduced indicators are moderately correlated between them. The 363 public and private European HEIs are grouped into six distinct categories, with the second cluster incorporating 68% of the investigated universities. The classification of private and public European HEIs shows the heterogeneity of tertiary educational systems. Some of the higher educational systems are homogenous as all the HEIs are grouped into one cluster, while the German, Spanish and Italian systems are not so homogenous, the HEIs are distributed in separate clusters.*

Keywords: HEIs, heterogeneity, cluster analysis, Europe.

Introduction

It is widely known that education promotes a developed society. Daily, starting at an early age, children learn at school and then at home with their parents, siblings or even other relatives. The same pattern of learning is applied to young people and even adults. Meanwhile, they are learning in different circumstances than children: in a formal educational setting, meaning that they are enrolled in a Higher Education Institution (HEI) for bachelor, master or even doctoral studies, or on an informal educational framework. Adults learn at work or home to improve their knowledge and to gain skills and competencies. In the last case, they learn individually or in small groups using various sources like books, online resources, and online platforms offering different courses on specialised topics. Also, they could be engaged in training programs founded by their employers.

The educational pathway can be classified according to the International Standard Classification of Education (ISCED 2011). As per this classification, the educational system is grouped into nine separate categories: ISCED 0 (early education) to ISCED 8 (doctoral studies). Tertiary education, representing the highest level of studies that can be achieved, is separated into four classes: ISCED 5 (tertiary education, short term), ISCED 6 (tertiary education, bachelor level), ISCED 7 (tertiary education, master level) and ISCED 8 (tertiary education, doctoral level).

Higher education institutions (HEIs) use multiple resources to provide educational services in the tertiary educational system. Participating in the higher education system is extremely important as it improves young people's and adults' skills and knowledge. In the long term, each year spent on education directly impacts the revenues gained by people (Mincer, 1974) and influences economic growth (Barro, 2001). Analysing how HEIs perform in their activities could

DOI: 10.2478/picbe-2025-0206
© 2025 A.-M. Munteanu, published by Sciendo.
This work is licensed under the Creative Commons Attribution 4.0 License.

be a starting point in establishing policies and measures that will impact the economy, the labour force and even the people's life quality.

This research analyses the heterogeneity of the tertiary educational system among Europe using multiple inputs and outputs. This paper represents a preliminary step in efficiency analysis that should be treated in future work. The objective is to build homogeneous groups of universities. Then in future research, the groups should be treated separately to obtain consistent and unbiased efficiency estimators. The representation of the efficiency frontier can be achieved in a two-dimensional space; aggregated measures should be constructed using a reducing dimensionality technique to obtain this.

Literature Review

Nowadays, evaluating the efficiency of tertiary educational institutions is quite an important topic. The key step in analysing the HEIs' performance is choosing the right inputs and outputs involved in the production activity.

The main analysed activities performed in HEIs can be classified into: (1) teaching activities, where the main objective is to deliver bachelor's and master's degrees, or even doctoral degrees; (2) research activities, where HEIs are focused on increasing their number of publications, citations, international collaborations, participation in research projects; or (3) teaching-research activities are a mixt activity, where universities are simultaneously focused on teaching and research. Other processes considered while evaluating how well the universities use their inputs to produce outcomes are knowledge dissemination and financial activities.

Since the production activity distinguishes between inputs and outputs, these can be grouped separately. Table 1 includes the separation between the frequently used inputs and outputs in the literature to assess the efficiency of HEIs.

Table 1. Selection of inputs and outputs

Type	Variable	Study
Inputs	Academic staff	Barra et al. (2018); Martínez-Campillo and Fernández-Santos (2020); Abbott and Doucouliagos (2003); Bonaccorsi et al. (2006); Daraio et al. (2015); Agasisti, and Wolszczak-Derlacz (2014)
	Non-academic staff	Abbott and Doucouliagos (2003); Bonaccorsi et al. (2006); Daraio et al. (2015)
	Expenditures (other than salaries for academic and non-academic staff)	Abbott and Doucouliagos (2003); Daraio et al. (2015); Agasisti, and Wolszczak-Derlacz (2014)
	Number of students enrolled	Barra et al. (2018); Martínez-Campillo and Fernández-Santos (2020)
	Total revenues	Martínez-Campillo and Fernández-Santos (2020)
Outputs	Graduates	Barra et al. (2018); Martínez-Campillo and Fernández-Santos (2020); Bonaccorsi et al. (2006); Daraio et al. (2015); Agasisti and Wolszczak-Derlacz (2014)
	Research grants	Barra et al. (2018)
	Publications	Martínez-Campillo and Fernández-Santos (2020); Bonaccorsi et al. (2006); Daraio et al. (2015); Agasisti, and Wolszczak-Derlacz (2014)
	Citations	Bonaccorsi et al. (2006)
	Number of students enrolled	Agasisti, and Wolszczak-Derlacz (2014)

Usually, inputs include human capital grouped into academic staff (cumulation of full professors, associate professors, lecturers and assistant lecturers), and non-academic staff consists of technical

DOI: 10.2478/picbe-2025-0206, pp. 2680-2690, ISSN 2558-9652 |
Proceedings of the 19th International Conference on Business Excellence 2025

and administrative staff and financial capital including expenditures on salaries, other categories of expenditure (other than remuneration for academic and non-academic staff) or even revenues. Another important input while analysing the universities' performance is the number of students enrolled. The total number of students enrolled can be reported at grouped levels (ISCED 5-8) or separately for each level (bachelor students – ISCED 5 or 6, master students – ISCED 7 and doctoral students – ISCED 8). Some educational measures could be classified either as input or output in the literature. Such example is denoted by the number of students enrolled that is considered an input in some research (Barra et al., 2018; Martinez-Campillo and Fernandez-Santos, 2020) or an output in another study (Agasisti and Wolszczak-Derlacz, 2014).

Meanwhile, educational outcomes can be organised into teaching outputs (number of graduates or degrees offered by the HEIs) and research outputs (research grants, publications and citations). Degrees awarded by HEIs can be expressed as the cumulation of the degrees delivered (ISCED 5-8) or separately for ISCED 5, ISCED 6, and ISCED 7, respectively, ISCED 8 levels. Research grants are monetary resources that institutions provide to support research activities performed in the universities. Citations are considered an indicator to assess the quality of the research processes performed in universities by their PhD students and the academic staff. Otherwise, the publications are a quantitative indicator frequently used to measure the volume of work produced by PhD students and educational personnel. Publications include the number of published articles, mainly the papers indexed in the Web of Science database or another international database, the number of published book chapters or books, and conference papers.

Methodology

The production activity of European HEIs implies transforming inputs or resources used in teaching and research activities into measurable outputs.

This activity can be described as: $\Psi = \{(x,y) | x \in R_+^p, y \in R_+^q \; and \; (x,y) \; is \; feasible\}$, where x is known as the input vector, and y is known as the output vector.

To avoid the curse of dimensionality imposed by the increased number of inputs and/or outputs participating in the production process, the aggregation method proposed by Mouchart and Simar (2002) is employed. This reduction dimensionality approach uses the eigen-decomposition of the inputs matrix, respectively, the outputs matrix. Mathematically, X is the input matrix, and Y is the output matrix. Variables used are standardised by dividing each of them by their standard deviation.

The aggregated input is calculated as $I_A = \alpha * X$, where α is the eigenvector of the $X^T X$ matrix corresponding to the largest eigenvalue λ_1, and X_{nxp} is the input matrix. In our case, $I_A = \alpha_1 * X_1 + \alpha_2 * X_2 + \alpha_3 * X_3$.

In the same manner, the aggregated output can be defined as $O_A = \beta * Y$, where β is the eigenvector of the $Y^T Y$ matrix corresponding to the largest eigenvalue λ_1, and Y_{nxq} is the output matrix. Particularly, aggregated output is $O_A = \beta_1 * Y_1 + \beta_2 * Y_2$.

Identifying patterns and homogenous groups among the European HEIs in their teaching and research activities is assisted by the hierarchical clustering algorithm. The Ward (1963) aggregation method is used to reduce the variance within classes and the Mahalanobis (1930) distance since it considers the high correlation between the aggregated input and output.

The Mahalanobis distance is described as: $d_M(I_A, O_A) = (I_A - O_A)^T * \Sigma^{-1} * (I_A - O_A)$, where $I_A \; and \; O_A$ are the aggregated input, respectively output vectors, and Σ is the covariance matrix.

Silhouette coefficients (Rouseeuw, 1987) are calculated to verify the quality of the cluster solution. The values of these measures are fluctuating between -1 and 1. Three possible scenarios can occur when evaluating the allocation into groups based on the sign and intensity of the Silhouette value. A value of -1 displays a wrong allocation of the HEI in the cluster. On the contrary, a value of 1 shows a correct distribution in the cluster. The investigated HEI cannot be placed correctly in a cluster when the Silhouette coefficient is 0. In this case, the observation is on the boundary between two clusters.

This research aims to check the heterogeneity of European Higher Education Institutions regarding their teaching and research activities. The research questions which are addressed in this paper are the following:

H_1: Can the dimension reduction technique be applied to inputs and outputs?

H_2: Are European HEIs heterogeneous in their teaching and research activities?

The analysis is performed in RStudio 4.1 using multiple packages (ggplot2, ecodist, factoextra, cluster, FEAR, etc.).

Results and discussion

The educational variables used in this paper are collected from the ETER database corresponding to the 2021-2022 academic year. The variables are described in Table 2, along with some descriptive statistics. The final dataset covers 363 public and private research-active HEIs. The geographical distribution shows a wide cover of 17 European countries. Inputs and outputs are chosen based on the variables already used in the literature to define the teaching and research activities. In this paper, outputs can be separated into teaching output represented by the total number of graduates ISCED 5-7 and research output quantified by the number of EU-FP projects. The inputs selected in this paper are classified into human resources indicators: total academic personnel (TAP) and number of support and administrative personnel (SAP). The PhD students (TS8) are also included in this category since they work together with educational personnel to prepare materials, assist lectures, grade projects and exams, etc, and with research and/or academic personnel for research purposes (attending conferences, writing papers, book chapters, delivering materials for research projects etc).

Table 2. Descriptive statistics

		Min	Mean	Max	Standard deviation
Inputs	Total academic personnel (HC)	36	1716.9	11452	1732.12
	Number of support and administrative personnel (HC)	4	1265.6	12689	2003.89
	Total students enrolled at ISCED 8	10	905.8	4908	1011.84
Outputs	Total graduates ISCED 5-7	65	3093	12349	2477.99
	Number of EU-FP projects	1	39.89	233	50.85

Source: Author computation using RStudio 4.1.

The synthesis of some descriptive statistics (minimum, mean, maximum, standard deviation) is presented in Table 2. Existing heterogeneity in the dataset is explained by the high variability defining all the selected indicators, except for the number of EU-FP projects. On average, the educational personnel category is greater than the support and administrative staff.

The highest value of ISCED 5-7 graduates is achieved by the University of Milano (UNIMI), which is a large and prestigious university in Italy. In this university, one academic staff

DOI: 10.2478/picbe-2025-0206, pp. 2680-2690, ISSN 2558-9652 |
Proceedings of the 9th International Conference on Business Excellence 2025

member is coordinating approximately four students for bachelor's and master's theses. Utrecht University is a well-known research active HEI, and in the 2021-2022 academic year, this university participated in 233 EU-FP projects. On the contrary, other universities from the analysed sample are not implicated in such many research projects, as the minimal value of 1 corresponds to 22 universities, seven of which are Bulgarian HEIs.

Figure 1. Correlation coefficients between inputs and outputs

Source: Author computation using RStudio 4.1.

In the 2021-2022 academic year, the ratio of total academic personnel reported to total graduates ISCED 5-7 is equal to 1:2, meaning that one professor is assisting, on average, approximately two students ISCED 5-7 in their activities to graduate. Considering the PhD students, the workload of educational personnel reported to ISCED 8 students is 2:1. In this case, each PhD student can work, on average, with two professors and benefit from their expertise and knowledge while preparing their doctoral thesis.

Looking at the correlation coefficients between inputs and outputs presented in Figure 1, we can conclude that inputs are moderately to highly correlated with each other (coefficients ranging between 0.54 and 0.88). The high correlation coefficient of 0.88 shows a strong connection between academic personnel and administrative & support staff. As the educational staff is working closely with administrative & support staff to ensure good teaching services, an increase in educational staff could be reflected in an expansion of administrative & support personnel. In the same manner, the outputs are moderately correlated between them (the correlation coefficient is 0.61).

Table 3. Correlation between inputs and aggregated input

	I1	I2	I3
Aggregated Input	0.97	0.89	0.85

Source: Author computation using RStudio 4.1.

The aggregated output consists of two variables (total graduates ISCED 5-7 and the number of EU-FP projects). According to correlation coefficients presented in Table 4, the aggregated output is also highly correlated with the initial variables as coefficients are equal to 0.86, respectively 0.93.

Table 4. Correlation between outputs and aggregated output

	O1	O2
Aggregated Output	0.93	0.86

Source: Author computation using RStudio 4.1.

Initially, as observed in Figure 1, there is a moderate association between inputs and outputs, the correlation coefficients varying between 0.38 (total graduates ISCED 5-7 and total academic & support staff) and 0.62 (PhD students and EU-FP projects). The aggregated indicators resulting from applying the dimension reduction technique are moderately correlated, and the coefficient is 0.67. As the correlation coefficients between initial variables and aggregated input, respectively output, are high, the dimension reduction method is suitable for this dataset. The first hypothesis imposed in this paper is validated.

The next step in this research is to identify homogenous groups among European HEIs using the aggregated input and output defined earlier. Grouping the HEIs is performed by a hierarchical clustering algorithm using the Mahalanobis distance, as the aggregated input and output are moderately correlated, as demonstrated earlier.

Determining the optimal number of clusters is achieved by comparing different average Silhouette widths for various configurations. Distinct solutions of two up to six clusters were compared, and the maximal average Silhouette width corresponds to a solution composed of six clusters. The average Silhouette width of 0.71 is an indicator of a good classification. According to the Silhouette plot from Figure 2, some HEIs are not correctly classified in clusters 2, 3 and 4, while the HEIs belonging to clusters 1, 5 and 6 are correctly allocated in these classes.

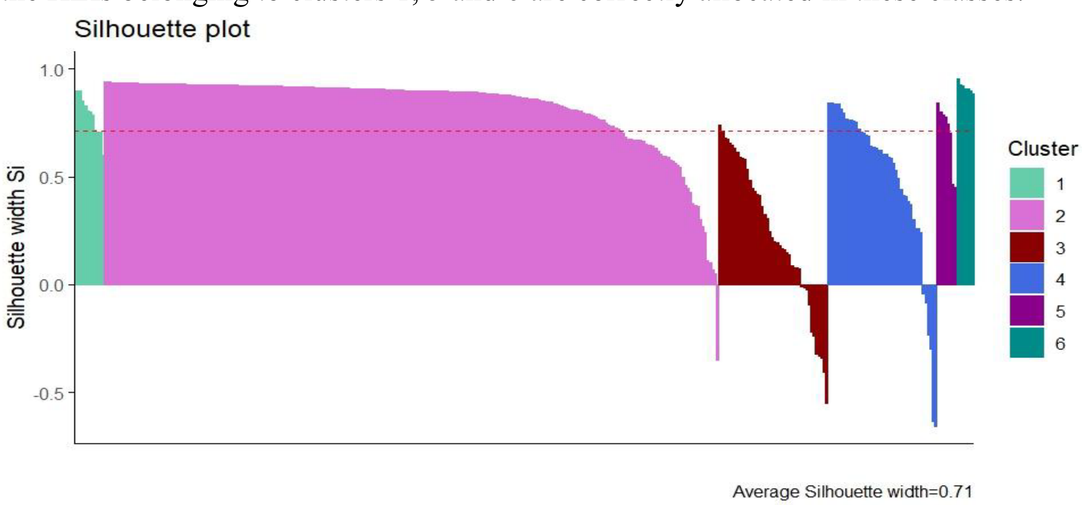

Figure 2. Silhouette plot

Source: Author computation using RStudio 4.1.

Table 5 summarises the number of HEIs, the average Silhouette width, and the number of incorrectly allocated HEIs by cluster. Cluster 2 encompasses the most European HEIs, approximately 68% of the analysed HEIs are classified in this group, the average Silhouette width is 0.83. The smallest cluster is the sixth, including only seven HEIs (3 Italian HEIs and 4 Dutch HEIs). All the universities are very well classified in this group due to the high average Silhouette value of 0.92. On the contrary, the third cluster is defined by the most misassigned universities. The incorrect allocation is also reflected in the average Silhouette measure, which is the smallest for this cluster compared to the others.

Table 5. Silhouette coefficients

	# of universities	Average Silhouette width	# of wrong universities allocated in cluster
Cluster 1	12	0.79	0
Cluster 2	248	0.83	1
Cluster 3	44	0.23	11
Cluster 4	44	0.49	6
Cluster 5	8	0.70	0
Cluster 6	7	0.92	0

Source: Author computation using RStudio 4.1.

The 18 wrongly allocated HEIs are distributed among the second cluster (one HEI), third cluster (eleven HEIs) and fourth cluster (six HEIs). Seven German HEIs are inaccurately assigned in the third cluster, the other HEIs forming this cluster are three Spanish universities and one Austrian university. 6 out of 18 inappropriately allocated HEIs have Silhouette measures close to 0, showing an imprecise allocation in the cluster.

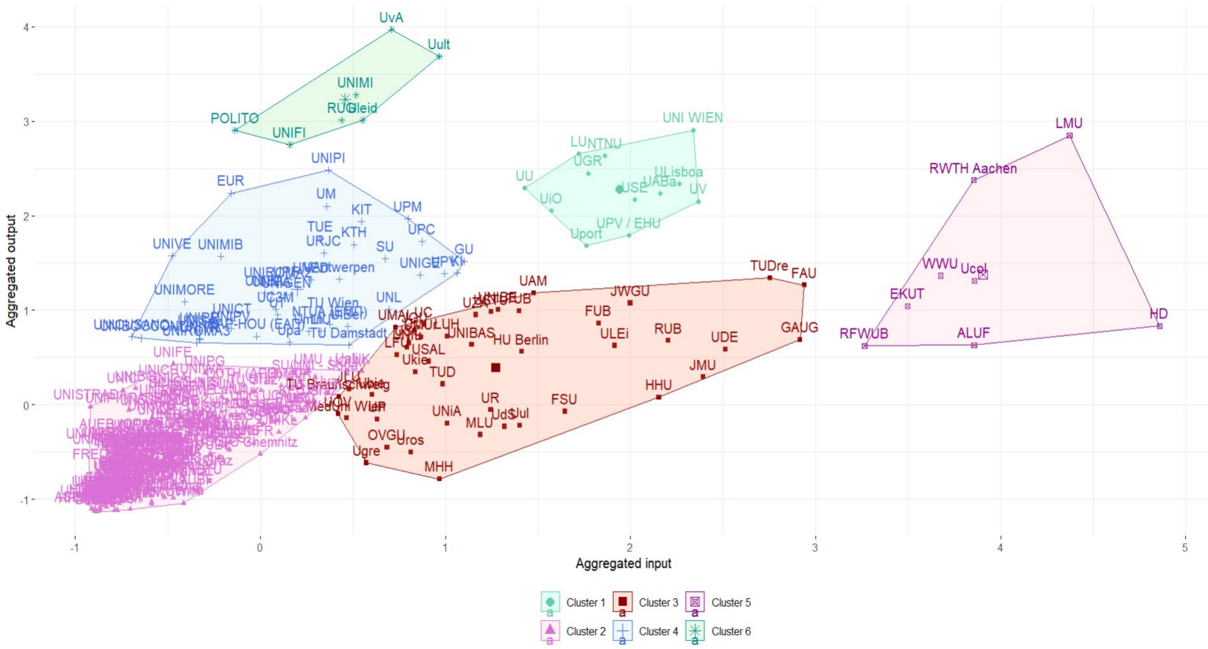

Figure 3. European HEIs repartition

Source: Author computation using RStudio 4.1.

According to Figure 3, the 363 European HEIs are grouped into six distinct clusters based on their similarities regarding the aggregated resources and outcomes defining the teaching-research processes. We conclude that the resulting groups are heterogeneous, confirming the second hypothesis analysed in this paper.

To better understand their particularities, the obtained groups should be analysed separately. The HEIs are diversely allocated in clusters depending on the country. As can be seen in Figure 4, the second cluster includes universities exclusively from Bulgaria, Slovakia, Cyprus, Latvia, Lithuania and Luxembourg. German, Spanish and Italian tertiary educational systems are diversified, as 56% of the analysed HEIs are concentrated in these three countries and are grouped into three to four clusters.

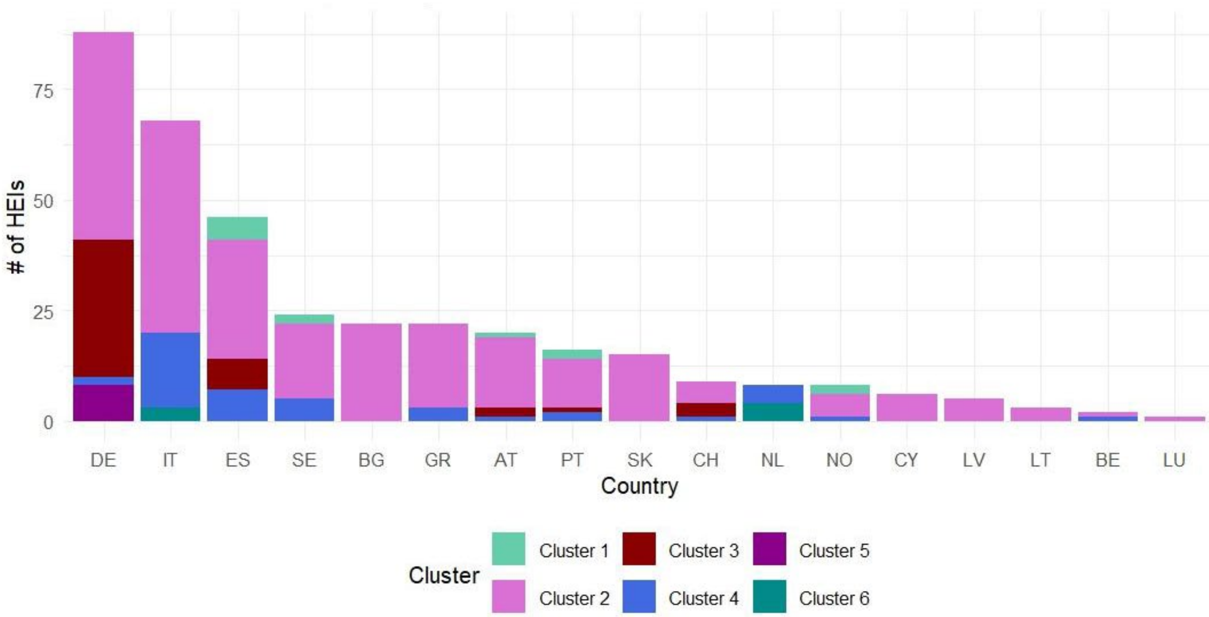

Figure 4. Distribution of HEIs by country and cluster

Source: Author computation using RStudio 4.1.

The six clusters can be compared based on the aggregated input and output average values presented in Table 6. The average aggregated indicators vary depending on the cluster. The aggregated input fluctuates between 0.70 (cluster 2) and 7.56 (cluster 5), while the aggregated output ranges between 0.80 (cluster 2) and 5.53 (cluster 6).

Table 6. Centroids and initial variables (average) by cluster

	Aggregated Input	I1	I2	I3	Aggregated Output	O1	O2
Cluster 1	4.49	4479	2570	3836	4.34	8315	140
Cluster 2	0.70	898	464	443	0.80	1905	15.7
Cluster 3	3.46	3837	3672	1944	1.96	3989	56.8
Cluster 4	1.78	2053	1236	1243	3.00	5736	97.5
Cluster 5	7.56	8425	10309	3221	3.21	5973	108
Cluster 6	2.19	2892	2157	998	5.53	10702	176

Source: Author computation using RStudio 4.1.

The first cluster incorporates 12 HEIs from Spain, Sweden, Austria, Portugal and Norway. 5 out of 12 are elderly Spanish HEIs, and all of them are popular universities assessed by the number of graduates, varying between 8028 and 10875. The Spanish HEIs manifest an immense interest in EU-FP projects. The Autonomous University of Barcelona is showing a great interest in research project participation, as in the 2021-2022 academic year, this university was engaged in 134 projects.

As mentioned, the second cluster includes 248 HEIs covering 16 European countries. Based on the teaching and research outputs, HEIs included in this category are small and medium as the number of graduates ISCED 5-7 ranges between 65 and 5114, with an average value of 1905. Also, the focus on research measured by the implication in EU-FP projects is low, as the values vary between 1 and 98. 21 universities have participated in only one EU-FP project in the 2021-2022 academic year, showing a deficiency regarding the research activity.

The third cluster is an association of 44 universities from Germany, Spain, Austria, Portugal and the Czech Republic. On average, these universities use more resources in their teaching and research processes than the outputs result. TU Dresden can obtain the maximum aggregated output, but this represents only 55% of their cumulative resources used in the production activity. This configuration includes considerable universities, as the academic and non-academic staff vary between 1887 and 7959, respectively 1058 and 8824.

Also, the fourth cluster includes 44 medium and large universities. In this case, the aggregated input varies between 0.38 and 3.18, while the aggregated output fluctuates between 2.26 and 4.59. The centroids for this configuration of universities show a moderate orientation towards teaching-research activities. The number of ISCED 5-7 graduates exceeds the average value of 5736 in 23 out of 44 analysed universities. The focus on research output is diminished as only 19 out of 44 universities are actively engaged in taking initiative and collaborating in research projects, on average, these universities are implicated in 98 EU-FP projects. UNIPI, known as the University of Pisa, records the maximum aggregated output for this configuration of universities showing a high interest in teaching and research as in the 2021-2022 academic year, approximately 8900 students ISCED 5-7 graduated, and the university participated in 146 EU-FP projects.

The eight German HEIs consisting exclusively of the fifth cluster used the most human resources compared to the other classes. These universities are moderately oriented on teaching and research activities as the aggregated effort of these HEIs is not reflected in the output measures. The average aggregated output represents only 42% of the inputs used in the production process by these German HEIs. Only three universities are engaged in more than 108 EU-FP projects. On the other dimension, these universities are more implicated in teaching activities, as four universities can be defined by more than 5973 graduates ISCED 5-7 (the average value).

On the contrary, the sixth cluster is exclusively distinguished from the other five clusters obtained. This group, resulting in three Italian and four Dutch universities, is characterised by fewer human resources (the centroid corresponding to aggregated input is 2.19) and the highest research and teaching outcomes (the centroid corresponding to aggregated output is 5.53). Polytechnic University of Turin (POLITO), highly oriented on STEM programmes, is one of the oldest Italian technical universities and is included in this category, along with others oldest, well-known and with a good academic reputation universities like the University of Florence (UNIFI) and the University of Milan (UNIMI), which is an intensive research Italian HEI. The analysed Italian HEIs are placed on 12th (Polytechnic University of Turin), 14th (University of Milan) and 24th (University of Florence) according to QS World University Rankings by Region 2025 – Southern Europe. The Dutch universities include the University of Amsterdam, the University of Groningen, Leiden University and Utrecht University. The Dutch HEIs are elderly and prestigious universities like the Italian ones.

These seven universities are highly oriented towards teaching and research activities since in five HEIs, the number of graduates ISCED 5-7 exceeds the average value of 10702 graduates. The same behaviour is applied to the number of collaborations in EU-FP projects, only four HEIs are implicated in more than 176 EU-FP projects in the 2021-2022 academic year. The University of Amsterdam is included in the intensive teaching-research activities category and is placed 55th according to QS World University Rankings 2025. Also, this university can be characterised as the most intensive in research and teaching activities due to the maximum aggregated output value

DOI: 10.2478/picbe-2025-0206, pp. 2680-2690, ISSN 2558-9652 |
Proceedings of the 19th International Conference on Business Excellence 2025

recorded, which translates into more than 12300 students ISCED 5-7 that graduate and more than 210 EU-FP projects contracted in the 2021-2022 academic year.

Conclusion

In this paper, I aimed to verify if the European tertiary education system is homogenous or heterogeneous using three inputs and two outputs defining the teaching and research activities. Firstly, the dimension reduction technique defined by Mouchart and Simar (2002) is utilised to create one aggregated input, respectively output. The main reason for choosing this approach resides in the possibility of representing the efficiency frontier. Secondly, a cluster analysis using the Mahalanobis distance is employed to construct different configurations of universities based on the aggregated measurements. The Mahalanobis distance is preferred as it considers the high association between variables. By analysing the distribution of the 363 investigated HEIs, we can conclude that the European higher education system is not homogenous in its teaching-research activities. The European HEIs are grouped into six clusters, the second cluster covering 68% of the analysed European HEIs. The other five clusters are smaller than the second, as the number of HEIs forming these clusters varies between 7 and 44. Most HEIs are German, Spanish and Italian, showing that these academic systems are sizable compared to the other European tertiary educational systems. Some academic systems are homogenous since all the HEIs are grouped into only one cluster. Such examples are Bulgarian or Slovakian universities. Other tertiary educational systems are not so homogenous as the HEIs are distributed among different clusters. German, Spanish and Italian tertiary educational systems are in this situation. One important factor that can contribute to this behaviour is the university's size.

This paper has some limitations; the research activity can be quantified by considering other research measures than the number of EU-FP projects. Additional inputs and outputs can be included in this analysis; for example, the number of publications and citations may be considered as research outputs. Such indicators were unavailable in the ETER database, and other sources should be investigated to retrieve these data.

As a future research direction, the mentioned research outputs can be included in the analysis, along with other teaching and research inputs or outputs based on the frequently used variables in the practice. Moreover, some filters can be applied while analysing the heterogeneity or homogeneity of the European academic system, such as STEM orientation or the universities' size. Another important aspect that can be considered in another study is performing the analysis at the faculty level to check if the faculties are homogenous based on their field of study across Europe.

Acknowledgement

This paper was co-financed by The Bucharest University of Economic Studies during the PhD program.

References

Agasisti, T., & Wolszczak-Derlacz, J. (2014). Exploring universities' efficiency differentials between countries in a multi-year perspective: an application of bootstrap DEA and Malmquist index to Italy and Poland, 2001-2011.

Abbott, M., & Doucouliagos, C. (2003). The efficiency of Australian universities: a data envelopment analysis. *Economics of Education review*, *22*(1), 89-97.

Barro, R.J., 2001. Human capital and growth. American economic review, 91(2), pp.12-17

Barra, C., Lagravinese, R., & Zotti, R. (2018). Does econometric methodology matter to rank universities? An analysis of Italian higher education system. *Socio-Economic Planning Sciences*, *62*, 104-120.

Bonaccorsi, A., Daraio, C., & Simar, L. (2006). Advanced indicators of productivity of universities An application of robust nonparametric methods to Italian data. *Scientometrics*, 66(2), 389-410.

Daraio, C., Bonaccorsi, A., & Simar, L. (2015). Efficiency and economies of scale and specialization in European universities: A directional distance approach. *Journal of Informetrics*, *9*(3), 430-448.

Martínez-Campillo, A., & Fernández-Santos, Y. (2020). The impact of the economic crisis on the (in) efficiency of public Higher Education institutions in Southern Europe: The case of Spanish universities. *Socio-Economic Planning Sciences*, 71, 100771.

Mahalanobis, P. C. (1930). On test and measures of group divergence: theoretical formulae.

Mincer, J.A., 1974. The human capital earnings function. In *Schooling, experience, and earnings* (pp. 83-96). NBER.

Mouchart, M., & Simar, L. (2002). Efficiency analysis of Air Controllers: first insights. *Consulting report*, 202.

Rousseeuw, P. J. (1987). Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. *Journal of computational and applied mathematics*, *20*, 53-65.

Ward Jr, J. H. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American statistical association*, *58*(301), 236-244.

https://www.topuniversities.com/qs-world-university-rankings