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Efficiency of European public higher education institutions: a two-stage multicountry approach

Joanna Wolszczak-Derlacz · Aleksandra Parteka

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Abstract The purpose of this study is to examine efficiency and its determinants in a set of higher education institutions (HEIs) from several European countries by means of non-parametric frontier techniques. Our analysis is based on a sample of 259 public HEIs from 7 European countries across the time period of 2001–2005. We conduct a two-stage DEA analysis (Simar and Wilson in J Economet 136:31–64, 2007), first evaluating DEA scores and then regressing them on potential covariates with the use of a bootstrapped truncated regression. Results indicate a considerable variability of efficiency scores within and between countries. Unit size (economies of scale), number and composition of faculties, sources of funding and gender staff composition are found to be among the crucial determinants of these units' performance. Specifically, we found evidence that a higher share of funds from external sources and a higher number of women among academic staff improve the efficiency of the institution.

Keywords Higher education · Two-stage DEA · Research output

Jel Classifications I23 · C14 · I22

Introduction

The development of nonparametric methods such as Data Envelopment Analysis (DEA), Free Disposal Hull (FDH) and others (e.g. Malmquist indices) have resulted in burgeoning literature on efficiency assessments of decision-making units (DMUs) across different industries. However, the issue of university/school efficiency was the subject of a limited number of studies. For example, a bibliographic database of DEA articles published in

J. Wolszczak-Derlacz (✉) · A. Parteka
Faculty of Management and Economics, Gdansk University of Technology,
ul. Narutowicza 11/12, 80-233 Gdańsk, Poland
e-mail: jwo@zie.pg.gda.pl

A. Parteka
e-mail: aparteka@zie.pg.gda.pl

scientific journals in the years 1950–2007, maintained by Gattoufi et al. (2010), records only about 3.5% of studies dedicated to the higher education issues.[1]

Existing studies on the efficiency of tertiary education institutions have been mainly based on country-specific data, and only a small sample of countries has been covered, as apart from a few exceptions (concerning, for example, HEIs in the UK or in Finland) micro data on HEIs are not easily obtainable and comparable across countries and time periods. For the review of the first empirical studies utilising frontier efficiency measurement techniques in education, see Worthington's 2001 study.

Interestingly, Australian universities have already been analyzed in depth, e.g., see Abbott and Doucouliagos 2003; Avkiran 2001; Carrington et al. 2005; Worthington and Lee 2008. Among European countries, the UK has a particularly long and rich tradition in formal analysis of the efficiency and productivity of the higher education sector (among others: Flegg et al. 2004; Glass et al. 1995; Izadi 2002; Johnes and Johnes 1995; Johnes 2006a, b). Other country-specific studies on tertiary education systems' efficiency in Europe considered HEIs in Italy (Abramo et al. 2008; Agasisti and DalBianco 2006; Agasisti and Salerno 2007; Bonaccorsi et al. 2006; Ferrari and Laureti 2005; Tommaso and Bianco 2006), Austria (Leitner et al. 2007), Germany (Fandel 2007; Kempkes and Pohl 2010; Warning 2004), Poland (Wolszczak-Derlacz and Parteka 2010) and Finland (Räty 2002). Cross-country studies are difficult to perform due to problems with gathering comparable microdata on HEI performance.

Only a few studies have looked at the efficiency of HEIs from more European countries. Bonaccorsi et al. (2007a) covered universities from Italy, Spain, Portugal, Norway, Switzerland and the UK; Bonaccorsi et al. (2007b) compared universities this time by research field from Finland, Italy, Norway and Switzerland; Agasisti and Johnes (2009) compared the technical efficiency of English and Italian universities in the period 2002/2003 to 2004/2005.

The aim of this research is not only to evaluate the relative technical efficiency of European higher education institutions in a comparative setting, but also to reveal external determinants of their performance.

To achieve this, analysis is enriched by the second step in which the DEA scores are regressed on a couple of potential determinants of efficiency with the use of Simar and Wilson's bootstrap procedure (2007), in order to ensure statistical proficiency.

In the context of the determinants of school or university performance, a two-stage procedure has been already used. For example, Ray (1991) utilised OLS in the second step in the analysis of the impact of socioeconomic characteristics on the efficiency scores of 122 Connecticut high schools, finding that parents' education level had a positive impact on the pupil's performance, and that belonging to a minority ethnic group and being raised in a single parent family had a negative impact. Mancebón and Bandrés (1999) analysed Spanish secondary schools, trying to detect, through descriptive analysis, and without a formal second step regression, characteristic differences between the most efficient and least efficient schools, and as such to point out an urban location. The Tobit model is most often used in a second step that is explained by the boundedness of DEA scores. Among others: Kirjavainen and Loikkanen (1998) employ the tobit model in the analysis of Finnish senior secondary schools, finding that inefficiency decreases with class size and the parents' education level. Similarly, the tobit model was utilised by Kempkes and Pohl

[1] The search was performed on April 2, 2011 with the use of Version 0.70 of the DEA bibliographic database containing 3911 studies (deabib.org) and returned 65 hits for the "university" or "universities," 44 for "schools" and 27 hits were obtained for the phrase "higher education."

(2010), who regress the efficiency scores of the German universities obtained through the DEA on regional GDP per capita and dummies for the existence of engineering and/or medical departments. They conclude that HEIs located in more prosperous regions (Western German lands) are more likely to benefit, in terms of efficiency, from the environment.

Oliviera and Santos (2005) and Alexander et al. (2010) appear to be the only ones (to the best of our knowledge) who have thus far implemented the bootstrapping procedure created by Simar and Wilson (2007) to study the issue of educational institutions. Oliviera and Santos (2005) analysed the efficiency of 42 Portuguese public schools, finding that school efficiency can be explained positively by the number of physicians per 1,000 people and negatively by the unemployment rate of the region where the school is located. In the second study, Alexander et al. (2010) analysed the secondary school sector in New Zealand, and found that the school type—integrated versus state, girls' versus co-educational—affects school efficiency, as well as the location (urban vs. rural areas), and teacher quality.

Alternatively, Bonaccorsi et al. (2006) use the ratio of conditional to unconditional efficiency scores to investigate the effects of external variables on performance in the set of Italian universities. However, in their case, the conditional measures of efficiency allow them to check the impact of external factors only one by one, and not simultaneously, as in our approach. They conclude that neither economies of scale (size of the unit) nor economies of scope (interdisciplinary of unit) are significant factors in explaining research and education productivity.

The limits of the existing literature usually concern restricted country and time coverage, and the use of inappropriate estimation methods [censored (tobit) regression].[2]

We paid attention and attempted to rectify the shortcomings of previous studies, using an original and vast set of data on individual characteristics of HEIs from 7 countries for the period 1995–2005. In conjunction with a consistent estimation methodology, this study presents an important extension of the existing literature.

To the best of our knowledge, this is one of the first attempts to analyse the technical efficiency of European academic units from more than two countries, but also the first study that tries to identify the determinants of HEIs' performance from several countries. Such a broad view of the efficiency evaluation of higher education units is necessary if one considers the growing pressure to provide high-quality research publishable in international journals, high competitiveness for external funding (European grants etc.) and the internationalisation of studies. The need for such a broad analysis was expressed in previous studies (e.g., Agasisti and Johnes 2009).

The rest of the study is structured as follows. In section "Two-stage bootstrap DEA analysis", we present a theoretical and methodological basis for the non-parametric analysis of efficiency performance. Section "Empirical setting" contains the description of our panel and data, along with key descriptive statistics on European HEIs from our sample. In section "Results of the empirical analysis on efficiency performance" we present the results of our empirical assessment of the efficiency of European HEIs: the first stage of our analysis is based on the computation of DEA scores, while the second stage is dedicated to the exploration of potential determinants of inefficiency.

Our principal results indicate a relatively low level of efficiency of HEIs in the sample of 7 European countries. When looking at the mean efficiency scores over the period of analysis, they could improve output by as much as 55% by keeping their inputs stable. The

[2] Simar and Wilson (2007) discuss in detail why the traditionally used censored (tobit) regression is not adequate here.

mean efficiency score hides a considerable variability of efficiency scores within and between countries. Consequently, there is no one country that can be chosen as having “the best,” meaning the most efficient, higher education system. Finally, the second-step analysis confirmed that unit size (economies of scale), number and composition of faculties, source of funding and gender staff composition are among crucial determinants of the units’ performance. The results indicate that the higher the share of funds from external sources and higher the number of women among academic staff, the lower the inefficiency of the institution. These findings can have clear policy implications, and can be especially important from the point of view of HEIs’ managers.

Two-stage bootstrap DEA analysis

We focus on the assessment of the efficiency of European public higher education institutions, where efficiency is understood not in absolute terms but as performance relative to an efficient technology (represented by a frontier function). The frontier can be estimated through DEA[3] or by stochastic frontier methods.

In the context of higher education, the DEA is a very useful tool, as it allows the researcher to capture multiple inputs and multiple outputs at the same time, focusing on the nonparametric treatment of the efficiency frontier. The analysis of education institutions’ productivity is different from standard productivity measurements, not only because no profit is maximised here, but also because HEIs are not standard firms with one output and a set of inputs. On the contrary, HEIs are producers of at least two outputs: teaching and research. The methodology of efficiency measurement has to take this specificity into account.

Nonparametric treatment of the efficiency frontier does not assume a particular functional form (as in the case of parametric methods), but relies on general regularity properties, such as monotonicity, convexity, and homogeneity. DEA is based on a linear programming algorithm, constructing an efficiency frontier from data on single decision-making units (DMU)—in our case, universities (or, more generally, HEIs).

Turning to the formal presentation of the method, we present the concept of DEA, largely following the notation and exposition provided by Simar and Wilson (2000, 2007). In the context of HEIs, output-oriented models are most frequently used because the quantity and quality of inputs, such as student entrants or academic staff, are assumed to be fixed exogenously, and universities cannot influence these numbers or characteristics, at least not in the short run (Bonaccorsi et al. 2006). Consequently, we present here an output-oriented version of the model.

The production process is constrained by the production set:

$$\Psi = \left\{(x, y) \in R_{+}^{N+M} | x \text{ can produce } y\right\} \tag{1}$$

where x represents a vector of N inputs and y the vector of M outputs.

The production frontier is the boundary of Ψ. In the interior of the Ψ there are units that are technically inefficient, while technically efficient ones operate on the boundary of Ψ, i.e. the technology frontier. If we describe the production set Ψ by its sections, then the output requirement set is described for all $x \in R_{+}^{N}$:

[3] DEA’s origins date back to the seminal paper by Farrell (1957). For a thorough presentation of the method see: Cooper et al. (2000) or Coelli et al. (2005).

$$Y(x) = \left\{ y \in R_+^M \,|(x, y) \in \Psi \right\} \tag{2}$$

Then the (output-oriented) efficiency boundary $\partial Y(x)$ is defined for a given $x \in R_+^N$ as:

$$\partial Y(x) = \{y|y \in Y(x), \lambda y \notin Y(x), \forall \lambda > 1\} \tag{3}$$

and the output measure of efficiency for a production unit located at $(x, y) \in R_+^{N+M}$ (x, y) is:

$$\lambda(x, y) = \sup\{\lambda|(x, \lambda y) \in \Psi\} \tag{4}$$

Because the production set Ψ is unobserved, in practice, efficiency scores $\lambda(x,\ y)$ are obtained by DEA estimators, for example, for output orientation with constant returns to scale (CRS), the solution is found through the linear program:

$$\begin{aligned} \hat{\lambda}_{\text{CRS}}(x, y) = \sup & \left\{ \lambda \middle| x, \lambda y \leq \sum_{i=1}^{n} \gamma_i y_i; x \geq \sum_{i=1}^{n} \gamma_i x_i \text{ for } (\gamma_1, \ldots \gamma_n) \right. \\ & \text{such that: } \gamma_i \geq 0, i = 1, \ldots, n \Big\}. \end{aligned} \tag{5}$$

In the second stage, we use the DEA efficiency scores (previously calculated) as the dependent variable ($\hat{\lambda}_i$) regressing them on potential exogenous (environmental) variables (z_i):

$$\hat{\lambda}_i = a + z_i\beta + \varepsilon_i \tag{6}$$

where ε_i is a statistical noise with the distribution restricted by: $\varepsilon_i \geq 1 - a - z_i\beta$ since DEA efficiency scores are larger than or equal to one in the output-orientation approach.

A couple of problems arise due to the fact that true DEA scores are unobserved and replaced by the previously estimated $\hat{\lambda}_i$, which in turn are serially correlated in an unknown way. Additionally, the error term ε_i is correlated with z_i since inputs and outputs can be correlated with environmental variables. To obtain unbiased beta coefficients and valid confidence intervals, we follow the bootstrap procedure of Simar and Wilson (2007). It involves obtaining estimates of $\hat{\lambda}_i$ in the first step and then regressing them on potential covariates (z_i) with the use of a bootstrapped truncated regression. Alternatively, as a robustness check we follow so-called double bootstrap method in which DEA scores are bootstrapped in the first stage to obtain bias corrected efficiency scores, and then the second step is performed, as before, on the bases of the bootstrap-truncated regression.

Practically, to obtain the DEA efficiency scores, we utilize Wilson's FEAR 1.15 software (2008) which is freely available online, and the truncated regression models were then performed in STATA.[4]

Empirical setting

The data and panel composition

The analysis is based on the university-level database, containing information on the outputs and inputs of public higher education institutions from a set of EU (Austria, Finland, Germany, Italy, Poland and the United Kingdom) and non-EU (Switzerland) countries for

[4] Stata codes are available from authors upon request.

which it was possible to gather comparable micro data.[5] Table 4 in the Appendix contains the information on the number of HEIs from every country, while a detailed list of all universities covered by our study is presented in Table 5, also in the Appendix.

The collection of micro data (at the level of single HEIs) is not a trivial issue. Countries differ in availability and coverage of university-level data. In Table 6 in the Appendix, the source of the data is presented. From the sample of our countries, the most comprehensive databases concerning HEIs exist in Finland, the UK and Italy, with freely available online platforms giving access to all statistics that are not confidential.[6] For Swiss, Austrian and German HEIs, the data was kindly provided by the staff of the respective Central Statistical Offices. Part of the data (e.g., year of foundation or location) can be accessed through the HEIs' web pages. In the case of Poland, unfortunately, micro-data on HEIs practically does not exist for research purposes. There is no online platform containing the data; some statistics are available in a paper version in various sources published by the Ministry of Science and Higher Education or Central Statistical Office. Consequently, the data on Polish HEIs that we have managed to gather come from multiple sources—both from officially published statistical sources, and through direct contact with statistical offices possessing the data (detailed information is available from the authors upon request).

Even though our data comes from various sources and concerned institutions from distinct countries, particular attention has been put on assuring a maximum level of comparability of crucial variables across countries, in accordance with the UNESCO-UIS/OECD/Eurostat's (UOE) 2004 data collection manual, and with the Frascati manual (OECD 2002). Table 7 in the Appendix presents the definition of core variables that were used either in the first or second step of the analysis. As for the input measures, our dataset contains information on the total number of students, academic staff and total revenues. The total revenues, which were originally reported in national currencies, have been recalculated into real (2005 = 100) purchasing power in standard Euros.

Given the double mission of higher education institutions (teaching and research)[7] as outputs, we consider teaching output (measured in terms of graduations) and research output, quantified by means of bibliometric indicators. The research output is measured by the number of publication records of individual HEIs' indexes in Thomson Reuters' ISI Web of Science database, (being a part of the ISI Web of Knowledge[8]) which lists publications from quality journals in all scientific fields.[9] We count all publications (scientific articles, proceedings papers, meeting abstracts, reviews, letters, notes etc.) published in a given year, with at least one author declaring as an affiliate institution the HEI under

[5] Contrary to the aggregated data on the higher education system, there is a lack of a unique, integrated database providing comparable information on individual HEIs from different European countries. There are some attempts to create foundations for regular data collection by national statistical institutes on individual higher education institutions in the EU-27 Member States (for more information about the Aquameth project, see Daraio et al. 2011. For its continuity under the EUMIDA project, see Bonaccorsi et al. 2010 and for the current state of the micro data collection consider EUMIDA webpage: www.euimida.org).

[6] In case of the UK, data are not free of charge, see Table 6 in the Appendix.

[7] Additionally, the so-called 'third mission' (links of HEIs with industrial and business surroundings) can be considered. Due to the unavailability of comparable across-country data that would permit us to measure the degree of links between HEIs and the business sector, we are not able to include a third mission in our study.

[8] www.apps.isiknowledge.com.

[9] In 2009, the Web of Science covered over 10,000 of the highest impact journals worldwide, and over 110,000 conference proceedings. However, the coverage of the database is field sensitive (see EUMIDA final report for a detail discussion: www.eumida.org).

consideration.[10] The units with the most missing observations concerning publication records or ambiguous affiliations used for the identification of the publication record[11] were not taken into consideration.

Additionally, we dispose of the following information on individual HEIs: year of foundation, faculty composition, number of different faculties and dummy variables indicating whether medicine/pharmacy faculty is included, location and statistics related to the level of economic development of the region where a single HEI is located, gender structure of the academic staff and source of funding. In order to create the last variable, we divide total revenues into two streams: core budget and third-party funding. In general, data on third-party funding includes: grants from national and international funding agencies for research activities, private income, student fees and others. Alternatively, the core funding comes mainly from the government (central, regional or local) in the form of teaching or/and operating grants. See Table 7 in the Appendix for the detailed breakdown of funding by country.

Crucial variables concerning inputs and outputs needed for the computation of DEA efficiency scores are available for HEIs from all countries and across the whole period of 2001–2005. The coverage of other variables, used in the second stage analysis, is sometimes limited, but it will only affect the number of observations used in the second stage estimation. For example, in the case of Italy, due to the problematic breakdown between core and third-party funding, the variable describing the funding source was not considered (Bonaccorsi et al. 2010).

Our initial sample includes 266 HEIs. Aware that the nonparametric methods we are going to utilise are especially sensitive to outliers, we follow the procedure written by Wilson (1993) to detect atypical observations. Finally, a sample of 259 HEIs remains.[12]

Key characteristics of European HEIs from our sample

The HEIs covered by our study comprise a very heterogeneous sample—they differ in size, structure, financial resources or scientific output. In Table 1 we show key figures describing HEIs from separate countries, from the point of view of output/input relations. Note that measures such as the number of publications per academic employee can be treated as partial indicators of efficiency (in this case: scientific efficiency).

Taking into account country averages, the lowest publication record was found for HEIs from Poland—on average, an academic staff member employed at a Polish HEI has a third of the number of publications per year listed in the ISI Web of Knowledge as the average Italian, Austrian or British academic staff member. However, in the case of the number of graduates per academic staff members, Polish HEIs lead the pack, together with the UK and Italy. Moreover, HEIs differ greatly in size. The biggest universities, in terms of the number of students, exist in Poland and Italy. The smallest HEIs function in Switzerland and Finland. Unsurprisingly, also the amount of funding is very uneven, even if we take

[10] Note that studies co-authored by persons affiliated at the same institution are counted once.

[11] For example, we excluded the University of London from our analysis, because as a confederational organization it is composed of several colleges. It was not possible to identify the publication record because we cannot be sure whether the academic staff of the University of London, as her/his affiliation, would give the name of the college or the "University of London.".

[12] In the case of the DEA approach, outliers are understood as the most efficient units with the biggest impact on the frontier, Wilson (1993). Seven universities were detected as outliers and deleted from the sample: Sapienza University of Rome, The University of Cambridge, The University of Oxford, The University of Bologna, The University of Vienna, University of Munich, and University of Naples Federico II.

Table 1 Key statistics on HEIs-summary values by country (period 2001–2005 averages)

Country	Publications[a] per academic staff member	Graduates per academic staff member	Total number of students	Revenues per student per year in euro PPS	Revenue from the core funding in total revenues in %	Women per total academic staff in %
Austria $N = 8$						
Mean	0.64	1.78	12726	9677	82	23
Min	0.12	0.59	1821	5562	70	7
Max	1.29	3.00	24211	20224	95	40
Finland $N = 15$						
Mean	0.52	1.39	10996	8630	65	36
Min	0.06	0.74	2005	4103	52	11
Max	1.11	2.52	38454	14022	86	49
Germany $N = 66$						
Mean	0.46	1.19	17192	9503	80	40
Min	0.02	0.39	1769	3569	63	23
Max	1.36	3.85	61292	24812	95	74
Italy $N = 51$						
Mean	0.75	4.32	25550	5472	na	na
Min	0.02	1.53	5164	1178	na	na
Max	1.66	9.81	63630	17721	na	na
Poland $N = 31$						
Mean	0.19	3.73	25733	3307	64	37
Min	0.01	1.56	8243	583	42	13
Max	0.59	11.74	56292	7087	79	53
Switzerland $N = 11$						
Mean	0.49	0.77	9635	21016	82	29
Min	0.04	0.21	1584	9916	48	17
Max	0.86	3.10	23832	40879	93	38
UK $N = 77$						
Mean	0.62	5.34	17947	9749	42	44
Min	0.05	2.04	4115	4546	15	16
Max	2.05	11.72	36205	39042	65	74

[a] All publications (articles, conference proceedings, book reviews) listed in ISI Web of Science. *na* unavailable data

Source Own elaboration

into account large differences in the level of prices across countries through PPS. On average, Polish HEIs are confirmed as having the lowest level of funding—Austria, Finland and Germany have similar levels of funding (2 times higher than that of Poland), and Switzerland has very well-funded universities, with almost 7 times the per student-revenue than Poland. At the same time, the proportion of money coming from governmental sources in the form of core funding accounts for the larger share of funds in all countries, except the UK, where on average it constitutes 44% of funding. Women represent the biggest share of academic staff members in the UK and Germany, while in Austria, only one out of five academicians on average is female.

Results of the empirical analysis on efficiency performance

First step DEA results

For each year of analysis, we run an output-oriented (CRS) efficiency model. Our basic specification considers two outputs and three inputs. As inputs we consider the number of total academic staff, the number of students and total revenues. The set of outputs include the number of graduations (teaching outcome) and the number of scientific publications (research outcome) as described in the previous section. As suggested in the recent study by Daraio et al. (2011), in such a heterogeneous panel there is a need for standardization, and consequently all inputs and outputs are expressed as ratios with respect to the country mean (country average = 100).

Because our task is not to rank universities, but instead to explore the determinants of their efficiency, due to the space constraints, we present here only the results expressed as the country averages. The mean value of the efficiency score for the whole sample is 1.55, the highest efficiency score (meaning the lowest relative efficiency) is 3.2 and only 5% of HEIs are 100% efficient, obtaining efficiency scores equalling one. Since we are assuming an output-oriented approach, the inefficient university would have to increase its output by the factor (DEA score-1) × 100% in order to reach the frontier. Therefore, the efficiency score of 1.55 indicates that, when examining the universities in all seven countries analyzed here, their output could improve by as much as 55%, keeping their inputs stable. Of course, this average efficiency score is the result of different country patterns that also change over time. The kernel distribution of efficiency scores (pooling all years) country by country is shown in Fig. 1. All countries are characterised by a unimodal and skewed distribution, with the concentration of mass in the lower tail, in the direction of more efficient units. The units are more efficient the closer they come to the value of one. In the case of Switzerland, the dispersion of the distribution is smaller, without longer tails, which suggests that the universities are similar in their efficiency. Additionally, unbiased efficiency scores obtained by bootstrap method described by Simar and Wilson (2000) are presented. Their distributions are moved slightly to the right indicating lower efficiency (higher efficiency scores) in relation to the original ones.[13] In Table 2, we present the average DEA scores by country and their dynamics over time. In 2001, Austria had the lowest score at 1.301, meaning it had on average the most efficient HEIs (with respect to the average scores from other countries), followed by Switzerland at 1.387 and Italy at 1.389. Since then, in all the years for which analysis was done, universities from Switzerland obtained the best efficiency scores. The dynamics in DEA scores show a rise in scores (fall in efficiency) from 2001 to 2004, and the trend is then reversed.[14] Again, the average scores covered large country deviations (see Fig. 1 and the last rows of Table 2).

Interestingly, in all countries (except Austria and Finland) units exist that are situated at the efficiency frontier. However, there are only two universities that, regardless of the year of the analysis and DEA specifications (3 inputs vs. 2 inputs[15]), have an efficiency score

[13] Unbiased efficiency scores will be used in the second stage as a robustness check in so-called double bootstrap method. See section "Robustness checks".

[14] To analyse the dynamics in productivity, the so-called Malmquis index should be constructed, see for example Parteka and Wolszczak-Derlacz (2011).

[15] As a robustness check, we also perform a 2 input, 2 output model. See section "Robustness checks".

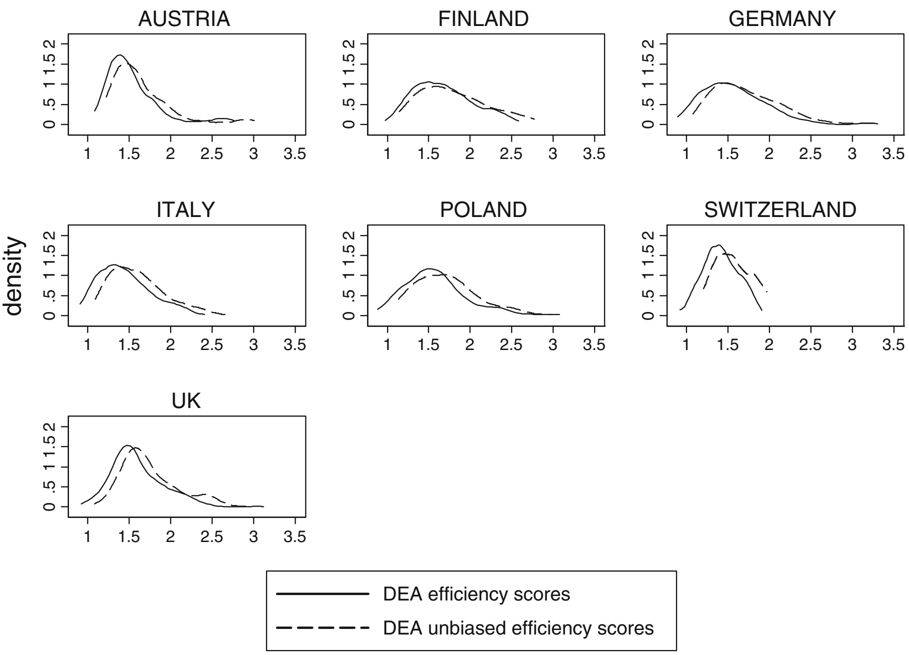

Fig. 1 The distribution of efficiency scores by country (all years pooled). *Source* Own elaboration

Table 2 DEA scores by country and year (pooled data)

	AU	FIN	GER	IT	POL	CH	UK
2001	1.301	1.494	1.480	1.389	1.444	1.387	1.404
2002	1.542	1.606	1.552	1.423	1.574	1.385	1.557
2003	1.413	1.579	1.515	1.420	1.500	1.347	1.482
2004	1.815	1.865	1.710	1.518	1.714	1.496	1.782
2005	1.658	1.838	1.612	1.473	1.693	1.445	1.757
Mean	1.546	1.676	1.574	1.444	1.585	1.412	1.597
Min	1.194	1.104	1	1	1	1	1
Max	2.658	2.452	3.19	2.312	2.862	1.826	2.901
Std. Dev	0.336	0.347	0.390	0.312	0.374	0.206	0.311

Note DEA scores obtained from 3 inputs (total academic staff, total revenues, total number of students) 2 outputs (total number of graduations, total number of publications) model

Source Own compilation

equal to one in all cases: The University of York (UK) and Humboldt-Universität Berlin (Germany).

Given that the efficiency scores of HEIs exhibit high variability, both across countries and within countries, it is interesting to discover what the determinants of universities' performance are and, consequently, what can be done to improve the efficiency of single university units. This task will be performed in the second step of the analysis presented below.

Second step—determinants of efficiency scores in European HEIs

Empirical specification

At this stage, DEA scores are linked through a parametric model with additional variables, describing institutional setting, faculty composition, funding schemes, specific characteristics for the country and region, etc. The model to be estimated takes on the following form:

$$\lambda_{i,j,t} = \alpha + \beta_1 \mathrm{GDP}_{n,t} + +\beta_2 \mathrm{nofac}_{i,t} + \beta_3 \mathrm{med}_i + \beta_4 \mathrm{yearfound}_i + \beta_5 \mathrm{Rev\_core}_{i,t} + \beta_6 \mathrm{Women}_{i,t} + \chi_j + \chi_t + u_{i,j,t} \quad (7)$$

where i refers to single HEI, t denotes time period and j country where HEI i is located; $\lambda_{i,j,t}$ is DEA scores calculated as in (5); $\mathrm{GDP}_{n,t}$ is the real GDP per capita in euro PPS of the region n (NUTS2) where the university is located; $\mathrm{nofac}_{i,t}$ is the number of different faculties; med_i is a dummy variable, equals 1 if university has medical or pharmacy faculty, 0 otherwise, $\mathrm{yearfound}_i$ year of foundation; $\mathrm{Rev\_core}_{i,t}$ is the share of core funding revenues in total revenues; $\mathrm{Women}_{i,t}$ is the share of women in the academic staff.

A summary of the statistics is presented in Table 8 in the Appendix. Additionally, we include a set of country and time dummies. Time dummies control for exogenous changes in technology and/or for the change in the number of publications that are indexed in the ISI database. Country-specific effects are introduced to control for differences, for example, due to the cross-country diversity of education systems.

The choices of independent (environmental) variables, together with predictions concerning their impact on HEIs' efficiency scores, are discussed briefly below.

A university's location can be an important determinant of its performance, as rich and poor regions offer different business surroundings and a local climate for the HEI. In order to check this proposition, we use the value of real GDP per capita in euro PPS of the NUTS2 region n, in which the university is located ($GPD_{n,t}$). For example: Kempkes and Pohl (2010) found a positive impact of a wealthier location on school efficiency, while Bonaccorsi and Daraio (2005) and Oliviera and Santos (2005) did not confirm the agglomeration effect.

Furthermore, we introduce the variable (nofac_i). The number of different faculties that can be a proxy for the degree of a unit's interdisciplinarity. This refers to the concept of economies of scope, and answers the question of whether increasing the variety of different faculties brings a growth in efficiency, or if specialisation in fewer fields is more beneficial to the university. An intensive review of the previous empirical studies concerning the potential existence of economies of scope in the education sector is presented in Bonaccorsi et al. (2006), and the overall picture is mixed, without unambiguous conclusions. The variable (nofac_i) reflects not only the interdisciplinary of a unit, but also is related to the size of the university, as larger universities usually have a larger number of faculties. This is confirmed by the pairwise correlation between nofac_i and the total number of students $\mathrm{Stud}_{i,t}$. (see Table 9 in the Appendix, where partial correlation coefficients between all the variables are presented). Assuming that institutions that operate under a large scale can realize greater productivity growth due to positive economies of scale, we would expect a negative coefficient in front of this variable. However, there is no consensus regarding whether economies of scale exist in the higher education sector (see for example Cohn et al. (1989) versus Felderer and Obersteiner (1999), and for the in-depth literature review and discussion of the economies of scale in higher education, see Bonaccorsi et al. (2006)).

Diseconomies of scale may also occur due to bureaucracy in big units and a possible waste of resources. In this case we would expect a positive variable in front of this parameter.

Next, we consider a dummy variable med_i equalling one if the HEI has medical or pharmacy faculty to take into account the specificity of faculty composition. A similar approach was performed by Kempkes and Pohl (2010).

Then, we proxy the level of tradition of a given HEI using its year of foundation, (yearfound_i). It is often perceived that HEIs with a longer tradition have a better reputation, but it could also be the case that younger HEIs have more flexible and modern structures, assuring a more efficient performance.

Additionally, we introduce into the Eq. 7 the share of core funding in total revenues ($\text{Rev\_core}_{i,t}$), which allows us to investigate whether the source of funding (public versus private) matters to the research outcome. Moreover, in the literature, the importance of universities' autonomy for its performance is often underlined, which can be proxies by the share of non-governmental funds in its total revenue (Bonaccorsi and Daraio, 2007; Aghion et al., 2009).

Subsequently, we test the relation between the gender composition of academic staff and university units' DEA scores. The structure of the academic staff is measured by the ratio of women to the total staff ($\text{Women}_{i,t}$).

As for the estimation strategy, we use the procedure described in section "Two-stage bootstrap DEA analysis" involving a truncated regression with 1000 bootstrap replicates (the number of L replicates from point 2 in the described algorithm), which should ensure the statistical correctness of the findings. This is followed by numerous robustness checks.

Results

Firstly, we estimate the regression (7) with DEA scores obtained from the 3 inputs 2 outputs model. The results are presented in Table 3 where we show three alternative models, depending on the variables included.

Recalling output DEA formulation from Eq. 4, a positive sign of the estimated regression parameter indicates that, *ceteris paribus*, an increase in a variable corresponds to higher inefficiency (lower efficiency), while a negative sign of estimated parameter indicates lower inefficiency (greater efficiency).

In the first column, bias-adjusted coefficients of a basic regression are presented. Next, two columns show the lower and upper bounds of the 95% bootstrap confidence interval, which is used to check the statistical significance of the estimated coefficients. The statistical significance indicates that the value of zero does not fall within the confidence interval associated with a coefficient under examination.

The estimation results reveal that the coefficient associated with the GDP per capita of the region where the university is located is not statistically significant, so development level of the region is not among statistically significant determinants of HEIs efficiency. This is confirmed in all three specifications of the model. When including a dummy variable for medical faculty (column 1), we found a coefficient to be negative and significant, which indicates a higher efficiency for universities with medical faculty. Similarly, we confirmed the statistical significance of the number of different faculties. The negative parameter in front of the nofac_i variable shows that HEIs with a higher number of different faculties have lower DEA scores (which means they are more efficient), which in turn can be a sign of the economy of scope and/or economies of scale. Finally, younger universities are less efficient (a positive coefficient for the yearfound_i variable).

Table 3 The determinants of inefficiency scores (truncated regression), DEA 3 input 2 output model

Variables	(1) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(2) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(3) Bias-adjusted coefficients	95% Bootstrap confidence intervals	
		Low	High		Low	High		Low	High
$GDP_{n,t}$	−0.0004	−0.00117	0.00024	0.0001	−0.00065	0.00069	0.0001	−0.00062	0.00072
$nofac_{i,t}$	−0.0091***	−0.01594	−0.00306	−0.0095***	−0.01642	−0.00349	−0.0085***	−0.01482	−0.00244
med_i	−0.1470 ***	−0.20217	−0.08823	−0.0987***	−0.15826	−0.03772	−0.1000***	−0.15820	−0.04766
$yearfound_i$	0.0003 ***	0.00022	0.00053	0.0008***	0.00061	0.00102	0.0008***	0.00058	0.00098
$Rev\_core_{i,t}$				0.0088***	0.00577	0.01150	0.0106***	0.00740	0.01333
$Women_{i,t}$							−0.0032***	−0.00552	−0.00083
Obs	1245			945			896		

* Value of zero does not fall within 90% confidence interval,** Value of zero does not fall within 95% confidence interval, *** Value of zero does not fall within 99% confidence interval. Confidence intervals obtained from 1000 bootstraping interactions

Constants are not reported. Year and country dummies included in all models

Source Own calculations

Additionally, we ran an augmented regression, including the percentage of revenues from the core funding in total revenues ($\text{Rev\_core}_{i,t}$) and the ratio of female staff $\text{Women}_{i,t}$ to the total academic staff model (2). In the case of both variables, we do not dispose of information for the whole sample of HEIs (e.g., the lack of data for Italy), so the number of observations drops. All signs of the coefficients and the statistical significance of the variables that were already included in the model (1) are as they were in the first basic specification. The coefficient in front of $\text{Rev\_core}_{i,t}$ is positive and statistically significant, indicating that an increase in the share of the university budget represented by core funding is negatively associated with the technical efficiency of analysed universities. However, it should be underlined that determining a strict causal relationship can be difficult. Efficient universities can attract more third-party funding; on the other hand, universities with a higher share of external funding may benefit from more financial resources and improve their efficiency. Finally, we found that higher share of women employed in academia is positively correlated with efficiency (note negative and statistical significant coefficient of $\text{Women}_{i,t}$).

Robustness checks

We assessed the robustness of the estimations results in several ways. First of all, we considered the restricted DEA model with 2 inputs and 2 outputs, without the number of students as an input, like the study by Mancebón and Bandrés (1999), who underline that students are not *normal* inputs of university production. Generally, the DEA scores obtained through the 2 input, 2 output model give very similar results to the basic 3 input 2 output specification. The Spearman rank correlation coefficient that tests the correlation between the rankings equals 0.72. Then we repeat the second step, with the DEA scores obtained in the 2 input 2 output model. Additionally, in this case we could include in the regression the variable directly indicating the size of the institution measured by the total number of students (Stud_{it}), as this variable was not among the inputs in the first step. However, to be sure that there is no multicollinearality between covariates, we exclude nofac_i from the independent variables. The results of the truncated regression are presented in Table 10 in Appendix.

In general, most of the previous findings are confirmed: the parameter associated with the country's or region's GDP is still not statistically significant. The negative parameters of med_i and $\text{Women}_{i,t}$ and positive parameters of yearfound_i (the latter is statistically significant in two out of three regressions) are confirmed. Additionally, the size of the institution when measured by the number of students (Stud_{it}) seems to be an important factor of the units' efficiency. The higher the number of students, the higher the institutions' efficiency; this can indicate economies of scale in big units (negative parameter). The only differences concern the coefficient associated with $\text{Rev\_core}_{i,t}$, which lose its statistical significance.

Similarly, the change in the number of bootstrap replications performed in the second step did not have a considerable impact on the results (we have considered 500 as well 2000 replications).

Additionally, we utilised the so-called double bootstrap method[16] in which DEA scores are bootstrapped in the first stage, and then the second step is performed, as before, on the bases of the bootstrap-truncated regression. The results from the double bootstrap procedure are shown in Table 11 in Appendix. The estimation is very similar to one obtained previously, but in the augmented model (3) the coefficient of the gender structure is statistically significant at a lower level. Moreover, in most of the cases the actual coefficient estimates tend to be slightly larger.

[16] Algorithm 2 from Simar and Wilson 2007.

Finally, we change the point of truncation in the second stage. Originally, in the truncated regression, only scores greater than one were included; the efficient units were excluded, and in this sense part of the information was lost (Monchuk et al. 2010). Alternatively, we used a truncated point near one (e.g., 0.99). The comparison of the results obtained with 1.00 and 0.99 truncation is presented in Table 12 in Appendix. Regardless of the point of truncation, the sign, statistical significance and the value of the coefficients are substantially the same.

Conclusions

The main aim of this research was to evaluate efficiency in a large sample of universities from as many European countries as possible, and to assess the importance of potential factors in improving their performance.

We have proposed a two-stage analysis, combining non-parametric and parametric methods. First, with the use of non-parametric frontier techniques, we measured the technical efficiency for 259 HEIs from 7 European countries within the years 2001–2005. Given that universities differ in the 'production process' from standard firms or companies, due to the presence of multiple inputs and multiple outputs, we have adopted an output-oriented formulation of DEA. Two specifications of DEA analysis were performed, one with two outputs (publications and graduations) and three inputs (total academic staff, total number of students and total revenues) and the second with two outputs and two inputs (total academic staff and total revenues).

On average, universities in the seven countries analysed exhibit rather poor levels of efficiency in publication and graduations, with a mean DEA score of 1.55. However, due to the high variability of scores within each country, we cannot point out one country as possessing a superiorly efficient higher education system that could constitute a benchmark for the other countries.

At the second stage of our analysis, we linked the technical efficiency scores of single HEIs with characteristics describing their location, faculty composition, year of foundation, funding sources, structure of employment and size. Contrary to the previous studies, we utilised a bootstrapped truncated regression in order to guarantee the accuracy of the estimates. In all specifications, we include country and year-specific characteristics to be sure that the impact of the covariates is not due to the country/period characteristics. By doing so we were able to determine factors crucial in promoting efficiency gains in the context of public higher education. Several interesting conclusions can be drawn that may be important from the policy point of view.

In general, it seems that the size of the institution is an important factor in its efficiency: the higher the number of students or the number of faculties, the higher institutions' efficiency. The latter variable can be also a crude proxy for university interdisciplinarity. The importance of faculty composition also has to be taken into consideration when assessing efficiency. We found that universities with medical/pharmacy faculty are characterised by higher efficiency. Additionally, we found that the gender structure of the academic staff can be also important for institutions' performance, with the presence of women being positively correlated with efficiency. Tradition (proxied by the year of founding) was among the other statistically significant determinants of efficiency: younger universities seemed to be less efficient.

As far as location is considered, HEIs from our sample that are located in more prosperous regions (with higher GDP levels per capita) were not found to register higher efficiency. In fact, the coefficient for GDP per capita did not prove to be statistically significant in any of our specifications, and its sign was not stable.

Moreover, in the model where DEA was calculated on the basis of 3 inputs and 2 outputs, it was confirmed that funding structure is an important performance factor: an increase in the share of core funding in total revenues can be matched with a drop in efficiency. Such a result suggests that HEIs funded predominantly from the public funds exhibited higher inefficiency. This result can have clear policy implications and can serve as guidance, especially for those who manage individual HEIs, regarding ways to improve their performance.

We addressed the robustness of our findings in several ways. We changed the number of replications in the bootstrap procedure, employed different procedures of estimation and changed the truncation point. None of these changes influence the results in a considerable way, and the main conclusions hold.

Our study shows that in the context of higher education sector analysis, further effort is needed in order to extend the country sample and time dimension. We strongly call for a more transparent policy concerning microdata collection and dissemination at the European level. It would also be very interesting to confront patterns of efficiency in public and private academic units, but unfortunately the unavailability of data (especially concerning funding) for private universities remains the main obstacle in doing so.

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Appendix

See Tables 4, 5, 6, 7, 8, 9, 10, 11 and 12.

Table 4 Sample composition

Country	Number of HEIs
Poland	31
Austria	8
Finland	15
Germany	66
Italy	51
UK	77
Switzerland	11
Total	259

Source Own elaboration

Table 5 List of HEIs in our sample

Lp.	HEI_ID	Country
1	University of Leoben	AUT
2	Technical University of Graz	AUT
3	Technical University of Wien	AUT
4	University of Graz	AUT
5	University of Innsbruck	AUT
6	University of Klagenfurt	AUT
7	University of Linz	AUT
8	University of Salzburg	AUT
9	Federal Institute of Technology Lausann	CH
10	Federal Institutes of Technology Zurich	CH
11	University of Basel	CH
12	University of Bern	CH
13	University of Fribourg	CH
14	University of Geneva	CH
15	University of Lausanne	CH
16	University of Lugano	CH
17	University of Neuchatel	CH
18	University of St. Gallen	CH
19	University of Zurich	CH
20	Abo Akademi University	FIN
21	Helsinki School of Economics	FIN
22	University of Helsinki	FIN
23	University of Joensuu	FIN
24	University of Jyväskylä	FIN
25	University of Kuopio	FIN
26	University of Lapland	FIN
27	Lappeenranta University of Technology	FIN
28	University of Oulu	FIN
29	Tampere University of Technology	FIN
30	University of Tampere	FIN
31	Helsinki University of Technology	FIN
32	Turku School of Economics and Business Admin.	FIN
33	University of Turku	FIN
34	University of Vaasa	FIN
35	Bauhaus-University of Weimar	GER
36	Brandenburgische Technical University of Cottbus	GER
37	University of Vechta	GER
38	Humboldt-Universität Berlin	GER
39	TH Aachen	GER
40	Technical University of Bergakademie Freiberg	GER
41	Technical University of Berlin	GER
42	Technical University of Braunschweig	GER
43	Technical University of Chemnitz	GER
44	Technical University of Clausthal	GER

Table 5 continued

Lp.	HEI_ID	Country
45	Technical University of Darmstadt	GER
46	Technical University of Dresden	GER
47	Technical University of Hamburg	GER
48	Technical University of Ilmenau	GER
49	Technical University of Kaiserslautern	GER
50	Technical University of München	GER
51	University of Augsburg	GER
52	University of Bamberg	GER
53	University of Bayreuth	GER
54	University of Bielefeld	GER
55	University of Bochum	GER
56	University of Bonn	GER
57	University of Bremen	GER
58	University of Dortmund	GER
59	University of Düsseldorf	GER
60	University of Erfurt	GER
61	University of Erlangen-Nürnberg	GER
62	University of Flensburg	GER
63	University of Frankfurt a.M.	GER
64	University of Gießen	GER
65	University of Greifswald	GER
66	University of Göttingen	GER
67	University of Halle	GER
68	University of Hamburg	GER
69	University of Hannover	GER
70	University of Heidelberg	GER
71	University of Hildesheim	GER
72	University of Hohenheim	GER
73	University of Jena	GER
74	University of Karlsruhe	GER
75	University of Kassel	GER
76	University of Kiel	GER
77	University of Koblenz-Landau	GER
78	University of Konstanz	GER
79	University of Köln	GER
80	University of Leipzig	GER
81	University of Magdeburg	GER
82	University of Mainz	GER
83	University of Mannheim	GER
84	University of Marburg	GER
85	University of Münster	GER
86	University of Oldenburg	GER
87	University of Osnabrück	GER
88	University of Paderborn	GER

Table 5 continued

Lp.	HEI_ID	Country
89	University of Passau	GER
90	University of Potsdam	GER
91	University of Regensburg	GER
92	University of Rostock	GER
93	University of Siegen	GER
94	University of Stuttgart	GER
95	University of Trier	GER
96	University of Tübingen	GER
97	University of Ulm	GER
98	University of Wuppertal	GER
99	University of Würzburg	GER
100	University of des Saarlandes Saarbrücken	GER
101	Politechnical University of Ancona	ITA
102	University of Bari	ITA
103	Technical University of BARI	ITA
104	University of Basilicata	ITA
105	University of Bergamo	ITA
106	University of Brescia	ITA
107	University of Cagliari	ITA
108	University of Calabria	ITA
109	University of Camerino	ITA
110	University of Cassino	ITA
111	University of Catania	ITA
112	University of Catanzaro	ITA
113	University of Chieti	ITA
114	University of Ferrara	ITA
115	University of Firenze	ITA
116	University of Foggia	ITA
117	University of Genova	ITA
118	The University of Insubria	ITA
119	University of Lecce	ITA
120	The University of l'Aquila	ITA
121	University of Macerata	ITA
122	University of Messina	ITA
123	University of Milano	ITA
124	University of Milano-Bicocca	ITA
125	Politecnico Milano	ITA
126	The University of Modena	ITA
127	The University of Molise	ITA
128	The University of Napoli	ITA
129	The University of Padova	ITA
130	University of Palermo	ITA
131	University of Parma	ITA
132	University of Pavia	ITA

Table 5 continued

Lp.	HEI_ID	Country
133	University of Perugia	ITA
134	Piemonte Orientale	ITA
135	University of Pisa	ITA
136	University of the Mediterranean	ITA
137	Roma Tre University	ITA
138	University of Rome “Tor Vergata”	ITA
139	University of Salerno	ITA
140	University of Sannio	ITA
141	University of Sassari	ITA
142	University of Siena	ITA
143	University of Teramo	ITA
144	University of Torino	ITA
145	Politecnico Torino	ITA
146	University of Trento	ITA
147	University of Trieste	ITA
148	University of Tuscia	ITA
149	University of Udine	ITA
150	University of Venezia	ITA
151	University of Verona	ITA
152	AGH Cracow	POL
153	Bialystok University of Technology	POL
154	Cracow University of Technology	POL
155	Czestochowa University of Technology	POL
156	Gdansk University of Technology	POL
157	Gliwice University of Technology	POL
158	Katowice Silesian University	POL
159	Kielce University of Technology	POL
160	Lodz University of Technology	POL
161	Lublin University	POL
162	Lublin University of Technology	POL
163	Olsztyn University	POL
164	Opole University	POL
165	Opole University of Technology	POL
166	Poznan University of Technology	POL
167	Radom University of Technology	POL
168	Rzeczow University	POL
169	Rzeszow University of Technology	POL
170	Szczecin Technical University	POL
171	Szczecin University	POL
172	Torun University	POL
173	University of Bialystok	POL
174	University of Cracow	POL
175	University of Gdańsk	POL
176	University of Lodz	POL

Table 5 continued

Lp.	HEI_ID	Country
177	University of Poznan	POL
178	University of Warsaw	POL
179	Warsaw University of Technology	POL
180	Wroclaw University	POL
181	Wroclaw University of Technology	POL
182	Zielonogora University	POL
183	Aberystwyth University	UK
184	Anglia Ruskin University	UK
185	Aston University	UK
186	Bangor University	UK
187	Bath Spa University	UK
188	Bournemouth University	UK
189	Brunel University	UK
190	Coventry University	UK
191	Cranfield University	UK
192	De Montfort University	UK
193	Edinburgh Napier University	UK
194	Glasgow Caledonian University	UK
195	Heriot-Watt University	UK
196	Kingston University	UK
197	Leeds Metropolitan University	UK
198	Liverpool John Moores University	UK
199	Loughborough University	UK
200	Middlesex University	UK
201	Oxford Brookes University	UK
202	Queen Margaret University, Edinburgh	UK
203	Sheffield Hallam University	UK
204	Staffordshire University	UK
205	Swansea University	UK
206	The Manchester Metropolitan University	UK
207	The Nottingham Trent University	UK
208	The Queen's University of Belfast	UK
209	The University of Aberdeen	UK
210	The University of Bath	UK
211	The University of Birmingham	UK
212	The University of Bradford	UK
213	The University of Brighton	UK
214	The University of Bristol	UK
215	The University of Central Lancashire	UK
216	The University of Dundee	UK
217	The University of East Anglia	UK
218	The University of Edinburgh	UK
219	The University of Essex	UK
220	The University of Exeter	UK

Table 5 continued

Lp.	HEI_ID	Country
221	The University of Glasgow	UK
222	The University of Greenwich	UK
223	The University of Huddersfield	UK
224	The University of Hull	UK
225	The University of Keele	UK
226	The University of Kent	UK
227	The University of Lancaster	UK
228	The University of Leeds	UK
229	The University of Leicester	UK
230	The University of Lincoln	UK
231	The University of Liverpool	UK
232	The University of Newcastle-upon-Tyne	UK
233	The University of Nottingham	UK
234	The University of Plymouth	UK
235	The University of Portsmouth	UK
236	The University of Reading	UK
237	The University of Salford	UK
238	The University of Sheffield	UK
239	The University of Southampton	UK
240	The University of Stirling	UK
241	The University of Strathclyde	UK
242	The University of Sunderland	UK
243	The University of Surrey	UK
244	The University of Sussex	UK
245	The University of Teesside	UK
246	The University of Warwick	UK
247	The University of Westminster	UK
248	The University of Winchester	UK
249	The University of Wolverhampton	UK
250	The University of York	UK
251	University of Abertay Dundee	UK
252	University of Chester	UK
253	University of Derby	UK
254	University of Durham	UK
255	University of Glamorgan	UK
256	University of Hertfordshire	UK
257	University of Manchester	UK
258	University of Ulster	UK
259	University of the West of England, Bristol	UK

Note The initial sample included 266 HEIs, seven (Sapienza University of Rome, The University of Cambridge, The University of Oxford, The University of Bologna, The University of Vienna, University of Munich, University of Naples Federico II) were detected as outliers and deleted from further analysis

Source Own elaboration

Table 6 European sources of data on individual HEIs

Country	Source	Online platform	Data publicly available
Finland	Finnish Ministry of Education	https://kotaplus.csc.fi/online/Haku.do	Yes
Switzerland	Swiss Federal Statistic Office	www.statistique.admin.ch	Yes
Germany	Federal Statistical Office (Destatis)	www.destatis.de	Yes
Austria	Austrian Federal Ministry of Science and Research	http://www.bmwf.gv.at/unidata	Yes
UK	Higher Education Statistics Agency	http://www.heidi.ac.uk/	Yes, but not free of charge
Italy	Ministry of Science and Education (MIUR)	www.nuclei.cnvsu.it; www.dalia.cineca.it	Yes
Poland	Ministry of Science and Higher Education, Central Statistical Office	www.nauka.gov.pl www.stat.gov.pl	No

Source Own elaboration

Table 7 Detailed description of variables used in first and second step

Variable	Country	Remarks
Number of students[a, b]	Finland	Total number of registered students (all types of undergraduate and postgraduate studies with foreigners), headcounts
	Switzerland	Total number of registered students (all types of undergraduate and postgraduate studies with foreigners) headcounts, referring to beginning of the academic year
	Germany	Total number of registered students (all types of undergraduate and postgraduate studies), with foreigners, referring to the winter semester; headcounts
	Austria	Total number of registered students (all types of undergraduate and postgraduate studies) referring to the winter semester with foreigners, headcounts
	UK	Total number of registered students (all types of undergraduate and postgraduate studies) with foreigners, headcounts, full time and part time
	Italy	Total number of registered students (all types of undergraduate and postgraduate studies) with foreigners
	Poland	Total number of registered students (all types of undergraduate and postgraduate studies without foreigners (separate data concerning foreign students available only since 2006, when total percentage of foreign students ranged between 0.02 and 2.6%) headcounts, full time and part time
Total academic staff[a, b]	Finland	Professors, associate professors, senior assistants, assistants, lecturers, teachers and research personnel, full time equivalent,
	Switzerland	Professors, adjuncts and lectures, full time equivalent, referring to the last day of each year
	Germany	Professors, lecturers, scientific assistants, scientific and artistic employees, teaching personnel, full time employment
	Austria	Professors, assistants and other academic staff, full time equivalent

Table 7 Detailed description of variables used in first and second step

Variable	Country	Remarks
	UK	Teachers, teachers and researchers, researchers, full time equivalent.
	Italy	Professors (1st and 2nd category) researchers, registered at the end of the year, who in December received at least 95% of the salary typical for the post at the full-time employment level
	Poland	Professors, docents, adjuncts, assistants, senior lecturers, lecturers and specialist librarians, full time employment
Total revenues[a]	Finland	Originally reported in euro, yearly
	Switzerland	Originally reported in Swiss frank, yearly
	Germany	Originally reported in euro, yearly
	Austria	Originally reported in euro, yearly
	UK	Originally reported in pounds, yearly
	Italy	Originally reported in euro, yearly
	Poland	Originally reported in PLN, yearly
Number of publications	Finland	According to Thomson Reuter's ISI Web of Science (set of journals, conference proceedings etc. common to all countries). HEIs for which identification of the publication record was impossible were excluded from the sample
	Switzerland	
	Germany	
	Austria	
	UK	
	Italy	
	Poland	
Number of graduations[a]	Finland	Total number of graduations (all types of studies), all
	Switzerland	Total number of graduations (all types of studies), all
	Germany	Total number of graduations (all types of studies), all
	Austria	Total number of graduations (all types of studies), all
	UK	Total number of graduations (all types of studies), all
	Italy	Total number of graduations (all types of studies), all
	Poland	Total number of graduations (all types of studies) without foreigners (separate data concerning foreign students available only since 2008 when total percentage of foreign students ranged between 0 and 2.25%)
Revenues core	Finland	Budgetary funding and building investments. External financing: Academy of Finland, Tekes, domestic company, other domestic funding, EU, foreign company, other foreign financing.
	Switzerland	Funding from central, regional and local governments (mainly cantonal), investment, innovation and contribution projects contribution from central government. Third-party funds: tuition fees, Swiss National Science Foundation, KTI, EU projects, other international research programmes, research grants from government private organisation and public sector, income from services.
	Germany	Basic subsidies from the government. Third-party funds: German Research Council (DFG), government grants, international organisations, private organisation, foundation, funds raised from companies.
	Austria	Federal funds, in the period 2000–2003 together with pension contribution. Third-party funds: tuition fees, research grants and projects, EU projects, others.

Table 7 continued

Variable	Country	Remarks
	UK	Total funding from general budget and central government: total income from the higher education funding councils. External funding: tuition fees, OST research council grants, industry, commerce and public corporations research grants and contracts, UK based charities research grants and contracts, EU and EC research grants and contracts, other research grants and contracts.
	Italy	NA
	Poland	Funding from the government in the form of teaching and operational donations. The research grants from the government, if awarded at the basis of open competition, is classified as external funding.
Women academic staff[a]	Finland	Women teachers, full time equivalent (The share of women in academic staff calculated as the ratio of women teachers to total teachers, no data on the gender structure of research personnel).
	Switzerland	Women professors, adjuncts and lectures, full time equivalents, referring to the last day of each year.
	Germany	Women professors, lecturers, scientific assistants, scientific and artistic employees, teaching personnel, full time employment.
	Austria	Women professors, assistants and other academic staff, full time equivalent, available only for the years 2002 and 2005.
	UK	Women teachers, teachers and researchers, researchers, full time equivalent.
	Italy	NA
	Poland	Women professors, docents, adjuncts, assistants, senior lecturers, lecturers and specialist librarians, full time employment
Nofac	Finland	Number of faculties
	Switzerland	Number of faculties
	Germany	Number of faculties
	Austria	Number of faculties
	UK	Number of faculties
	Italy	Number of faculties
	Poland	Number of faculties
GDP	Finland	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.
	Switzerland	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.
	Germany	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.
	Austria	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.
	UK	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.

Table 7 continued

Variable	Country	Remarks
	Italy	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.
	Poland	GDP per capita in euro PPS of the NUTS2 region in which the given university is located.

[a] If not stated differently, data reported originally for the respective academic year (thus, the value in our dataset matched with the year 2002 refers to the academic year 2001/2002, and so on)

[b] According to the UOE manual (2004, p. 22) we consider a student to be any individual participating in the tertiary education service in the reference period

[c] In line with the UOE manual (2004, p. 34) as academic staff we consider: "personnel whose primary assignment is instruction, research or public service; personnel who hold an academic rank with such titles as professor, associate professor, assistant professor, instructor, lecturer, or the equivalent of any of these academic ranks; personnel with other titles if their principal activity is instruction or research."

NA—not available

Source Own elaboration

Table 8 Summary statistics of variables used in the second stage analysis

Variable	Obs	Mean	Std. Dev.	Min	Max
$GDP_{n,t}$	1295	106.90	39.30	33.50	337.50
$nofac_{i,t}$	1295	7.69	3.92	1	24
med_i	1295	0.53	0.50	0	1
$yearfound_i$	1295	1844.49	191.18	1050	2001
$Rev\_core_{i,t}$	971	61.74	18.71	15.44	95.37
$Women_{i,t}$	984	40.00	11.52	6.65	74.24
$Students_{i,t}$	1295	19266.81	12097.42	1584	63630

Source Own compilation

Table 9 Pairwise correlation between variables used in the second stage analysis

	DEA_{it}	$GDP_{n,t}$	$nofac_{i,t}$	med_i	$yearfound_i$	$Rev\_core_{i,t}$	$Women_{i,t}$	Students
DEA_{it}	1							
$GDP_{n,t}$	−0.069	1						
$nofac_{i,t}$	−0.060	−0.044	1					
med_i	−0.497	0.172	0.069	1				
$yearfound_i$	0.175	−0.114	−0.384	−0.316	1			
$Rev\_core_{i,t}$	0.593	−0.062	0.080	−0.382	−0.130	1		
$Women_{i,t}$	−0.275	0.051	−0.054	0.183	0.036	−0.084	1	
$Students_{i,t}$[a]	−0.311	−0.033	0.506	0.352	−0.353	−0.170	0.100	1

[a] In log

Source Own compilation

Table 10 The determinants of inefficiency scores (truncated regression), DEA 2 input 2 output model

Variables	(1) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(2) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(3) Bias-adjusted coefficients	95% Bootstrap confidence intervals	
		Low	High		Low	High		Low	High
$GDP_{n,t}$	−0.0005	−0.00179	0.00067	−0.0004	−0.00177	0.00063	−0.0002	−0.00154	0.00077
$Students_{i,t}$	−0.2615***	−0.32730	−0.19267	−0.3343***	−0.40814	−0.25983	−0.3013***	−0.37489	−0.22853
med_i	−0.2377***	−0.33174	−0.13572	−0.1228***	−0.22047	−0.01620	−0.1129***	−0.20974	−0.01037
$yearfound_i$	0.0001	−0.00018	0.00029	0.0007***	0.00042	0.00109	0.0008***	0.00051	0.00120
$Rev\_core_{i,t}$				−0.0039	−0.00838	0.00041	0.0027	−0.00201	0.00713
$Women_{i,t}$							−0.0120***	−0.01591	−0.00795
Obs	1261			954			905		

* Value of zero does not fall within 90% confidence interval, ** Value of zero does not fall within 95% confidence interval, *** Value of zero does not fall within 99% confidence interval. Confidence intervals obtained from 1000 bootstraping interactions

Constants are not reported. Year and country dummies included in all models

Source Own calculations

Table 11 Robustness check: the determinants of inefficiency scores—double bootstrap procedure, DEA 3 input 2 output

Variables	(1) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(2) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(3) Bias-adjusted coefficients	95% Bootstrap confidence intervals	
		Low	High		Low	High		Low	High
$GDP_{n,t}$	−0.0005	−0.00119	0.00020	0.0003	−0.00048	0.00084	0.0003	−0.00038	0.00088
$nofac_{i,t}$	−0.0099***	−0.01638	−0.00328	−0.0099***	−0.01673	−0.00322	−0.0075***	−0.01391	−0.00119
med_i	−0.1678***	−0.22174	−0.10921	−0.1192***	−0.17812	−0.05848	−0.1218***	−0.17899	−0.06505
$yearfound_i$	0.0003***	0.00019	0.00049	0.0007***	0.00052	0.00093	0.0006***	0.00045	0.00086
$Rev\_core_{i,t}$				0.0109***	0.00809	0.01365	0.0118***	0.00896	0.01461
$Women_{i,t}$							−0.0024*	−0.00462	0.00003
Obs	1295			971			919		

* Value of zero does not fall within 90% confidence interval, ** Value of zero does not fall within 95% confidence interval, *** Value of zero does not fall within 99% confidence interval. Confidence intervals obtained from 1000 bootstraping interactions

Constants are not reported. Year and country dummies included in all models

Source Own calculations

Table 12 Robustness check: the determinants of inefficiency scores—alternative truncation points

Model 1: truncation point: 1.0				Model 2: truncation point: 0.99		
Variables	(1) Bias-adjusted coefficients	95% Bootstrap confidence intervals		(2) Bias-adjusted coefficients	95% Bootstrap confidence intervals	
		Low	High		Low	High
$GDP_{n,t}$	0.0001	−0.00062	0.00072	0.0001	−0.00062	0.00065
$nofac_{i,t}$	−0.0085***	−0.01482	−0.00244	−0.0077***	−0.01410	−0.00097
med_i	−0.1000***	−0.15820	−0.04766	−0.1264***	−0.17989	−0.06450
$yearfound_i$	0.0008***	0.00058	0.00098	0.0008***	0.00054	0.00097
$Rev\_core_{i,t}$	0.0106***	0.00740	0.01333	0.0129***	0.00947	0.01527
$Women_{i,t}$	−0.0032***	−0.00552	−0.00083	−0.0031***	−0.00531	−0.00064
Obs	896			919		

* Value of zero does not fall within 90% confidence interval, ** Value of zero does not fall within 95% confidence interval, *** Value of zero does not fall within 99% confidence interval. Confidence intervals obtained from 1000 bootstraping interactions

Constants are not reported. Year and country dummies included in all models

Source Own calculations

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