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Exploring efficiency differentials between Italian and Polish universities, 2001–11

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Abstract

In this study, data envelopment analysis (DEA) is used to evaluate the relative efficiency of a sample of 54 Italian and 30 Polish state universities over the period 2001–11. The investigation was conducted in two steps. Unbiased DEA efficiency scores were first estimated and then regressed on external variables to quantitatively assess the direction and size of the impact of potential determinants. The analysis reveals a strong heterogeneity in the efficiency scores for each country, which is more pronounced than the difference in average efficiency scores between them. There is evidence that efficiency is determined by the structure of a university's revenues and academic staff: competitive versus non-competitive resources, and the number of professors. The study also explores the variation in the efficiency and productivity over time. While changes in pure efficiency were similar between the two countries, the efficiency frontier improved more in Italy than in Poland.

Key words: efficiency; productivity; two-stage data envelopment analysis; higher education institutions.

1. Introduction

The most recent and promising trend for studying the performance, productivity and efficiency of universities in Europe is to promote cross-country comparisons. It has been claimed (Aghion et al. 2010) that one of the key policy challenges for the future is the necessity of providing a European-level vision in the development of higher education (HE) and, in general terms, setting the transnational objectives of the 'Europe 2020 Strategy' has renewed interest in European coordination of activities and policies in the HE field (Soriano and Mulatero 2010). At the same time, the necessity for a wider European space for HE and research is not new. Discussion on this topic started with the signing of the Bologna Declaration and the implementation of the subsequent Bologna Process (Keeling 2006). Today, the international (i.e. European) discourse is simply reinforced by the increasing trend to compare the performance of HE institutions (HEIs) in different countries (Dill and Soo 2005).

With the aim of engendering better cross-country comparisons, an increasingly viable pathway concerns the use of administrative datasets that were originally collected for descriptive purposes and can be used by academic researchers and analysts at single university level to compare their performance and results. To the extent that these datasets can be compared across European countries, it is possible to undertake a cross-national assessment of the relative performances of HEIs.[1] However, empirical studies on HEI efficiency and productivity that cover several countries are still scarce.[2] Bonaccorsi et al. (2007) compared HEIs from Italy, Spain, Portugal, Norway, Switzerland and the UK, and Wolszczak-Derlacz and Parteka (2011) analysed universities from seven European countries in the period 2001–5. They conducted a two-stage data envelopment analysis (DEA), where DEA scores are first evaluated and then regressed on potential covariates. The authors found that unit size (economies of scale), number and composition of departments, sources of funding and staff composition in terms of gender are among the crucial determinants of the efficiency of these universities.

An alternative approach to cross-country studies of university efficiency has been proposed by Agasisti and Johnes (2009), who compared the relative performance of Italian and English HEIs, concentrating, therefore, on only two countries, but including all the universities rather than just a sample. The focus on two countries makes it easier to use qualitative information about the policies being set (analogies and differences), which can help enormously in interpreting the results. This attention to country-specific particularities is more difficult when the number of countries is higher.

The present paper follows the latter stream of the literature, proposing a comparison of the efficiency-related performance of Italian and Polish universities, and making use of the most recent bootstrap DEA techniques (Simar and Wilson 2007) and Malmquist indices.

These were supplemented by a second step in the analysis, which involved evaluating the potential determinants of the efficiency scores. To the best of our knowledge, this is the first paper that explores (evaluates and explains) the dynamics of efficiency and productivity for two important EU countries, using long panel data sets (a 10-year perspective).

The Italian and Polish HE systems have some common characteristics that make this comparison meaningful and interesting. First, in both countries, the HE sector is large, with 2 million students in Italy and around 1.7 million in Poland. In both countries, there is no binary system[3] of HE All HEIs are universities, either public or private, where, however the former are quantitatively more important in terms of research and teaching (in both countries, the vast majority of students attend state-funded public universities: around 90% in Italy and 76% in Poland).

On the other hand, the Italian and Polish HE systems differ in a number of aspects, which can be used beneficially to investigate the way in which specific regulations or structural characteristics can affect the universities' performance. To start with, Polish universities are significantly more underfunded than their Italian counterparts and their budgets rely mainly on government resources relating to teaching (a synopsis of the most interesting institutional features of the two HE systems is given in Section 2). The comparison between two important countries, one in Western and the other in Eastern Europe, is certainly a potential source of interesting results, as one of the main topics in the present debate is how a greater integration of the HE systems in two very different parts of Europe can best be achieved.

This paper is innovative in three main directions. First, it considers a relatively long panel data set (2001–11). While some studies on single countries are starting to cover such long periods (e.g. Johnes 2008 for England, and Garcìa-Aracil 2013 for Spain), this is the first time that an analysis has been carried out on the evolution of the efficiency of HEIs over a significant medium-length period in a cross-country perspective. Second, we have correlated the efficiency scores of each university (in both within-country and between-countries analyses) to a set of descriptive characteristics (e.g. their size, whether there is a medical school, their share of public funds etc.) that can help to describe why some institutions are more efficient than others—and how common these differences are across the two countries. Third, while a growing attention is being paid to the reforms in the Polish HE system (Kwiek 2012), no studies have been published in international academic journals to describe the performance of Polish HEIs. This paper fills that gap, while, at the same time, presenting the comparison with a major European country like Italy. It is also interesting to check whether Polish HE, together with its research-related productivity, is converging towards Western Europe standards.

The remainder of this paper is organised as follows. A brief sketch of the main features of the Italian and Polish HE systems is presented in Section 2. Section 3 describes the methodology and data. The results are presented in Section 4. Section 5 outlines the main policy implications, followed by some concluding remarks.

2. Background of Italian and Polish HE

Both the Italian and the Polish HE systems consist of public and private universities, with the vast majority of students (around 90% in Italy and 76% in Poland) attending state institutions. Consequently, the empirical analysis in the present paper only includes data on public universities.

The Italian and Polish universities analysed in this study rely mainly on government funding (with 60–80% of their budget coming from government sources). However, the level of finance and pattern of funding (the structure of income) are different for the two countries.

In Italy, throughout the 1990s and in the first decade of the 2000s, the national public funds allocated to universities (*Fondo di Finanziamento Ordinario* (FFO)) grew substantially from around €3.5 billion to approximately €7.5 billion. Public resources, however, started declining in 2010 and the probably trend is of further reduction over the coming years. Given the parallel decline in number of students, expenditure per student only declined in the period 2008–11, and now seems to be growing once again, although slowly (these are nominal figures, while inflated figures show a decline across the entire period) (see Fig. 1). The greater part of university budgets (especially FFO) is expended on staff salaries, while the rest is for developing research work and teaching initiatives alongside the institutional courses.

An important feature of the Italian HE system is that universities can charge tuition fees. Usually, these fees are quite low (around €1,200 per year) and only cover a small fraction of the real cost per student. Nevertheless, this source of income has gained importance over recent years (to counterbalance the reduction in public funds or FFO) and now represents, on average, 15% of the total income of a university. This average, however, masks substantial variations, with tuition fees making up to 25% of their income in some universities (which means that these institutions charge much higher fees per head). It is likely that the (economic) behaviour of the various universities—especially their level of responsiveness towards students—varies depending on how much they rely upon the students' financial contribution.

In contrast to Italian HEIs, Polish public universities are free of charge for full-time students (with some administration fees e.g. for registration or retaking a year). Tuition fees are, however, paid by part-time students enrolled in the public sector (whose courses are run over the weekend). The share of revenue from these tuition fees for public universities was around 12% of total revenues in 2012 (15.5% of all teaching revenue (GUS 2013)). This proportion is significant if we take into account the legal basis that HE is free of charge in the public sector. Nevertheless, the share of teaching-related funding (both from tuition fees and other university revenues) is now decreasing, having reached its peak in the mid 2000s.

Until 2001, Italian students could only study for one kind of degree (known as the *Laurea*) with courses lasting four or five years, depending on the subject. The Italian HE system was criticised for its inefficiency. Despite enrolment rates that were lower than in other major EU countries, a huge number of students dropped out: with the resulting graduation rates being very low (Triventi and Trivellato 2008). Last, but not least, many students stayed at university much longer than the time necessary for the degree (seven or eight years, for instance, instead of four or five). After 2001, a major reform was implemented to follow the Bologna Process: an agreement between EU countries to adapt their HE degree systems to a Bachelor/Master structure. Italy implemented this reform quickly and extensively, requiring all universities to start all new courses under the Bachelor/Master structure from 2001. The new Bachelor degree was immediately very attractive, because it only lasts three years, and many prospective students saw it as an opportunity to obtain a HE degree in less time than previous cohorts.

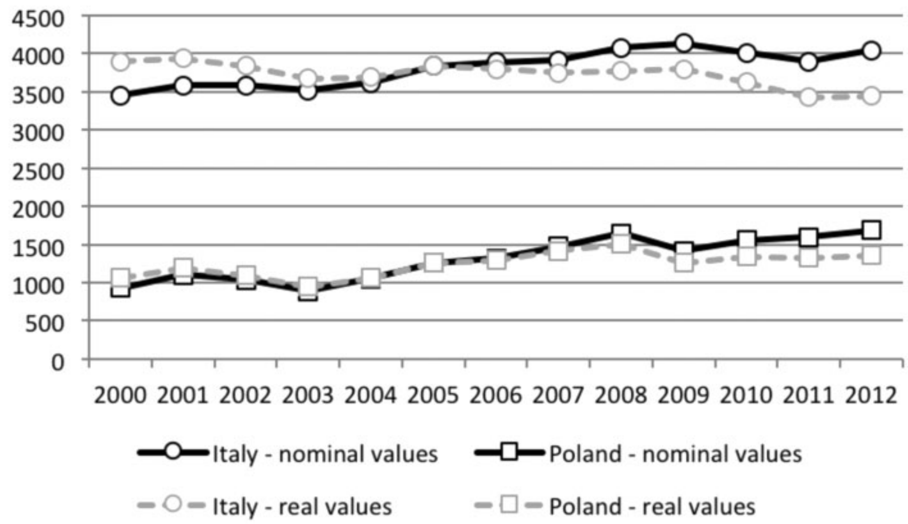

Figure 1. Public spending per student in both countries, nominal and real terms: only public universities (2000–12).

Source: authors' elaboration. For Italy (IT) based on Italian State's Financial Reports, various years; for Poland (PL) Central Statistical Office (GUS 2013), in real terms (values expressed in 2005 prices) inflated by Polish and Italian Harmonised Index of Consumer Prices (HICP) from Eurostat.

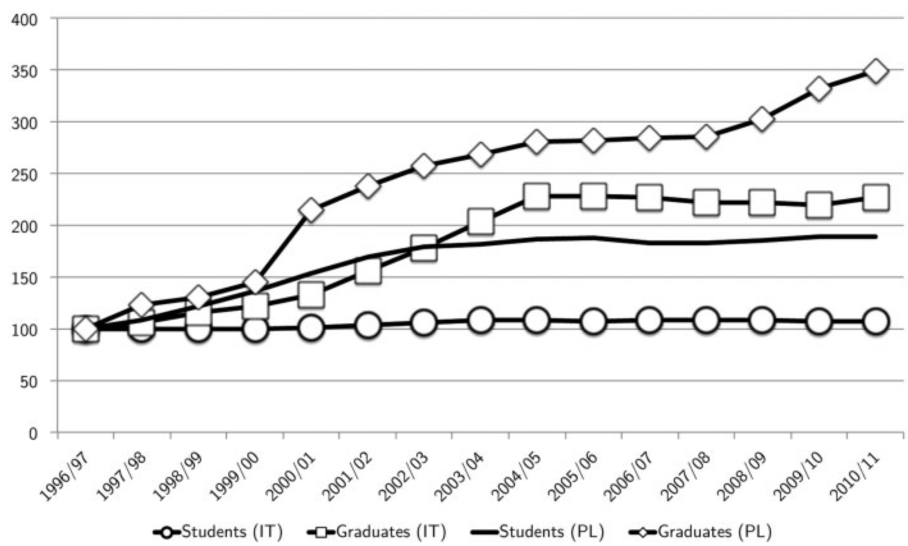

Figure 2. Number of students and graduates, 1996/97–2010/11 (only public universities) (index numbers: 1996/97 = 100)

Source: authors' elaboration. For Italy: Ministry of Education's Statistics Office, various years. For Poland: Central Statistical Office (GUS 2013).

As a consequence, there was an increase in the number of first-year students. At the same time, the number of graduates increased steeply in the early years following the reform, because students were allowed to switch from the *Laurea* to a new Bachelor course, and many of them (including those who had been at university for a long time) already had enough credits to give them a degree. Lastly, the number of graduates also increased after the reform because a greater number of them now gain their degree on time, and they can obtain two degrees (Bachelor and Master) in five years, instead of the previous single-tier degree (*Laurea*) (see Fig. 2). Overall, the reform was a major change that radically affected the Italian HE system (at least, in the years that immediately followed), contributing, in the medium-term, towards increasing both enrolment and graduation rates (the latter more than the former).[4] This specific trend must be kept in mind when assessing the efficiency of Italian universities over time, because we define the concept of efficiency, in part, by making a comparison between the number of students and number of graduates.

In the case of the Polish HE system, an enormous growth in the number of graduates and total number of students has been observed since the early 1990s up to 2005/6. This process is rooted in the transformation from a centrally planned economy to a market economy, which resulted in the expansion of private institutions and growth of part-time students at public universities. As a consequence of the increasing number of enrolments, universities have become more focused on teaching (for more about the transformation period, see Kwiek 2012). Additionally, due to the non-competitive salaries offered in public institutions, most academic staff hold parallel jobs in the private universities (according to Kaszubowski and Wolszczak-Derlacz 2014, about 60% of academic staff earn additional income outside their home university). All of this erodes the research activity of Polish HEIs. Due to demographic changes (drop in population among the 19–24 age range), the total number of students started to decrease from 2006 (so far the decline has mainly resulted in a decrease in the number of part-time students). This (together with the need to increase research productivity) initiated the Polish HE reforms. The first work started in 2005 and a new law was introduced in 2010–11. The intention behind this new law was that universities which had concentrated on teaching would instead also focus on research (e.g. through the introduction of highly competitive funding mechanisms).

3. Methodology and data

In order to evaluate the efficiency of HEIs, we employed a DEA, in which efficiency is measured in relation to a non-parametric frontier estimation of efficient units, which is conditional estimated to the observed data. The authors of DEA in the currently used form (Charnes et al. 1978) refer to the earlier work by Farrell (1957), who defined efficiency as success in producing as many outputs as possible from a given set of inputs. Analysed entities are referred to as decision-making units (DMU) as they 'decide' either which inputs or which outputs are to be used in the production process. The authors who defined the term DMU (Charnes et al. 1978), explained that they intended to emphasise that this is an appropriate method, not only to test the efficiency of profit-making companies, but also that of many different types of organisation/institution (e.g. public enterprises, hospitals, schools, non-profit organisations, programmes and even individual people).

Here, we will only present the basic concept of DEA, a detailed explanation can be found elsewhere (Cooper et al. 2004; Coelli et al. 2005). Below, we will refer to an output-oriented model with variable returns to scale, the model utilised in the empirical part of our analysis. The notation used closely follows that of Simar and Wilson (2008).

The activity of a given DMU can be described by the production set Ψ of physically possible points (x, y):

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

Where x indicates a vector of N inputs and y the vector of M outputs. Its output feasibility sets can be defined for all x as:

$$Y(x) = \{y \in R_{+}^{M} | (x, y) \in \psi\}$$

The efficient DMU operates at the boundary of optimal production (frontier), which in case of output-oriented model $\partial Y(x)$ is defined as:

$$\partial Y(x) = \{y | y \in Y(x), \lambda y \notin Y(x), \forall \lambda > 1\} \tag{2}$$

The Debreu–Farrell measure of efficiency is found by maximising the achievable output given the level of the inputs:

$$\lambda(x, y) = \sup \{\lambda | (x, \lambda y) \in \Psi\} \tag{3}$$

The DEA estimator for the variable returns to scale (replacing Ψ with $\hat{\Psi}_{VRS}$ in Equation (3)), can be computed by solving the linear programme:

$$\hat{\lambda}_{VRS}(x, y) = \sup \{\lambda | \lambda y \leq \sum_{i=1}^{n} \gamma_i y_i; x \geq \sum_{i=1}^{n} \gamma_i x_i \quad \text{for} \quad (\gamma_1, \ldots \gamma_n) \tag{4}$$

$$\text{such that:} \sum_{i=1}^{n} \gamma_i = 1 \text{ and } \gamma_i \geq 0, i = 1, \ldots, n\}.$$

According to the traditional definition, efficiency measures must be in the range between zero and one. However, for practical purposes, we have parameterised them, as their reciprocal and efficient DMUs are defined by an efficiency score of 100%, or 1 (DEA = 1), while inefficiency is indicated by the values greater than 100% or 1 (DEA > 1).[5]

To obtain the statistical properties of the estimated efficiency scores (to estimate the bias and variance, and to construct confidence intervals together with unbiased scores), we have followed the bootstrap procedure of Simar and Wilson (2000), which involves the generation of pseudo-data and approximating the unknown distribution of efficiency scores using the distribution of bootstrap values.[6]

In the empirical part of this paper, we have also provided evidence about the potential determinants (Z_i) of previously estimated bias-corrected efficiency scores (DEA_i) where the regression is represented as:

$$DEA_i = \alpha + Z_i\beta + \varepsilon_i \tag{5}$$

Where $\varepsilon_i$is a statistical noise with left truncation at: $(1 - Z_i\beta)$, since DEA efficiency scores are larger than or equal to one. The estimation of regression (Equation (5)) may cause some statistical problems (e.g. DEA efficiency scores are estimated, not observed, and are, by construction, serially correlated, inputs and outputs can be in correlation with Z_i) and, as a result, traditional estimation methods (e.g. the Tobit model) can be inadequate. The bootstrap truncated regression procedure of Simar and Wilson (2007) has been employed here to address these limitations properly.[7]

Changes in efficiency over time are evaluated on the basis of the Malmquist index (MI), which measures the change in the total factor productivity of DMUs in two periods of time. The concept of the MI derived by Färe et al. (1992, 1994) was developed from efficiency and productivity measurements (Farrell 1957; Caves et al. 1982) and is rooted in DEA methodology. Productivity changes can be due to the catch-up effect (with changes in technical efficiency (ε_i), DMUs approach the efficiency frontier) or/and as the result of frontier shift (changes in technology (τ_i)) and the MI can be decomposed as:

$$M_{i,(t_1,t_2)} = \underbrace{\frac{D_i^{t_2}(x_{t_2}, y_{t_2})}{D_i^{t_1}(x_{t_1}, y_{t_1})}}_{(\varepsilon_i)} \times \underbrace{\left[\frac{D_i^{t_1}(x_{t_2}, y_{t_2})}{D_i^{t_2}(x_{t_2}, y_{t_2})} \times \frac{D_i^{t_1}(x_{t_1}, y_{t_1})}{D_i^{t_2}(x_{t_1}, y_{t_1})}\right]^{1/2}}_{(\tau_i)} \tag{6}$$

Where D_i denotes the efficiency distance function, and x and y are inputs and outputs in periods t_1 and t_2, respectively. For example, $D_i^{t_1}(x_{t_1}, y_{t_1})$ represents the distance of the ith DMU from the period t_1 with the reference to the technology of the same period: t_1, while, for $D_i^{t_2}(x_{t_2}, y_{t_2})$ the period, t_2 is the reference technology etc. The calculation of Equation (6) involves computing different component distance functions expressed by linear programming problems similar to those defined in Equations (3) and (4) (see Coelli et al. (2005: 291–4) for details).[8] Once again, a bootstrap procedure is involved (Simar and Wilson 1999) to check the statistical properties of the indices and to verify the statistical significance of changes in efficiency and technology. The values of $M_{i,(t_1,t_2)} > 1$ indicate positive total factor productivity (TFP) growth between periods t_1 and t_2, while values$M_{i,(t_1,t_2)} < 1$ indicate a drop in productivity. If the index is equal to unity, then no change in productivity is detected between times t_1 and t_2.

There are clear advantages to the non-parametric DEA approach compared to traditional methods (e.g. econometric production

Table 1. Descriptive statistics

	Italy ($N = 54$)			
	Mean	Min	Max	Std. Dev
Expenditure in € (in thousands)*	195,000	22,000	1,730,000	175,000
Academic staff	1,027	113	4,950	877
Students	30,076	5,183	139,937	24,841
Graduates	4,428	261	21,517	3,777
Doctoral students	611	0	5,040	563
PhD degrees awarded	191	0	2,095	233
Publications**	991	2	5,549	1,028
Expenditure per academic staff in € (in thousands)	191.47	102.07	1337.47	63.18
Expenditure per student in € (in thousands)	6.43	1.75	45.92	2.61
Publications per academic staff	0.89	0.02	2.15	0.42
Graduates per academic staff	4.56	1.34	11.13	1.52
	Poland ($N = 30$)			
	Mean	Min	Max	Std. Dev
Expenditure in € (in thousands)*	64,500	7,144	243,000	43,900
Academic staff	1,413	287	3,642	744
Students	21,262	4,495	46,282	9,974
Graduates	4,122	732	10,887	2,163
Doctoral students	674	0	3,021	629
PhD degrees awarded	94	0	510	81
Publications**	367	1	1,810	345
Expenditure per academic staff in € (in thousands)	43.73	6.92	72.41	10.58
Expenditure per student in € (in thousands)	2.73	0.44	5.36	0.93
Publications per academic staff	0.22	0	0.63	0.13
Graduates per academic staff	3.09	1.4	8.01	1.06

*Values expressed in real terms, reference year: 2011.

**All publications (articles, proceedings papers, editorial materials, book chapters, book reviews etc.) listed in WoS core collections: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Conference Proceedings Citation Index–Science, Conference Proceedings Citation Index–Social Science & Humanities, Book Citation Index–Science, Book Citation Index–Social Sciences & Humanities, Current Chemical Reactions and Index Chemicus.

functions estimated through stochastic frontier methods). Key strengths include the fact that no or few restrictions are imposed on production technology and there is no presumption of any particular functional form of inputs and outputs. This is particularly useful in the case of multiple inputs and outputs, where the process of production is influenced by external factors—as in the case in HE. Due to the bootstrap procedure used in our study, we were also able to overcome the main limitations of the DEA procedure which, as it is deterministic, lacks statistical power.

One critical aspect of DEA methodology is the choice of inputs and outputs. In our analysis we have followed previous studies (see the discussion in Johnes 2004). However, we are also bound by the availability of data. The set of indicators that we eventually chose was, therefore, completely in line with the best practice set out in this literature, as it includes as inputs: expenditure and number of academic staff; and as outputs: the number of students and graduates (divided by level, under/postgraduates and PhD students) and publications.[9]

For the study in Italy, we used the administrative data collected by the National Agency for the Evaluation of Universities (ANVUR, see <www.anvur.org>). Every year, ANVUR collects data from all universities about the number of students (at Bachelor, Master and PhD level), staff and graduates. Most of this information is also available by subject (although we did not employ data by subject mix in this paper). ANVUR also holds data provided by the universities' statistical offices in their financial reports. We can gain information from this source about the overall level of expenditure, student tuition fees etc.

In Poland, there is no common database with information on individual HEIs. Non-financial data (academic staff, non-academic staff, professors, total number of students, graduates and PhD degrees awarded) was taken from publications issued by the Polish Ministry of Science and Higher Education (*Szkoły wyższe – dane podstawowe*, issues for the period 2002–12). Financial data comes from the individual institution's financial reports, which universities are obliged to publish in the *Journal of Laws*, '*Monitor Polski B*'. Information about the number of different departments, the university's year of foundation and whether or not it has a medical school is taken from the webpages of each HEI.

For both countries, we collected the data about the publications (articles, proceedings papers, editorial material, book chapters, book reviews etc.) produced by the affiliated staff of each university and listed in the Web of Science (WoS) database, part of the ISI Web of Knowledge.[10]

Table 1 presents some descriptive statistics about the inputs and outputs chosen for the analyses, as well as some simple indicators of productivity that were calculated from these. Overall, Italian universities have many more resources than their Polish counterparts (the real expenditure per student is around €6,400 and €2,700, respectively), and this is reflected in the different resources available for academic staff (the expenditure per unit for academic staff is €191,400 and €43,700, respectively). The average Italian university is larger than the average Polish university in terms of student numbers (30,000 vs 21,000 students), but smaller when considering the number of academic staff (1,000 vs 1,400). When considering teaching output, Italian universities, on average, produce 4,400 graduates per year, while the Polish figures indicate around 4,100 graduates per year. Since there are one-third less Polish students, this would suggest that universities in Poland are more efficient in terms of teaching (this intuition is explored later through appropriate empirical modelling). The numbers concerning research are different, as they show that the average Italian university produces almost three times the number of publications that a Polish university (around 1,000 and 350, respectively), and the difference per capita academic staff is even greater (0.9 vs 0.2).

4. Empirical analysis

4.1 First step: Evaluation of efficiency

We have carried out estimations for different versions of the DEA model, depending on the input–output sets and assumptions, considering the (common or country-specific) frontier. The same set of inputs was used in all the models (i.e. the number of academic staff and total expenditure), but the output mix varies according to the model adopted (number of publications, graduates, students and PhDs awarded). Additionally, we have distinguished between common and country-specific frontiers (see Table 2). The common frontier relates to the pooled data: institutions from both countries are considered together, while in the country-specific frontier model, DEA efficiency scores are calculated separately for the subsamples of Italian and Polish institutions (where each HEI is evaluated against other universities from the same country (e.g. comparing the performance of Italian HEIs against other Italian HEIs).

The main results of the DEA empirical analyses are reported in Tables 3 and 4. The rows give the country-average DEA efficiency scores for each year, the columns give the different models described above. For both countries, we have presented both the baseline scores and the bias-corrected scores (using the bootstrap method outlined in Section 3). However, the remaining part of the comments in this paper considers the bias-corrected scores. All the estimates show that, on average, inefficiency decreased over time for both countries, whichever model was considered. The correlation between the estimates obtained through the different models (see Table 5) are all statistically significant and quite high (ranging from around 0.5 to >0.95), suggesting that the results are quite robust across different specifications of the efficiency analysis. The overall picture is not substantially different whether a common or a country-specific efficiency frontier is assumed, suggesting that this assumption is not a major determinant of our results.

Polish universities turn out to be more efficient for Models 1 and 2, where the number of PhDs awarded is not included among the outputs. The positive efficiency differential is driven by two factors. The first factor is that, on average, Italian universities are better funded than their Polish counterparts, but their production of outputs (especially teaching outputs) is not proportionally higher. Even the higher average number of academic staff per Polish institution does not compensate for the higher average expenditure in Italian institutions. The second factor is that, in Polish universities, the student–graduate ratio is, on average, much higher than that in Italian universities (i.e. less dropouts, more students graduating on time

Table 2. Different DEA models at a glance

First set of models: common frontier		
	Inputs	Outputs
Model 1	Expenditure in €, number of academic staff	Publications, graduates
Model 2		Publications, students
Model 3		Publications, graduates, PhD degrees awarded
Second set of models: country-specific frontier		
	Inputs	Outputs
Model 4	Expenditure in €, number of academic staff	Publications, graduates
Model 5		Publications, students
Model 6		Publications, graduates, PhD degrees awarded

Table 3. Summary of efficiency scores in Italy

	DEA scores						DEA unbiased scores					
	Common frontier			Country-specific frontier			Common frontier			Country-specific frontier		
Model	1	2	3	4	5	6	1	2	3	4	5	6
2001	1.367	1.325	1.189	1.311	1.315	1.17	1.486	1.43	1.293	1.434	1.44	1.265
2002	1.283	1.2	1.218	1.215	1.196	1.157	1.388	1.271	1.321	1.313	1.279	1.248
2003	1.355	1.265	1.202	1.322	1.261	1.165	1.476	1.35	1.292	1.453	1.366	1.254
2004	1.261	1.241	1.128	1.243	1.231	1.113	1.353	1.317	1.2	1.345	1.322	1.187
2005	1.275	1.225	1.153	1.234	1.213	1.124	1.375	1.305	1.237	1.33	1.304	1.195
2006	1.332	1.255	1.143	1.303	1.248	1.125	1.44	1.341	1.218	1.43	1.35	1.195
2007	1.307	1.229	1.195	1.296	1.222	1.183	1.408	1.304	1.282	1.416	1.31	1.277
2008	1.228	1.169	1.178	1.216	1.169	1.172	1.303	1.235	1.254	1.307	1.241	1.257
2009	1.211	1.149	1.157	1.196	1.148	1.149	1.292	1.208	1.238	1.28	1.211	1.229
2010	1.192	1.16	1.098	1.166	1.16	1.092	1.263	1.224	1.156	1.235	1.229	1.146
2011	1.167	1.13	1.111	1.162	1.129	1.111	1.234	1.205	1.17	1.235	1.19	1.174
Mean	**1.271**	**1.214**	**1.161**	**1.242**	**1.208**	**1.142**	**1.365**	**1.29**	**1.242**	**1.343**	**1.295**	**1.221**
Min	1	1	1	1	1	1	1.046	1.041	1.041	1.037	1.035	1.036
Max	2.158	2.543	1.913	2.158	2.543	1.85	2.332	2.695	2.012	2.34	2.724	1.96
Std. Dev	0.259	0.228	0.194	0.24	0.226	0.176	0.265	0.234	0.195	0.246	0.236	0.176

DEA unbiased scores obtained by bootstrap method following Simar and Wilson (2000).

Table 4. Summary of efficiency scores in Poland

	DEA scores						DEA unbiased scores					
	Common frontier			Country-specific frontier			Common frontier			Country-specific frontier		
Model	1	2	3	4	5	6	1	2	3	4	5	6
2001	1.269	1.164	1.255	1.258	1.154	1.244	1.409	1.269	1.367	1.391	1.242	1.377
2002	1.281	1.124	1.254	1.262	1.119	1.238	1.405	1.202	1.374	1.386	1.189	1.362
2003	1.196	1.115	1.163	1.19	1.108	1.157	1.318	1.202	1.263	1.275	1.171	1.258
2004	1.167	1.116	1.118	1.153	1.104	1.107	1.261	1.194	1.19	1.234	1.167	1.178
2005	1.214	1.137	1.198	1.192	1.118	1.181	1.315	1.219	1.285	1.29	1.183	1.288
2006	1.221	1.143	1.194	1.183	1.107	1.166	1.324	1.221	1.267	1.271	1.164	1.254
2007	1.199	1.126	1.154	1.152	1.097	1.129	1.302	1.2	1.248	1.231	1.154	1.207
2008	1.135	1.131	1.135	1.101	1.111	1.098	1.215	1.201	1.213	1.159	1.177	1.16
2009	1.21	1.121	1.195	1.13	1.092	1.109	1.291	1.182	1.275	1.197	1.145	1.175
2010	1.218	1.164	1.199	1.118	1.104	1.095	1.298	1.231	1.259	1.185	1.162	1.151
2011	1.145	1.335	1.138	1.061	1.139	1.051	1.214	1.417	1.194	1.102	1.206	1.087
Mean	**1.205**	**1.152**	**1.182**	**1.164**	**1.114**	**1.143**	**1.305**	**1.231**	**1.267**	**1.247**	**1.178**	**1.227**
Min	1	1	1	1	1	1	1.048	1.037	1.042	1.032	1.037	1.028
Max	2.802	2.37	2.747	2.802	2.37	2.747	3.07	2.572	2.945	3.041	2.499	2.979
Std. Dev	0.281	0.191	0.259	0.268	0.169	0.245	0.296	0.197	0.267	0.281	0.17	0.259

DEA unbiased scores obtained by bootstrap method following Simar and Wilson (2000).

Table 5. Correlations between different DEA models

	DEA scores						DEA unbiased scores					
	Common frontier			Country frontier			Common frontier			Country frontier		
Model	1	2	3	4	5	6	1	2	3	4	5	6
1	1											
2	0.64	1										
3	0.82	0.52	1									
4	0.96	0.62	0.78	1								
5	0.62	0.97	0.49	0.64	1							
6	0.79	0.51	0.95	0.82	0.52	1						
1	0.99	0.62	0.8	0.96	0.61	0.78	1					
2	0.61	0.99	0.49	0.59	0.96	0.48	0.61	1				
3	0.81	0.51	0.99	0.78	0.48	0.95	0.81	0.49	1			
4	0.95	0.6	0.76	0.99	0.63	0.8	0.96	0.59	0.76	1		
5	0.59	0.95	0.45	0.61	0.99	0.48	0.59	0.96	0.45	0.61	1	
6	0.78	0.49	0.94	0.81	0.5	0.99	0.78	0.47	0.95	0.81	0.47	1

etc.). When including doctoral-level education in the analysis, the results suggest that Italian universities are, on average, more efficient, and this is probably due to the higher number of PhD degrees awarded, since the number of graduate students per institution is quite similar for the two HE systems.

The most important result to highlight, however, is the strong heterogeneity in the efficiency scores within each country. In both Italy and Poland, the standard deviation of the efficiency scores is substantial, in the range 0.19–0.29, and it is higher than the difference in average efficiency scores between the two countries. This also means that there is no 'average' university in each country in terms of efficiency, but there is a wide distribution of efficiency scores within the countries, making the within-country differences more relevant than those between countries. Looking at Fig. 3, where the distribution of efficiency scores is given for both Italian and Polish universities (we present both baseline and bias-corrected scores), it is clear how the two groups of universities can be compared against each other in terms of relative efficiency. Also, there are no striking differences between the two that make the distribution of efficiency structurally different. Another feature that stresses the importance of taking heterogeneity into account is that, despite its higher level of average efficiency, the efficiency scores in Polish universities also have wider tails, suggesting a higher level of heterogeneity within the Polish HE system than in the Italian one (this is cross-confirmed by the efficiency scores of Polish universities with lower scores, >3 in some cases).

Table 6 analyses the change in TFP in the period 2001–11 (the computation is based on an unbiased MI that considers annual changes), and, specifically, its decomposition into pure efficiency change and frontier shift. The specific results refer to Model 1, but a correlation matrix between the indices obtained with different models is given in the Appendix, showing that they are qualitatively and quantitatively (Pearson's scores) similar (Table A.1). Table 6 not only reports the average MI calculated for all universities, as is usually the case in the literature, but we follow Parteka and Wolszczak-Derlacz (2013) in also presenting the index calculated as the average

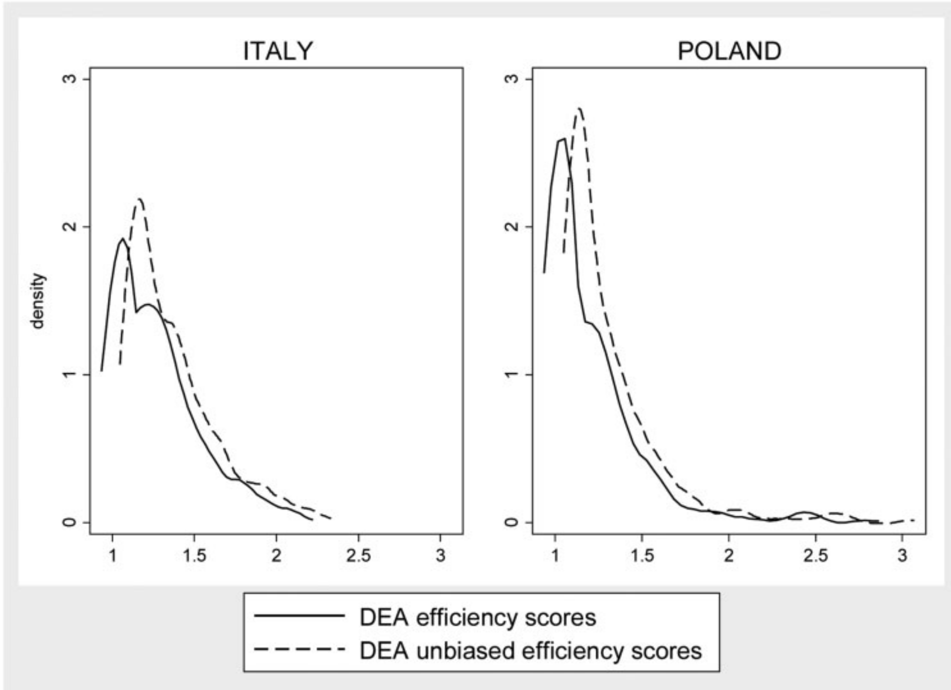

Figure 3. Distribution of efficiency scores by country (all years pooled) obtained from Model 1.

All elaborations are obtained assuming a common efficiency frontier.

Table 6. Trends in productivity (*TFP*), efficiency and technology in Italian and Polish HEIs, based on annual changes in period 2001–11

	Malmquist (TFP)	Efficiency change	Technology (frontier shift)
Italy			
Number of all indices	540	540	540
Average value of all indices	*1.070*	*1.023*	*1.051*
Number of statistically significant indices	495	311	330
Average value for statistically significant indices	*1.075*	*1.038*	*1.074*
Number (and %) of statistically significant improvements	431	187	238
	80%	35%	44%
Poland			
Number of all indices	300	300	300
Average value of all indices	*1.029*	*1.019*	*1.012*
Number of statistically significant indices	272	131	112
Average value for statistically significant indices	*1.032*	*1.050*	*1.030*
Number (and %) of statistically significant improvements	187	76	70
	62%	25%	23%

Values are considered as statistically significant assuming conventional 10% level.

Results are based on Model 1 (two inputs: expenditure and academic staff; two outputs: publications and graduates); a common efficiency frontier is imposed.

of only the universities where it is statistically significant (the same holds for the indices of efficiency change and technology change). In both countries, this choice translates into a slightly higher magnitude for all coefficients. We have, therefore, commented on these adjusted coefficients, which are net of the values that are not statistically significant in describing productivity changes.

On average, Italian universities improved their productivity more than the Polish ones (the MI values are 1.075 and 1.032, respectively). An interesting story emerges if one looks at the components of the synthetic index in Italy, as the productivity improvement is completely driven by the technology change (1.074) and not by pure efficiency gains (1.038). The opposite has been verified for the Polish universities, where the indices for technology change and efficiency improvements are 1.030 and 1.050, respectively. The evidence about the shift of efficiency frontier that increased the Italian universities' productivity is also confirmed by Agasisti and Lezzi (2013), and is coherent with previous studies that demonstrated how adopting a Bachelor/Master teaching structure (to follow the Bologna Process) resulted in an immediate improvement in the efficiency of their teaching (Agasisti and Dal Bianco 2009). A further corroboration of this interpretation stems from Fig. 2, where the annual increase in TFP is shown by country. The most pronounced difference in productivity improvement is concentrated in the years immediately after the introduction of the Bologna Reform in Italy. However, since 2005 the growth in productivity has been reducing over time, and now it is somehow mirrored in the two countries. The relatively low rate of improvement in productivity in both Italy and Poland is also in line with the values reported by Johnes (2008) for England and by Garcìa-Araril (2013) for Spain, in the only two studies that analyse a relatively long panel data set of around ten years, similarly to the work carried out in the present paper (see Fig. 4).

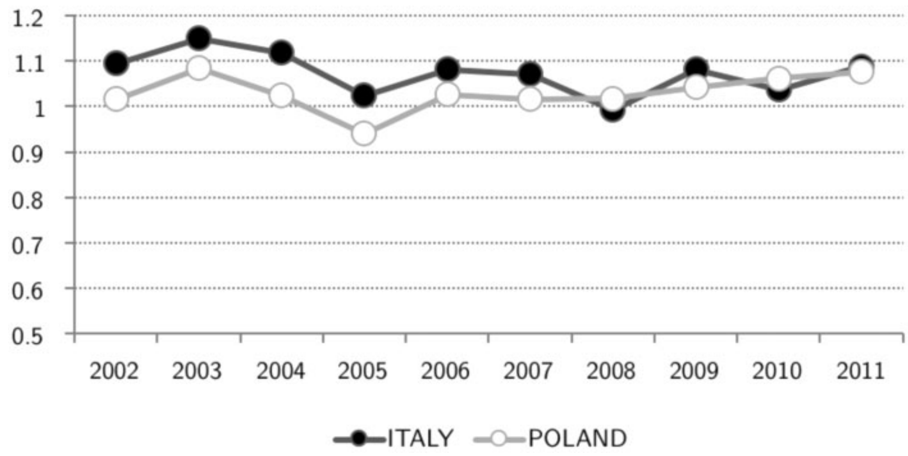

Figure 4. Average changes in productivity (Malmquist indices), by country and year.

Results based on Malmquist indices that are statistically significant at 10% level.

Results are based on Model 1 (two inputs: expenditure and academic staff; two outputs: publications and graduates). A common efficiency frontier is imposed.

4.2 Second step: Determinants of the efficiency

Our task was not only to measure the efficiency scores of HEIs, but also to check their possible determinants. We therefore conducted a second step analysis in which we treated the efficiency scores (previously estimated) as dependent variables in the regression equation. Since the scores are not observable, but have been estimated and are censored at one, in order to ensure the statistical accuracy of the analysis, we have employed a bootstrap truncated regression method, based on the procedure of Simar and Wilson (2007), previously used in Wolszczak-Derlacz and Parteka (2011). The procedure makes it possible to obtain unbiased regression coefficients and valid confidence intervals. Since the values of the efficiency scores are greater than or equal to one, positive/negative regression coefficients would mean that, due to the rise of the independent variables, inefficiency increases/decreases.

In order to provide quantitative evidence on the direction and strength of the links between HEI efficiency and the set of possible determinants, we fit the following equation, which corresponds to Equation (5):

$$DEA_{i,t} = \alpha + \beta X_{i,t} + \varepsilon_{i,t} \tag{7}$$

Where i refers to the single HEI, t denotes the time period, $X_{i,t}$ is a matrix of potential determinants of efficiency scores ($DEA_{i,t}$) and $\varepsilon_{i,t}$ is an error term. The basic specification (Equation (7)), when enriched by other covariates, has the following form:

$$\begin{aligned} DEA_{i,t} = \alpha &+ \beta_1 Rev\_NonComp_{i,t} + \beta_2 Prof_{i,t} + \beta_3 GDP_{n,t} \\ &+ \beta_4 depart_i + \beta_5 med_i + \beta_6 yearfound_i + \nu_t + \varepsilon_{i,t} \end{aligned} \tag{8}$$

Where the covariates are defined, synthetically:

$Rev\_NonComp_{i,t}$ = share of revenues from non-competitive sources, expressed in %
$Prof_{i,t}$ = number of professors in academic staff, expressed in %
$GDP_{n,t}$ = gross domestic product (GDP) per capita in € Purchasing Power Standard (PPS) of the Nomenclature des unités territoriales statistiques (NUTS) 2 region n, in which university i is located
$depart_i$ = number of different departments
med_i = dummy variable indicating university has a medical or pharmaceutical school
$yearfound_i$ = year of foundation
v_t = time dummies

The choice of independent variables was driven mainly by our general interest in factors that might determine the efficiency of HEIs (Wolszczak-Derlacz and Parteka 2011) and data availability. We are especially interested in checking whether the source and nature of funding is important in establishing a university's efficiency. Previous research (Agasisti and Haelermans 2015) demonstrated that the different methods used for funding universities' activities can provide alternative incentives and, thus have an impact on efficiency. We have divided the total revenues obtained by the universities into competitive and non-competitive revenues and we have defined the former as those received through the process of open competitions (e.g. research grants from research agencies). The idea is to have an indicator about the competition that each university faces, knowing that competition can be a driving force of HEIs' strategies and moves (see the theoretical discussion in Winston 1999). In the case of Polish HEIs, non-competitive resources are the share of government funds obtained as a lump sum, while, for Italian HEIs, non-competitive resources are calculated as the difference between total revenues and funds from grants and tuition fees. We then measured the rank structure of the universities' academic staff using their ratio of professors ($Prof_{i,t}$). This allowed us to check whether a higher share of professors within the academic body is associated with higher efficiency for a given university, and, in turn, whether professors are more 'efficient' than junior staff, especially considering that, in both countries, academics have to obtain a further special qualification in order to become a full professor. The idea that tenured/track faculty can be less productive than untenured ones has been discussed in the literature, and empirical studies are still scarce in this field. Figlio et al. (2013) found that untenured teachers were more effective in teaching results, for a sample of students in one important university in the USA. Further, we have accounted for the location of a university measured by the GDP per capita in € PPS for the NUTS 2 region where the university i is located (data from Eurostat).[11] Indeed, previous research about the efficiency of Italian universities, evidenced substantial efficiency differentials between those in the North or the South (Agasisti and Dal Bianco 2006). This can tell us whether universities located in wealthier regions have a higher efficiency as the result of their more advantageous environment (e.g. through collaboration with local business). On the other hand, economically disadvantaged regions

Table 7. Determinants of efficiency scores (truncated regression), when considering revenues from competitive sources including revenues from tuition fees

Variables	Common frontier			Country frontier		
	Bias-adjusted coefficients	95% bootstrap confidence intervals		Bias-adjusted coefficients	95% bootstrap confidence intervals	
		Low	High		Low	High
$Rev\_NonComp_{i,t}$	0.027***	0.0204	0.0318	0.028***	0.0208	0.0332
$Prof_{i,t}$	−0.022***	−0.0335	−0.0104	−0.021***	−0.0329	−0.0085
$GDP_{n,t}$	−0.143	−0.2871	0.0037	−0.157**	−0.3047	−0.0017
$depart_i$	−0.009*	−0.0223	0.0035	−0.011*	−0.0246	0.0025
med_i	−0.039	−0.1366	0.0617	−0.004	−0.1067	0.1018
$yearfound_i$	0.000	−0.0002	0.0001	0.000	−0.0003	0.0001

*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 1,000 bootstrapping interactions.

Constants are not reported.

Year dummies included in all models.

Results from Model 1 (DEA Model 1. Inputs: expenditure in € and number of academic staff. Outputs: publications and graduates).

Table 8. Determinants of efficiency scores (truncated regression), when considering revenues from competitive sources and revenues from tuition fees separately

Variables	Common frontier			Country frontier		
	Bias-adjusted coefficients	95% bootstrap confidence intervals		Bias-adjusted coefficients	95% bootstrap confidence intervals	
		Low	High		Low	High
$Rev\_NonComp_{i,t}$	0.009***	0.0034	0.0138	0.008***	0.0031	0.0136
$Prof_{i,t}$	−0.008*	−0.0174	0.0010	−0.006*	−0.0156	0.0031
$GDP_{n,t}$	−0.163**	−0.2816	−0.0292	−0.156**	−0.2779	−0.0190
$depart_i$	−0.012**	−0.0232	−0.0002	−0.013**	−0.0246	−0.0008
med_i	-0.050	−0.1287	0.0359	−0.022	−0.1038	0.0620
$yearfound_i$	0.000	−0.0002	0.0001	0.000	−0.0002	0.0001
$Revenues\_Fee_{i,t}$	−0.027***	−0.0339	−0.0179	−0.028**	−0.0359	−0.0189

See Table 7 for footnotes.

can be more attractive because of their lower cost of living, of transport etc., which can be important for the university under various aspects. As a consequence, the end result of a university's location (e.g. in wealthier regions) on the institution's overall efficiency can be either positive or negative.[12] The next variable included is the number of different departments ($depart_i$), which can be a proxy for the university's level of interdisciplinarity or/and its size. Additionally, the variable med_i is a dummy equal to one if an institution has a medical or pharmaceutical school. Finally, the possible impact of the tradition/reputation of a given HEIs on its efficiency is captured by its year of foundation ($yearfound_i$). We can expect older universities to be more efficient, although the relationship can be ambiguous as younger institutions can be more flexible and, as such, more efficient (Van Vught (2008) discusses the potential determinants of HEIs' reputation, and its impact on their performances).

The results of the estimation are presented in Table 7. First, as the dependent variables, we used the unbiased DEA scores obtained from the model, assuming a common frontier. We obtained a positive and statistically significant coefficient on the share of non-competitive funds ($Rev\_NonComp_{i,t}$), which indicates lower efficiency (higher inefficiency) for universities with a larger proportion of revenue from non-competitive resources. The next statistically significant variable is the share of professors among the academic staff ($Prof_{i,t}$) and if it has a negative sign, this means that universities with a higher share of professors are more efficient. The final statistically significant variable is the number of different departments ($depart_i$), which shows that HEIs with a higher number of different departments have lower DEA scores (which means that they are more efficient), indicating that there are economies of scope and/or economies of scale. None of the remaining variables ($GDP_{n,t}$, med_i and $yearfound_i$) have a statistically significant impact on the efficiency of universities. We then repeated the same exercise for the DEA scores obtained assuming a country-specific frontier (right panel of Tables 7). Most of the results are very similar as far as the sign and magnitude of coefficients are considered. Additionally, the $GDP_{n,t}$ now becomes statistically significant, indicating that the level of development of the given region where the university is located determines its efficiency.

It is also essential to discuss the magnitude of the estimated coefficients, in order to obtain an idea about their economic significance. The coefficient estimate for $Rev\_NonComp_i$, is 0.028, which indicates that a 10% rise in the share of non-competitive resources is associated with an increase in the efficiency score (rise in inefficiency) of 0.28. The interpretation for the share of professors is very similar, but with the opposite sign: a 10% increase in the share of professors among the academic staff lowers the scores by 0.22

points. In light of the fact that the mean DEA score was about 1.3, an increase in the DEA scores of the above points is economically worth noting.

When considering the revenues from competitive sources and tuition fees separately (see Table 8), it seems that universities with a higher proportion of fees are more efficient, and this could depend on the fact that they are more responsive to the students' needs and use their money in a more efficient way (e.g. on teaching services that help to 'produce' more graduates). Thus, the size of the negative effect of other non-competitive grants is substantially reduced.

We checked the robustness of our findings by employing the efficiency scores obtained in different versions of the DEA model (Models 2 and 3). The results are presented in the Appendix (Tables A2 and A3). The only noteworthy differences concern the sign and magnitude of the variable $GDP_{n,t}$ (compare the results in Tables 7, 8, A2 and A3) and the variable $depart_i$, which loses its statistical significance when the efficiency scores from the DEA Model 3 are treated as dependent variables (compare results from Tables 6, 7 and A.4). In the case of GDP per capita, we used NUTS 2 categories that might highlight some important regional differences which could appear at more disaggregated level (e.g. NUTS 3), and may not be seen from a regional perspective. The number of different departments, as stated before, should be treated as very crude proxy of a university's size, as it can also measure economy of scope. Additionally, the variable is time constant, so it neglects the changes in a university's development. Consequently, in both cases, we have not drawn a strong conclusion about the relationship between these variables and the efficiency of an HEI. However, the variable measuring revenue structure (source of the funds), which we are most interested in, withstands DEA model alterations.

5. Conclusions

This study employs DEA to evaluate the relative efficiency of a sample of 54 Italian and 30 Polish public universities for the period 2001–11. The examination was conducted in a two-step analysis. The unbiased DEA efficiency scores were first estimated and then regressed on external variables to quantitatively assess the direction and magnitude of the impact of potential determinants. The different versions of DEA models were estimated according to the output set (number of publications, graduates, students and PhDs awarded) and assumption made with regard to the frontier (common versus country-specific). This part of the analysis showed strong heterogeneity in the efficiency scores within each country, which were more pronounced than the difference in average efficiency scores between the countries. Additionally, it is difficult to determine which country performs better from an efficiency perspective, or give a definitive judgment. For example, Polish universities are more efficient in the models where the number of PhDs awarded is not included among the outputs, while the opposite is true when doctoral-level education is taken into consideration. However, the results are not substantially different in the cases where a common efficiency or a country-specific frontier is assumed.

The changes in TFP were then assessed, on the basis of an unbiased MI and are decomposed into pure efficiency change and frontier shift. On average, inefficiency decreased over time for both countries, irrespective of the specific model considered. However, in the case of Italian institutions, improvement in productivity is completely driven by technological change, while the opposite was confirmed for the Polish universities, where the indices for technology change and efficiency improvement are 1.030 and 1.050, respectively.

Finally, we carried out the second step analysis, in which we treated the (previously estimated) efficiency scores as dependent variables in the regression equation. Since the scores are not observable, but have been estimated previously and are censored at one, in order to ensure the statistical accuracy of the analysis, we employed a bootstrap truncated regression method based on the procedure of Simar and Wilson (2007). The results of this part indicate: first, higher efficiency in universities where a greater proportion of revenue comes from competitive resources (where competitive resources are defined as those received through the process of open competitions (e.g. research grants from research agencies). Second, the proportion of funding from students' tuition fees is positively associated with the university's efficiency. Third, there is evidence that a higher number of professors among academic staff improves efficiency. Finally, neither a dummy variable for a medical school nor the year of foundation of given institution have a robust statistically significant impact on its efficiency.

Due to the appropriate methodology and a rich micro-data panel, we are able to provide new insights into the activity of HEIs from two countries with a sizable HE sector, and draw some robust conclusions. More specifically, this study has a number of policy-related implications, some of which refer to both countries and some of which stem from their comparison and apply to a specific case. In suggesting these policies or recommendations, we are aware that our work is not exempt from assumptions and approximations, so they must be taken as suggestions rather than prescriptions, and their application should be guided by prudence. Indeed, the implications we can draw are intended to maximise the productivity of universities operating in their present conditions, and applying our general deductions without due care could lead to unintended consequences.

When considering a common efficiency frontier, it emerged that there are high-performing universities in both countries, and these institutions are comparable in terms of absolute and relative performance. It therefore seems that structural, country-level factors are less important in affecting performance than the individual university's actions and activities. This result is important, as it opens the doors to potential recommendations at a European level, with suggestions about policies that can be applied to universities in different countries.

At this stage, a positive productivity upheaval caused by the introduction of a Bachelor/Master structure (the Bologna Process) seems to have taken place in Italy, but much less so in Poland (see the frontier shift in Table 6), despite the overall number of graduates increasing in both countries (in Poland, this has been accompanied by a significant increase in the number of students). One potential explanation is the timing of the implementation, which occurred sooner in Italy. Future analyses may show if the effects will be equally strong in Poland over the coming years, or if this country's HE system has 'absorbed' the reform without any substantial structural productivity gains.

Polish universities should rethink the structure and results of their PhD education. Our results show that, when including variables about PhDs into efficiency analyses, the relative efficiency of Polish institutions declines substantially. In other words, while they provide higher value-for-money undergraduate and graduate education compared to Italy, they still suffer from efficiency problems in the PhD segment, and effort in terms of policies should be spent in increasing graduation rates at this level. The objective is challenging: the number of Polish PhD degrees (average per institution) today is 50% of the PhD degrees awarded by Italian universities.

Italian universities should revise the way in which they employ their own resources. Despite having less academic staff than their

Polish counterparts, they spend more per unit on salaries and on other activities without achieving better results in terms of graduation rates and publications. In order to become as productive as Polish universities, Italian universities should increase their graduation rates (reducing the number of students dropping out) and offer incentives to their faculty to increase their publication and research-related activities. In this perspective, the efficiency challenge consists in understanding which managerial practices help Polish universities to 'produce' relatively more graduates from less. Comparing several good practices in the two countries, in a benchmarking spirit, can be a beneficial exercise for future research.

There are also two additional areas that could be explored to further expand this line of research. On one side, adding more countries into the sample would allow us to calculate the efficiency scores for more universities in different settings, following the ideas of giving value to the new developed datasets of micro-data about single universities (e.g. the European Higher Education Register (ETER)). On the other side, new (parametric) frontier methods can be applied to estimate the efficiency of universities, also exploring the observed and unobserved heterogeneity across institutions, for instance, applying the models proposed by Greene (2005) or conditional efficiency measures (Daraio and Simar 2014). In this way, it could be possible to compare how efficiency scores vary when formulating different assumptions about the HE production process. This type of comparison is especially useful if these are potentially considered for policy purposes, such as formula-funding allocations—in such cases the analysts should provide evidence about the robustness of the scores obtained through different methods.

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Notes

1. Originally, two projects (called AQUAMETH and EUMIDA) were funded by the European Commission to collect data about teaching and research in universities on a periodical basis (Bonaccorsi and Daraio 2007; Bonaccorsi 2014). Both projects had major limitations: it was not possible to ensure that the micro-data were fully comparable, the group of countries studied was not consistent over time, the panel data did not cover all years from the start of the projects etc. Overall, updating the international dataset proved to be very expensive and time consuming. Several interesting academic studies have used the data from these projects to describe the European HE landscape (Bonaccorsi and Daraio 2009; Daraio et al. 2011). There is hope that limitations of the previous data collections will be overcome by the newly established initiative European Higher Education Register (see <http://eter.joanneum.at/imdas-eter/> accessed 8 Mar 2015. Although ETER contains information about Italian and Polish HEIs at the institutional level, at the moment the data only refers to one academic year (2011/12) and thus could not be used in our analysis.
2. Country-specific studies are more common (for some early reviews, see Worthington 2001 and Johnes 2004) but, since our paper concentrates on international and inter-temporal analyses, we will not refer to them directly.
3. In some countries (but neither in Italy nor in Poland) there is a binary HE system, with institutions divided into those concentrating on general education and research (the university sector) and others on vocational education, where research is only marginal (e.g. the German or Austrian *Fachhohschulen*).
4. This expansion in HE did not benefit all kinds of students in the same way, as those from disadvantaged socio-economic backgrounds are still under-represented among first-year university students and, even more so, among graduates (Bratti et al. 2008; Triventi and Trivellato 2009). However, this paper does not address this equality problem directly.
5. Efficiency scores are parameterised to be equal or greater than one, ensuring that bias-corrected distance function estimates will not be negative, something that can occur whenever the estimated bias is larger than the distance function estimate (Simar and Wilson 2008).
6. The exact steps to obtain unbiased efficiency scores and confidence intervals can be found in Simar and Wilson (2000: 788–91). In our analysis, all computations have been performed using the FEAR software (Wilson 2008).
7. The bootstrap truncated regression procedure involves using the maximum likelihood to estimates of unbiased DEA efficiency scores in order to obtain the β coefficients from Equation (5). The original coefficients are compared with bootstrap parameters (estimated empirically by resampling the original data series) to compute bias-corrected estimates of β and percentile bootstrap confidence intervals at a given level of significance. We employ Algorithm 2 from Simar and Wilson (2007: 42–3). The procedure is meant to yield a valid inference in the second-stage regression. However, it relies on a separability condition assuming that the external factors may only influence the distribution of the inefficiency scores, but they have no influence on the efficient frontier. In relation to this, some models have recently been introduced (e.g. based on the conditional efficiency measures (Badin et al. 2014, 2012; Daraio and Simar 2014)). We wish to thank an anonymous referee for pointing this out.
8. However, it has to be underlined that in order to interpret Malmquist indices as TFP indices, we have to base the efficiency measures on a comparison between the observations and the corresponding optimal scale points (assuming constant returns to scale [CRS]) (Førsund and Kalgahen 1999).
9. In recent years, there has also been a growing interest in the third mission of universities. There is still, however, no agreement about the appropriate indicators with which it can be measured and, to the best of our knowledge, the only study that tries to incorporate this type of indicators into efficiency analyses is that of Johnes et al. (2008). Additionally, we have to acknowledge that there are some limitations in the analysis, due to the lack of control for the subject mix or disciplinary specialisation of a given HEI. Unfortunately, data on students/graduates divided by study area (e.g. by different departments) is not available for both countries in our sample. We thank an anonymous referee for pointing this out.

10. We included all publications (articles, proceedings papers, editorial material, book chapters, book reviews etc.) listed in WoS core collections: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Conference Proceedings Citation Index–Science, Conference Proceedings Citation Index–Social Science & Humanities, Book Citation Index–Science, Book Citation Index–Social Sciences & Humanities, Current Chemical Reactions and Index Chemicus, with at least one author declared to be an affiliate of the HEI under consideration. This approach does not discriminate between the quality of different publications and WoS can be biased towards articles written in English and specific subjects. We wish to thank an anonymous referee for pointing this out.
11. Annual National Accounts, Regional gross domestic product (PPS per inhabitant) by NUTS 2 regions (tgs00005).
12. We thank an anonymous referee for pointing this out.

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Appendix

Table A.1. Pairwise correlations between Malmquist indices based on different DEA models (Pearson coefficients)

	Malmquist indices						Malmquist unbiased indices					
	Common frontier			Country frontier			Common frontier			Country frontier		
Model	1	2	3	4	5	6	1	2	3	4	5	6
1	1											
2	0.65	1										
3	0.31	0.48	1									
4	0.98	0.66	0.31	1								
5	0.64	0.99	0.47	0.66	1							
6	0.25	0.41	0.96	0.26	0.42	1						
1	0.99	0.66	0.31	0.97	0.65	0.24	1					
2	0.65	0.99	0.46	0.65	0.98	0.4	0.66	1				
3	0.36	0.48	0.99	0.36	0.47	0.95	0.35	0.47	1			
4	0.98	0.66	0.32	0.99	0.67	0.26	0.98	0.67	0.36	1		
5	0.64	0.98	0.46	0.66	0.99	0.41	0.65	0.99	0.46	0.67	1	
6	0.25	0.42	0.96	0.26	0.43	1	0.25	0.41	0.96	0.27	0.41	1

Malmquist unbiased indices are obtained by bootstrap methods following Simar and Wilson (1999).

All Pearson coefficients are significant at 1% level.

Table A.2. Determinants of efficiency scores (truncated regression), when considering revenues from competitive sources including revenues from tuition fees, efficiency scores from DEA Model 2

Variables	Common frontier			Country frontier		
	Bias-adjusted coefficients	95% bootstrap confidence intervals		Bias-adjusted coefficients	95% bootstrap confidence intervals	
		Low	High		Low	High
$Rev\_NonComp_{i,t}$	0.014***	0.0086	0.0181	0.017***	0.0113	0.0218
$Prof_{i,t}$	−0.008*	−0.0175	0.0023	−0.004	−0.0143	0.0063
$GDP_{n,t}$	0.227**	0.0854	0.3518	0.250***	0.1001	0.3843
$depart_i$	−0.030***	−0.0424	−0.0159	−0.035***	−0.0486	−0.0195
med_i	−0.182***	−0.2660	−0.0880	−0.171***	−0.2584	−0.0760
$yearfound_i$	0.000	−0.0003	0.0001	0.000	−0.0003	0.0000

*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 1,000 bootstrapping interactions.

Constants are not reported.

Year dummies included in all models.

Results from Model 2 (DEA Model 2 Inputs: expenditure in € and number of academic staff. Outputs: publications and students).

Table A.3. Determinants of efficiency scores (truncated regression), when considering revenues from competitive sources and revenues from tuition fees separately, efficiency scores from DEA Model 2

Variables	Common frontier			Country frontier		
	Bias-adjusted coefficients	95% bootstrap confidence intervals		Bias-adjusted coefficients	95% bootstrap confidence intervals	
		Low	High		Low	High
$Rev\_NonComp_{i,t}$	−0.002	−0.0065	0.0042	0.001	−0.0043	0.0076
$Prof_{i,t}$	0.001	−0.0081	0.0100	0.005	−0.0052	0.0139
$GDP_{n,t}$	0.228***	0.0887	0.3562	0.264***	0.1139	0.4026
$depart_i$	−0.033***	−0.0454	−0.0193	−0.038***	−0.0509	−0.0221
med_i	−0.183***	−0.2583	−0.0912	−0.174***	−0.2506	−0.0794
$yearfound_i$	0.000	−0.0003	0.0000	0.000	−0.0003	0.0000
$Revenues\_Fee_{i,t}$	r.025***	−0.0331	−0.0154	−0.026***	−0.0348	−0.0154

*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 1,000 bootstrapping interactions.

Constants are not reported.

Year dummies included in all models.

Results from Model 2 (DEA Model 2. Inputs: expenditure in € and number of academic staff. Outputs: publications and students).

Table A.4 Determinants of efficiency scores (truncated regression), when considering revenues from competitive sources including revenues from tuition fees, efficiency scores from DEA Model 3

Variables	Common frontier			Country frontier		
	Bias-adjusted coefficients	95% bootstrap confidence intervals		Bias-adjusted coefficients	95% bootstrap confidence intervals	
		Low	High		Low	High
$Rev\_NonComp_{i,t}$	0.021***	0.013	0.028	0.021***	0.0120	0.0296
$Prof_{i,t}$	−0.043***	−0.059	−0.025	−0.050***	−0.0677	−0.0283
$GDP_{n,t}$	0.088	−0.121	0.273	0.081	−0.1536	0.2877
$depart_i$	0.004	−0.014	0.020	0.002	−0.0181	0.0203
med_i	0.011	−0.124	0.154	0.035	−0.1166	0.1992
$yearfound_i$	0.000	0.000	0.000	0.000	−0.0002	0.0004

*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 1,000 bootstrapping interactions.

Constants are not reported.

Year dummies included in all models.

Results from Model 3 (DEA Model 3. Inputs: expenditure in € and number of academic staff. Outputs: publications, graduates and PhD degrees awarded).

Table A.5. Determinants of efficiency scores (truncated regression), when considering revenues from competitive sources and revenues from tuition fees separately, efficiency scores from DEA Model 3

Variables	Common frontier			Country frontier		
	Bias-adjusted coefficients	95% bootstrap confidence intervals		Bias-adjusted coefficients	95% bootstrap confidence intervals	
		Low	High		Low	High
$Rev\_NonComp_{i,t}$	0.000	−0.0054	0.0062	0.000	−0.0059	0.0060
$Prof_{i,t}$	−0.020***	−0.0303	−0.0077	−0.022***	−0.0333	−0.0092
$GDP_{n,t}$	0.043	−0.1059	0.1897	0.041	−0.1123	0.1952
$depart_i$	−0.001	−0.0144	0.0111	0.003	−0.0165	0.0105
med_i	−0.003	−0.0954	0.0950	0.007	−0.0912	0.1102
$yearfound_i$	0.000	0.0000	0.0003	0.000	−0.0001	0.0003
$Revenues\_Fee_{i,t}$	−0.029***	−0.0375	−0.0185	−0.029***	−0.0378	−0.0177

*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 1,000 bootstrapping interactions.

Constants are not reported.

Year dummies included in all models.

Results from Model 3 (DEA Model 3. Inputs: expenditure in € and number of academic staff. Outputs: publications, graduates, and PhD degrees awarded).