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Evaluating the efficiency of Italian public universities (2008–2011) in presence of (unobserved) heterogeneity

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ABSTRACT

In assessing the performance of universities, the most recent literature underlined that the efficiency scores may suffer from the presence of incidental parameters or time-invariant, often unobservable, effects that lead to biased efficiency estimates. To deal with this problem, we apply a procedure developed by [67]; for estimating the efficiency in Italian higher education through a multi-output parametric distance function. We show that models which do not consider unobservable heterogeneity tend to estimate divergent efficiency scores. We also study the determinants of efficiency; the findings provide a clue towards the expansion of pro-competitive policies in the Italian higher education sector, consistently with the interpretation that when market forces operate, there are benefits for university efficiency. When exploring differences in the performance of universities, by geographical areas, we claim that maintaining State-level policies can be detrimental for overall efficiency, and instead special interventions for universities in the South should be designed.

1. Motivation and objectives

The analysis of university costs is at the heart of institutional and academic debates since when [29] identified these organizations as multi-output, thus posing the challenge of measuring their scale and scope effects. Following this seminal study, several papers attempted at measuring the productivity of Higher Education Institutions (HEIs) – defined as the ratio between costs and output – in the USA (see, for instance [16,30], and Europe (especially in UK, see Refs. [37,42,64]. As widely discussed by Refs. [46]; the problem of assessing economic performances of HEIs is also exacerbated by inefficiency in production; then, when modeling production and cost functions, it must be kept in mind that HEIs are likely to produce using their inputs in a suboptimal way.

The statistical approach for incorporating inefficiency into the estimation of production is the method named Stochastic Frontier Analysis (SFA), proposed by Refs. [13,56]. SFA has been extensively applied in the literature for measuring efficiency in the higher education environment. Operationally, the method assumes that the error term is composed of two components with different distributions: the first component, regarding the "inefficiency", is asymmetrically distributed (typically as a semi-normal), while the second component, concerning the "error", is distributed as white noise. On methodological grounds, the most recent literature, which deals with panel data, emphasized the importance of separating inefficiency and fixed individual effects. As [67] have underlined: "(…) *stochastic frontier models do not distinguish between unobserved individual heterogeneity and inefficiency", forcing "all time-invariant individual heterogeneity into the estimated inefficiency*". For instance, in the field of higher education, (average) innate ability of students or researchers may be an important determinant of their individual academic achievement and thus account for an important share of the heterogeneity in data, when evaluating the efficiency of the institution in which they are studying or working.

In the context of the use of efficiency models for policy-making, or managerial considerations, the problem of separating the three elements: (i) unobserved structural differences in underlying inputs, (ii) inefficiency and (iii) heterogeneous production processes is of crucial importance. Indeed, the lack of judgment about the

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various parts would lead to a misleading evaluation of estimated inefficiency[1]. An approach to this end is promoted by Ref. [67] who show, in the context of panel data, that first-difference and within transformation can be analytically performed to remove the fixed individual effects, and thus the estimator (of efficiency) is immune to the incidental parameters problem. In other words, after transforming the model, the fixed effects are removed before the estimation.

This paper main objective is to apply the procedure developed by Ref. [67] for estimating the efficiency of Italian HEIs through a multi-output, parametric distance function, using data over the four-years 2008–2011; this way, the estimated efficiency is net of the influence of unobserved heterogeneity. To the best of authors knowledge, this is the first paper that attempts at separating inefficiency from heterogeneity when assessing the performances of Italian universities, with the only notable exception of [10]; who however used the [38] method for this purpose.

This paper is innovative because of two other reasons. Firstly, it tests the effects of assuming different functional forms of university production functions. While the theoretical problem of identifying the "correct" functional form of HEIs' production processes is discussed in the literature (see, for instance [28,43], the empirical tests about how different forms affect estimations are quite sparse. The topic itself is important in a managerial perspective; indeed, it is important to check whether the judgment about efficiency is affected by the assumptions behind the production process or not. In this paper, we conduct such tests systematically: we start the empirical analysis assuming a translog functional form for the output distance function, with and without input-output separability property. Furthermore, we also consider a Cobb-Douglas formulation (see Section 2 for a discussion of the different assumptions concerning the production process). To anticipate the findings, the functional form chosen seems to have a minor impact on main estimates, therefore we consider them empirically robust. Secondly, this paper directly investigates whether the efficiency of universities is influenced by some characteristics of the market structure in which they operate. More specifically, we look at the effect of variables like an indicator of market share (MK), the level of fees (FPS), and wealth – as measured through added value per capita (AV) - in the areas (Regions) where universities operate. This policy-oriented analysis is particularly relevant given that since the 1990s the Italian university system has been characterized by policy interventions that stimulate competition between universities [5].[2]

The paper is organized as follows. In the Section 2, we present the methodological approach; Section 3 illustrates the data, production set and model specification for the empirical analysis; Section 4 contains the main results. Finally, Section 5 discusses the managerial and policy implications of the main findings, together with concluding remarks.

2. Empirical methodology

The presence of a multidimensional nature of the production (i.e. multiple outputs and multiple inputs) may represent a problem when estimating stochastic production models. To solve this issue, a distance function approach has been considered [27,53]. Moreover, this technique is particularly useful when no price information regarding inputs and outputs is available [26]. Specifically, and following [1] and [48]; we choose to model the production set through an output distance function in a panel context.

Furthermore, as already mentioned before, we are aware that the estimates of the frontier and then, consequently, the efficiency scores suffer by the presence of incidental parameters or time-invariant effects that may distort the estimates. In order to deal with this problem and to estimate the technical efficiency, we apply a procedure developed by Refs. [67]; according to whom after transforming the model by either first-difference or within-transformation, the fixed effects are removed before estimation. More specifically, we impose on the data a within transformation. As [67] specified, "*by within-transformation, the sample mean of each panel is subtracted from every observation in the panel. The transformation thus removes the time-invariant individual effect from the model*". Following the notation in Refs. [67]; the transformation employed in our model is (being$w$, for instance, any input or output to be transformed):

$$w_{i.} = (1/T)\sum_{t=1}^{T} w_{it},\ w_{it.} = w_{it} - w_{i.} \tag{1}$$

The stacked vector of $w_{it.}$ for a given i is:

$$\tilde{w}_{i.} = (w_{i1.}, w_{i2.}, \ldots, w_{iT.})' \tag{2}$$

For simplicity, hereafter in our formulation does not include a subscript t.[3] The baseline model associated to distance function after the transformation can be written as:

$$f(\tilde{y}_{i.}) = f(\tilde{x}_{1.}, \ldots \tilde{x}_{n.}) + \tilde{\varepsilon}_{i.} \tag{3}$$

where $\tilde{y}$ represents the conventional outputs, $\tilde{x}$ denotes the conventional inputs and $\tilde{\varepsilon}$ denotes the disturbance term.

With stochastic frontier analysis, a frontier is estimated on the relation between inputs and outputs. This can be, for example, a linear function, a quadratic function or a translog function. This paper uses both translog and a Cobb-Douglas function. However, there is no general consensus about which one has to be adopted in the higher education environment (for a discussion on the different function forms, see Refs. [28] and [9]. Firstly, concerning the structure of production possibilities, a more general functional form, that is, the transcendental logarithmic, or "translog", could be considered for the frontier production function. The translog functional form may be preferred to the Cobb–Douglas form because of the latter restrictive elasticity of substitution and scale properties, and it allows for non-linear causalities, compared with the more simple Cobb-Douglas function (see Refs. [11]; who use a translog function in order to compare the efficiency of public universities among European countries). On the other hand, the assumptions behind the use of Cobb–Douglas production function are also plausible in view of the theoretical model which describes the human capital formation in the university system. It allows overcoming the multicollinearity problem associated to the estimation of a few number of parameters with respect to the translog function; therefore it is less susceptible to multicollinearity and degrees of freedom problems than the translog function (see Refs. [52]; who uses a Cobb-Douglas function in order to model exogenous variables in human

[1] Such a topic has been systematically investigated by Refs. [38]; who examined different ways to incorporate heterogeneity; his findings demonstrate that different models produce very different results. In particular, he analyses several extensions of the stochastic frontier that account for unmeasured heterogeneity as well as firm inefficiency (an application of these methods when analyzing the efficiency of universities is in Refs. [45]; and [10].

[2] See Refs. [5,20,60] and [23] for a brief review of the university system in Italy.

[3] Even though the formulation does not include a subscript *t*, the inefficiency component is time varying in order to examine how the (in)efficiency changes over time.

capital formation).[4]

Following common practice, we now assume a translog functional form for the output distance function:

$$lnD^{o}_{i.} = \sum_{m=1}^{M}\tilde{\alpha}_m ln\tilde{y}_{mi.} + \sum_{k=1}^{K}\tilde{\beta}_k ln\tilde{x}_{ki.} + \frac{1}{2}\left[\sum_{m=1}^{M}\sum_{n=1}^{N}\tilde{\alpha}_{mn} ln\tilde{y}_{mi.} ln\tilde{y}_{ni.} + \sum_{k=1}^{K}\sum_{j=1}^{L}\tilde{\beta}_{kl} ln\tilde{x}_{ki.} ln\tilde{x}_{li.}\right] + \sum_{k=1}^{K}\sum_{m=1}^{M}\tilde{\delta}_{km} ln\tilde{x}_{ki.} ln\tilde{y}_{mi.} \tag{4}$$

By within transformation, α_i (intercept that changes over time according to a linear trend with unit-specific time-variation coefficients and that represents time-invariant effects) disappears from our specification. In addition, time dummies are also included in the model in order to capture exogenous factors that might affect the production set. Normalizing by $\tilde{y}_i$,[5] that guarantees the linear homogeneity of degree 1 in outputs[6] ($\sum_{m=1}^{M}\tilde{\alpha}_m = 1$) as suggested by Refs. [53]; and imposing the linear ($\sum_{m=1}^{M}\tilde{\alpha}_{mn} = 0$ and $\sum_{m=1}^{M}\tilde{\delta}_{km} = 0$) and suitable symmetry restrictions ($\tilde{\alpha}_{mn} = \tilde{\alpha}_{nm}$ and $\tilde{\beta}_{kl} = \tilde{\beta}_{lk}$), the output oriented distance function becomes:

$$ln\left(\frac{\tilde{D}^{o}_{i.}}{\tilde{y}_{i.}}\right) = \sum_{m=1}^{M}\tilde{\alpha}_m ln\tilde{y}^{*}_{mi.} + \sum_{k=1}^{K}\tilde{\beta}_k ln\tilde{x}_{ki.} + 1/2\left[\sum_{m=1}^{M} \times \sum_{n=1}^{N}\tilde{\alpha}_{mn} ln\tilde{y}^{*}_{mi.}\ ln\tilde{y}^{*}_{ni.} + \sum_{k=1}^{K}\sum_{j=1}^{L}\tilde{\beta}_{kl} ln\tilde{x}_{ki.} ln\tilde{x}_{li.}\right] + \sum_{k=1}^{K} \times \sum_{m=1}^{M}\tilde{\delta}_{km} ln\tilde{x}_{ki.} ln\tilde{y}^{*}_{mi.} \tag{5}$$

where $\tilde{y}^{*}_{mi.} = \tilde{y}_{mi.}/\tilde{y}_{i.}$, $\tilde{y}^{*}_{ni.} = \tilde{y}_{ni.}/\tilde{y}_{i.}$ and thus $\tilde{y}_i = 1$. In addition, the time dummies are also taken into account in order to capture the technology change that can influence the production process of the decision-making units (i.e. universities). It's obvious that $ln(\tilde{D}^{o}_{i.})$ is not observable. Then, in order to solve this problem, we can rewrite $ln(\tilde{D}^{o}_{i.}/\tilde{y}_{i.}) = ln(\tilde{D}^{o}_{i.}) - ln(\tilde{y}_{i.})$. Thus, we transfer $ln(\tilde{D}^{o}_{i.})$ to the residuals, i.e. on the right and side of the equation (5), and $-ln(\tilde{y}_{i.})$ as dependent variable [27]. In our case, we follow [59]; i.e. imposing $ln(\tilde{y}_i)$. The equation (5) thus becomes:

$$ln(\tilde{y}_{i.}) = \sum_{m=1}^{M}\tilde{\alpha}_m \ln\tilde{y}^{*}_{mi.} + \sum_{k=1}^{K}\tilde{\beta}_k ln\tilde{x}_{ki.} + 1/2\left[\sum_{m=1}^{M} \times \sum_{n=1}^{N}\tilde{\alpha}_{mn} \ln\tilde{y}^{*}_{mi.} \ln\tilde{y}^{*}_{ni.} + \sum_{k=1}^{K}\sum_{j=1}^{L}\tilde{\beta}_{kl} ln\tilde{x}_{ki.} ln\tilde{x}_{li.}\right] + \sum_{k=1}^{K} \times \sum_{m=1}^{M}\tilde{\delta}_{km} ln\tilde{x}_{ki.} \ln\tilde{y}^{*}_{mi.} + \tilde{\nu}_i - \tilde{u}_i \tag{6}$$

where $\tilde{\nu}$ is the vector of random variables assumed to be i.i.d. $N(0,\ \sigma^2_{\tilde{\nu}})$ and independent of the $\tilde{u}$ term which stands for inefficiency component. In particular, $\tilde{u}$ is assumed to be heteroscedastic and, in particular, distributed as $\tilde{\sigma}^2_{\tilde{u}} = \exp(\tilde{z}_i; \tilde{\lambda})$ following a half-normal distribution, i.e. $N^{+}(0,1)$, where $\tilde{z}_i$ is a vector of environmental variables employed to explain determinants of inefficiency, and $\tilde{\lambda}$ denotes a vector of unknown coefficients. In this analysis, we do not impose the “scaling property” (for more details see Refs. [68]; in the context of cross-sectional data, and [15]; in the panel data context); indeed, as underlined by Refs. [67]; “*whether the scaling property holds in the data is ultimately an empirical question*”. In other words, we assume changes not only in scale but also in the shape of the inefficiency distribution. The validity of the heteroscedastic assumption is tested using a LR test which allows us to identify the fit of the model and to confirm the imposition of some explanatory factors in the variance of the inefficiency term. As already said, we estimate the function above described in a panel context, employing within transformation as recently suggested by Ref. [67] in order to eliminate the incidental parameters from our estimation, under the hypothesis of efficiency variability over time. Once singled out the best practice frontier from translog output distance function model, we compute the efficiency scores as deviations from this frontier.

For comparison, we model the last equation with (i) no input-output separability; (ii) input-output separability and (iii) Cobb-Douglas formulation. The rationale for employing three different functional forms relies upon the opportunity of verifying how these affect the efficiency estimates (i.e. whether the assumptions about the specific combination of inputs in producing the outputs influence the efficiency scores).

The coefficients $\tilde{\alpha}$, $\tilde{\beta}$, $\tilde{\delta}$, $\tilde{\lambda}$ and technical efficiency are estimated through a maximum likelihood estimator (MLE) using the STATA 12 software.

3. Data, the production set and model specification

3.1. Data and production set

The dataset refers to Italian public universities from years 2008–2011 and it has been constructed using data which are publicly available on the National Committee for the Evaluation of the University System (CNVSU) website.[7] We exclude all private sector universities, owing to the absence of comparable data on academic research variables; this leaves us with a sample of 53

[4] Moreover, in our case the presence of zero values for any inputs or outputs related to the choice of the functional forms does not represent a problem as we do not have any zero values for inputs and outputs; therefore, when we take the log values of both inputs and outputs, there was no need to omit universities with any zero values, thus without implications for the representativeness of the resulting sample.

[5] Since they are mathematically equivalent, the choice of the normalizing variable is innocuous when using stochastic frontier models (see Ref. [61], p. 16). More importantly, using a similar empirical method to the one we have used in the paper, such as a stochastic output distance frontier, Abbott and Doucouliagos [2] outlined that “*It is necessary to impose a number of constraints on the output distance function in order to ensure homogeneity of degree one in outputs, as well as symmetry* (see [57])*. This can be achieved by choosing arbitrarily one of the outputs as the normalizing variable; in this paper, research performance is used to serve this role*”. Therefore, following Abbott and Doucouliagos [2], we decide to normalize by research grants. However, for robustness, we also conduct a sensitivity analysis normalizing by the number of graduates weighted by their degree classification. Results (available on request) are similar.

[6] Generally, linear homogeneity of degree 1 in outputs also implies that the sum of alphas is equal to zero and the sum of deltas is null.

[7] Data were obtained, not without some difficulties in the collection derived from the absence of a single database and the non-comparability of certain data. Unfortunately a longer period of data was not available to us. A drawback is represented by the fact that the years included in the analysis are recession years, whose consequence could affect university output in terms of, for example, research grants funded by private firms in the South of Italy.

universities[8], each of which yields data over the four year period, so we have a total of 212 observations.

Referring to the literature on this subject, the production technology is specified, with two inputs: 1 – number of academic and non-academic staff; 2 - total number of students weighted by the quality of freshmen. More specifically, the first input is what we call the equivalent personnel (EQUIV_PERS), namely the total number of academic staff and non-academic staff[9]; it is a measure of a human capital input and it aims to capture the human resources used by the universities for teaching activities[10] (see Refs. [7,48]. The second input is the total number of students weighted by the percentage of enrolments with a score higher than 9/10 in secondary school (STU_{WEIGH})[11]. The total number of students measures the quantity of undergraduates in each university. Moreover, among the inputs that are commonly known to have effects on students' performances there is the quality of the students on arrival at university; indeed, there is strong evidence that pre-university academic achievement is an important determinant of the students' performances [17,21,51,63]. The underlying theory is that ability of students lowers their educational costs and increases their motivation [32]. To take this into account, we weight the number of students by a proxy of the knowledge and skills of students when entering tertiary education. Thus, this input aims to capture both the quantity and the quality of students.[12]

Two measures of outputs are included in the model reflecting the teaching and research functions of HEIs[13]: 1 – number of graduates; 2 – research grants. The first output is the number of graduates weighted by their degree classification ($GRAD_{MARKS}$), in order to capture the quantity and the quality of teaching and to treat in the same way quantity and quality in both the student input and output[14] (see Refs. [47,54,69]. The second output is a measure of research performances of the universities. Academic research is the most controversial output and different proxies have been used in the literature such as bibliometric indicators, peer review [30] and weighted indexes of publications [18,39,44,49,66]. Information on the number of publications is not available to us, thus we use research grants (RES) as a second output and as a proxy of research outputs (see Refs. [1,8,10,12,50,69]. According to [10]; *"Grants represent a measure of the market value of research done, and so provides a neat conflation of the quantity and quality of research effort. They also provide a measure of research output that is less retrospective than bibliometric analyses"*. Research grants reflect the market value of the research conducted and can, therefore, be considered as a proxy for output [25,65]. Specifically, in our case, it represents the amount that the government is willing to pay the universities for the research they produce. We are aware that the use of grant income might raise some problems related to the presence of a lag between the publication of research output and the generation of that research; however, according to [40] this is more important when using citation counts or number of patents than research income measure. Moreover, according to [48]; the use of research grants as an output *"is also an attractive measure of research in that it provides an up-to-date picture of research activity and output in the current academic year"*.[15] Thus, also considering that there are no clear criteria for deciding on the appropriate length of lag [34] [16]) and following [48] we use a static model in our analysis. For better appreciating the role of the variable RES, it is useful to give some details about the kind of grants that are included in the indicator. In our definition, we have the sum of research grants provided by the Italian Ministry of Education (MIUR) for basic research (the so called PRIN projects) and the other amounts provided by MIUR and other Ministries for basic and applied research. The criteria for allocating the grants is based on the quality of research proposals, and on the track record of past results obtained by research groups' proponents. In this sense, this measure includes both considerations about the current and past levels of research developed by the university, and can be safely included in the static model described above (i.e. research in year t compared with resources in year t). Also, the distribution of

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[8] Which is very representative of the higher education system in Italy, corresponding to almost 90% of the total number of public universities in the country. Confirming the representativeness of the sample used, in the 53 universities included in the empirical analysis are enrolled 88% of the students enrolled in the entire higher public education system in Italy.

[9] We also consider non-academic staff in order to take into account the administrative staff who support the academic staff and the students.

[10] The academic staff has been decomposed into three categories, namely professors, associate professors and researchers. In order to take into account this categorization, we assign weights to each category according to their salary and to the amount of institutional, educational and research duties the academic staff has to deal with [54] and assuming that a professor is expected to produce more teaching work than an associate professors and so on [24]. To the non-academic staff has been assigned the lower weight. Similarly to [39] we use the following aggregate measure of human capital input: Equivalent personnel (EQUIV_PERS) = 1*professors + 0.75*associate professors+0.50* researchers + 0.25* non-academic staff. The weights have been chosen so that the distance between two ranks is 1/4 = 0.25. A potential limitation of this choice is represented by the decision to assign different weights. Therefore, for robustness, we also further test how alternative weights given to this variable would change the results, to avoid a sever discounting of researchers and non-academic staff. We firstly give the same weigh to each category. In other words, we assume that the categories of academic staff contribute in the same way as well as the non-academic staff: Equivalent personnel (EQUIV_PERS _2) = 0.25*professors + 0.25*associate professors + 0.25* researchers + 0.25* non-academic staff. Secondly, we suppose that both professors and associate professors contribute in the same way. Followed by researchers, and then by non-academic staff. Equivalent personnel (EQUIV_PERS _3) = 1*professors + 1*associate professors + 0.75* researchers + 0.50* non-academic staff. In all cases results (available on request) are similar.

[11] A similar measure is also used in Ref. [7]. For robustness, we also weight total number of students by the percentage of enrolments from a Lyceum (i.e. non-vocational secondary school which are more academic oriented and specialized in providing students the skills needed in order to enroll in the university). Results, available on request, are similar.

[12] There are no measures of capital inputs (such as library, computing, buildings) which might have a role in determining university outputs; unfortunately such data are very difficult to obtain for Italy. This is confirmed by a recently published paper by Ref. [31] in which they reviewed the literature regarding the efficiency in education. In describing the inputs in the education production function, only a very small amount of paper included those inputs in the analysis in higher education.

[13] Unfortunately, due to the unavailability of data, we are not able to consider what is known to be the third function of the universities such as knowledge transfer to industry and links of HEIs with industrial and business surroundings.

[14] For the readers who are not familiar with the characteristics of the Italian higher education system, in Italy students can graduate obtaining marks from 66 to 110 with distinction. This grade is calculated mainly according to the average grades students have obtained in the exams; then a certain number of points is added after the final dissertation has been graded. In order to weight the graduates according to their degree marks, we apply the following procedure: $GRAD_{MARKS}$ = 1* graduates with marks between 106 and 110 with distinction + 0.75*graduates with marks between 101 and 105 + 0.5*graduates with marks between 91 and 100 + 0.25*graduates with marks between 66 and 90. The weights have been chosen so that the distance between two ranks is 1/4 = 0.25. For robustness, we also further test how alternative weights given to the $GRAD_{MARKS}$ variable, to avoid a severe discounting of the students earning less than top marks, would change the results as follows: $GRAD_{MARKS}\_2$ = 1*graduates with marks between 106 and 110 with distinction + 0.75*graduates with marks between 101 and 105 + 0.5*graduates with marks between 91 and 100 + 0.50*graduates with marks between 66 and 90. We've also used just the number of graduates without weighting by their degree classification. In all cases results (available on request) are similar.

[15] See also [35] for a discussion on the appropriate measures of research quality and quantity.

[16] One study, which develops a dynamic DEA model to capture the inter-temporal aspect, compares the results of the dynamic model with those derived from a static (or conventional) DEA model in the context of higher education, and finds considerable overall agreement between the efficiencies produced from the two approaches [34].

Table 1
Definition of the variables and descriptive statistics – Mean values by geographical areas.

		Mean values											
		North-Western			North-Eastern			Central			Southern		
		Mean (Std. Dev.)	Min	Max	Mean (Std. Dev.)	Min	Max	Mean (Std. Dev.)	Min	Max	Mean (Std. Dev.)	Min	Max
Inputs													
EQUIV_PERS	Weighted# of academic staff and non-academic staff	990.30 (615.89)	282.25	2262.25	1024.80 (805.12)	193.75	3060.25	1313.73 (1102.04)	286.25	4584.75	815.72 (710.31)	170.75	3235.5
STU_{WEIGH}	Total number of students weighted by the % of enrolments with a score higher than 9/10 in secondary school	5533.65 (3599.59)	943.92	14332.16	6051.28 (5519.36)	876.58	22575	8378.39 (7202.91)	116.19	31375.37	6813.13 (6282.04)	1086.07	29087.96
Output													
$GRAD_{MARKS}$	# of graduates weighted by their degree classification	3082.15 (1951.83)	826.4	6886.2	3241.96 (2649.28)	985	9854	4318.984 (3575.83)	867.2	14570.6	2435.7 (1962.20)	434	7851
RES	Research grants	1.17e+07 (7729784)	864088	3.02e+07	1.09e+07 (9783430)	953414	4.41e+07	1.25e+07 (9960390)	910829	4.26e+07	5808383 (5449196)	539808	2.86e+07
Explaining the inefficiency													
MK	Market share	0.27 (0.29)	0.046	1	0.30 (0.20)	0.054	0.59	0.40 (0.34)	0.04	1	0.36 (0.28)	0.034	1
AV	Value added	28.62 (2.43)	24.05	30.76	27.30 (1.04)	25.39	29.44	25.40 (1.76)	20.93	27.30	15.83 (1.57)	14.53	19.79
FPS	Fees per student	1157.13 (248.55)	812.13	1666.95	1202.83 (224.98)	845.99	1680.64	843.95 (205.94)	378.41	1417.49	588.47 (130.36)	256.47	896.42
Obs.		44			40			40			88		

Note: Authors calculation on data collected by the Italian Ministry of Education, Universities and Research Statistical Office.

research funds obtained in the different years allows considering the multi-year nature of research activities at institution level, in which different research groups obtain grants in different years. It is important to recall that our measure does not represent the final research's final output anyway, as it would be better represented by the final step of activities conducted, such as the academic publications, reports, patents, etc. – in this perspective, grants are much more surely an output, but an intermediate one.

We also include time trends in the output function in order to provide a measure of technology change.

When looking at the descriptive statistics (Table 1), it is interesting to notice that, considering the four geographical areas in which we have aggregated the universities and taking into account the inputs, the Southern area shows the lowest weighted number of academic and non-academic staff while the Central area shows the highest number of students weighted by the percentage of enrolments with a score higher than 9/10 in secondary school. Considering the performances (output side) by geographical areas, again the North-Central areas outperform the Southern area both considering the number of graduates weighted by their degree marks and the grants received for the research activities.

3.2. Explaining (in)efficiency: the role of market competition

It seems inadequate to assume that the variability of the efficiency behaviour is the same for each university. Therefore, given that several exogenous variables are available, the use of a heteroscedastic stochastic frontier model is particularly suitable for our analysis, to adequately measure the effects of exogenous characteristics on university inefficiency. Specifically, the market structure of the HEIs could play an important role in calculating the efficiency; indeed, as suggested by Refs. [5]; "*theoretical predictions in the economics of education are that a major increase in competition in the higher education sector must lead to greater efficiency, both from an allocative point of view (the choice of students will be more coherent with their utility function) and from a productive one (universities will obtain better performance without increasing costs, by managing more efficiently their resources)*" even though there are not many empirical studies testing the effects of competition in tertiary education and most of them regard the US context (see for instance [14,22,33,41]. It is also true that the character of competition among higher education institutions is complex to be analysed even though there are increasing calls for deregulating universities so that they can better compete in the global market for higher education. In order to study the determinants of inefficiency, we include in the variance of the inefficiency component the following three explanatory variables: *market share* (MK) measured as the ratio between the number of enrolments at university *i* and the total number of enrolments in the universities located in the same region, included for capturing the potential effects due to the presence of more concentration or competition between universities; *added value* per capita (AV) corresponding to the difference between the production value of goods and services created by individual productive branches and the value of the intermediate goods and services consumed by them, with the aim of controlling for the growth of the economic system in terms of new goods and services made available to the community for final use[17]; *fees per student* (FPS) calculated as the ratio of the amount of income received by the university from the fees pays by the students over the total number of students, in order to take into account the services offered by the institution (more specifically, it corresponds to the fee income received from undergraduates students).[18]

[17] According to The Italian National Institute of Statistics (ISTAT), this measure is equivalent to the Gross Domestic Product (GDP).

[18] Overseas fees and students fed in the calculation even though the impact is minimun. Indeed, on average among the years considered in our analysis, only around 3% of the students are non-nationals (even fewer are the overseas) and only few of them are enrolled in undergraduates courses; and more importantly with regard to the payment of tuition fees, Legislative Decree no. 286/98, underlines that foreigners are guaranteed equal treatment with Italian citizen. Moreover, many overseas students in Italy are enrolled in the University for Foreigners of Perugia and that of Siena, which are specialized in teaching and diffusion of the Italian language and culture for the non-national students but those two universities are not included in the analysis due to the non-comparability of certain data.

Some additional information is needed to clarify our assumptions at the basis of the use of Market Share (MK) as a proxy for the phenomenon of competition. The existence of competitive behaviours of HEIs in the Italian system has been highlighted by previous academic contributions, as [5] and [62]. An indirect way of describing such competition is by looking at the proportion of non-Italian students/freshmen in the system (3.3% and 4.2% in 2009/10) and by the proportion of freshmen who attend a university which is located in a Region different from their family's house (>20%).[19] Of course, competition among universities does not happen only on a geographical length, as various dimensions are considered by students for making their choices: disciplines, reputations (see, for example, the role of rankings), personal networks, cities' and regions' attractiveness beyond higher education, etc. (for a comprehensive discussion about the determinants of student choices, see for example [36]. In this perspective, the kind of 'competition effect' that we are measuring in the analysis is a partial one, that only refers to the pressures posed by geographical proximity with other institutions – in this case, the regional dimension appears as an adequate one, given that still the majority of students still opt to study within the region (see above). When interpreting the results, however, it must be kept in mind that the effect of competition should be considered comprehensive to the extent that geographical density of institutions is affecting also other factors at university level, which react to competitive pressures.

In our empirical model, specifically, following [61]; we also included time trend (YEAR), in order to capture the inefficiency trend over time. All these factors are modeled as variables, which directly influence the variability of the inefficiency term. In other words, they affect the efficiency with which inputs are converted into outputs. We measure AV at regional level and both FPS and MK at university level. See Table 2 below for a summary of the model implemented in the paper.

Table 2
Specification of inputs, outputs and exogenous factors.

	Model
Inputs	EQUIV_PERS; STU_{WEIGH}
Outputs	$GRAD_{MARKS}$; RES
Explaining the inefficiency	MK; AV; FPS

Notes: EQUIV_PERS: Weighted # of academic staff and non-academic staff; STU_{WEIGH}:: Total number of students weighted by the % of enrolments with a score higher than 9/10 in secondary school; $GRAD_{MARKS}$: # of graduates weighted by their degree classification; RES: Research grants; MK: Market share; AV: Value added; FPS: Fees per student.

4. Results

4.1. Efficiency scores

The estimated parameters of the stochastic education distance frontier, as specified through our baseline model, are presented in the Table 3.[20] From a methodological perspective, the null hypothesis that there is no heteroscedasticity in the error term has been tested and rejected, at 1% significance level, using a Likelihood Ratio Test (LR), giving credit to the use of some exogenous variables, according to which the inefficiency term is allowed to change. In other words, the validity of heteroscedastic assumption has been confirmed, leading to the significance of the inefficiency term. The coefficients show that all the input variables have a positive and statistically significant effect on the various outcomes of the universities; the value of such coefficients are quite stable across all the specifications (translog with and without separability – respectively Table 3, Columns a and b, Cobb-Douglas – Table 3, Column c) and their statistical significance is not majorly affected by clustering the production function at regional level (Table 3, Columns a, b and c present the results with standard errors not clustered in round brackets while the results with standard errors clustered at regional level are shown in squared brackets). In this sense, the stability of coefficients, as well as the high correlations between efficiency scores derived through the different models, suggest that the functional form of the production (cost) educational function of the Italian universities does not affect the quality of final judgments.

When looking at the (average) technical efficiency scores by geographical area (Table 4), the estimates reveal that institutions in the Central-North area (North-Western, North-Eastern and Central) outperform those in the Southern area; this result is consistent with previous evidence, as for instance that reported by Ref. [6]. This difference exists for all the four years and is quite constant over time; taking the average across years into consideration, the estimated gap of efficiency scores is in the order of 15%. Therefore, depending on the functional form, the average efficiency of Northern universities is estimated around 93% - in other words, the output can be expanded by 7% using the same amount of inputs, an increase that is substantial but not radical. Southern universities' efficiency, instead, is around 75% - thus, their inputs can be used more efficiently for producing 25% more outputs. What is stunning is that the big difference between efficiencies of universities in different geographical areas is not only in the mean, but more importantly in the distribution (see the three boxplots – one for each efficiency model – in the Fig. 1): while on average all universities in Northern and Central Italy are similarly efficient, in the South very efficient institutions coexist with very inefficient ones. This point would be of extreme importance when discussing potential implications for regional-level policies in the field.

This gap in efficiency requires some explanation, that can be useful for defining consistent policies that can improve the productivity of the overall HE system – indeed, the second-stage analysis is deemed at this specific objective. Before going into that, on a policy ground it is interesting to notice that technical efficiency levels are increasing over time, i.e. the average efficiency of the whole HE system is improving in the four years under scrutiny (this is true across all the geographical areas, on average). Such finding is not only detectable from the average efficiency scores, but is reinforced by the estimation of the parameters *Time trend* – the negative sign associated to the coefficient indicates that inefficiency is decreasing over time, with a more pronounced magnitude in the first year after the baseline one (2008). A graphical representation of the evolution of efficiency over time is in Fig. 2, and indicates that such a positive evolution of efficiency scores is detectable, irrespective of the functional form assumed for the production function – the subsequent figures show also the positive trend in all the geographical areas, with a tendency towards catch-up effect (albeit slow) for universities located in Southern Italy. The statistical correlations between the efficiency scores obtained through the various models are reported in Table 5 (Pearson correlation index[21]); overall, they suggest strong concordance both in terms of estimated efficiency levels and rankings, and they are also coherent in describing efficiency levels in the geographical areas.

[19] Data is obtained through the publication "University in Numbers 2009–10", produced by Ministry of Education, available online.

[20] We rely on the routines provided in STATA software (version 12) by Ref. [67] in order to make a within transformation to data using the "sf_fixeff" command.

[21] The Spearman correlation index has also been calculated; results, available on request, are similar.

Table 3
Parameters' estimation, baseline model.

	(a)	(b)	(c)
	Translog		Cobb Douglas
	Unrestricted	Separable	
X_1	0.300 (0.039)*** [0.074]***	0.304 (0.038)*** [0.064]***	0.460 (0.036)*** [0.074]***
X_2	0.596 (0.049)*** [0.107]***	0.591 (0.046)*** [0.095]***	0.459 (0.042)*** [0.088]***
Y_2	−0.765 (0.032)*** [0.060]***	−0.756 (0.029)*** [0.051]***	−0.768 (0.030)*** [0.070]***
Y_2*Y_2	0.330 (0.067)*** [0.107]***	0.301 (0.063)*** [0.102]***	
X_1*X_1	−0.295 (0.122)** [0.156]*	−0.300 (0.044)*** [0.061]***	
X_2*X_2	−0.005 (0.169) [0.316]	0.019 (0.112) [0.180]	
X_1*X_2	0.385 (0.279) [0.465]	0.371 (0.123)*** [0.195]*	
X_1*Y_2	−0.019 (0.081) [0.109]		
X_2*Y_2	−0.031 (0.092) [0.138]		
T_1	−0.187 (0.046)*** [0.037]***	−0.212 (0.041)*** [0.045]***	−0.250 (0.047)*** [0.047]***
T_2	−0.025 (0.033) [0.018]	−0.038 (0.032) [0.016]**	−0.058 (0.038) [0.019]***
T_3	−0.030 (0.028) [0.012]**	−0.034 (0.028) [0.009]***	−0.034 (0.035) [0.011]***
Inefficiency effects δ			
MK	−4.483 (1.115)*** [0.866]***	−4.283 (1.082)*** [0.996]***	−1.858 (1.100)* [1.091]*
MK^2	7.716 (2.417)*** [2.190]***	7.378 (2.302)*** [2.479]***	3.343 (2.680) [3.020]
AV	−0.158 (0.039)*** [0.033]***	−0.161 (0.040)*** [0.033]***	−0.257 (0.076)*** [0.079]***
FPS	−0.001 (0.0008)** [0.001]*	−0.002 (0.0008)** [0.001]**	−0.002 (0.001)** [0.001]*
Time trend	−0.670 (0.201)*** [0.255]***	−0.590 (0.186)*** [0.241]**	−0.308 (0.200) [0.216]
Log Likelihood	83.589	82.659	58.954
Wald	4182.87 [10658.99]	4164.35 [5193.01]	3450.07 [1454.06]
Observations	212	212	212

Standard errors in round brackets are not clustered.
Standard errors in squared brackets are clustered at regional level.
(a)–(b): Results are obtained through a Translog functional form for the output distance function, without and with input-output separability property.
(c): Results are obtained through a Cobb-Douglas functional form for the output distance function.
*, **, *** stand for significant at 10%, 5% and 1%, respectively.

Table 4
Technical efficiency – directional output distance efficiency scores by geographical areas.

	Unrestricted (translog)					
	Obs	2008	2009	2010	2011	All years
Geographical areas						
North-Western	44	0.8662	0.9125	0.9412	0.9596	0.9199
North-Eastern	40	0.8927	0.9260	0.9542	0.9678	0.9352
Central	40	0.8705	0.8951	0.9217	0.9423	0.9074
Southern	88	0.6466	0.7279	0.7953	0.8306	0.7501
Total	212	0.8190	0.8653	0.9031	0.9250	0.8781
Separable (translog)						
North-Western	44	0.8810	0.9169	0.9432	0.9591	0.9250
North-Eastern	40	0.9054	0.9307	0.9555	0.9678	0.9398
Central	40	0.8767	0.8972	0.9206	0.9394	0.9085
Southern	88	0.6538	0.7261	0.7875	0.8191	0.7466
Total	212	0.8292	0.8677	0.9017	0.9213	0.8799
Cobb Douglas						
North-Western	44	0.9612	0.9636	0.9727	0.9775	0.9688
North-Eastern	40	0.9619	0.9641	0.9732	0.9793	0.9696
Central	40	0.9263	0.9327	0.9448	0.9474	0.9378
Southern	88	0.7062	0.7388	0.7753	0.7976	0.7545
Total	212	0.8889	0.8998	0.9165	0.9254	0.9076

Summing up these general findings about the efficiency scores of universities, they are stable and consistent across various specifications and confirm the gaps across geographical areas; in other words, the functional form does not influence the general picture about the efficiency of HEIs in Italy.[22]

With the aim of providing an idea about how much the lack of consideration for unobserved heterogeneity would bias the results (i.e. if the [67] model is not used), we re-estimate the model through the [38] approach, by specifying two different settings: (i) one in which dummies for geographical macro-areas are included into the calculation of efficiency frontier (see Tables 6 and 7), and (ii) one in which the dummies are instead considering single regions, not macro-areas (see Tables 8 and 9). While the correlation indexes across all the models are high, it can be noted that the models that do not consider unobservable heterogeneity tend to estimate divergent efficiency scores, meaning that they fail to attribute inefficiency correctly to the various universities. This bias is higher for the universities operating in Southern Italy (see that, in some cases, they receive efficiency scores not far from those of universities in other areas), and leads to under- or overestimate the degree of inefficiency in their operations.

4.2. (In)efficiency scores' determinants: the role of market competition

When considering the explanatory factors included in the analysis, our findings show that the variables used to control for the different competitive environment in which institutions live have an important role in describing the variance of the inefficiency term. Specifically, inefficiency is U-shaped relationship with respect to the measure of market competition (MK), showing a negative and statistically significant relationship between inefficiency and market share while, instead, a positive and statistically significant relationship between inefficiency and (squared) market share has been found. In other words, the increase in concentration does not lead to a linear change in efficiency; instead, at low values of concentration, having additional students has a negative effect on inefficiency (i.e. universities are more efficient, maybe because they are able to obtain benefits from scale of operations). At some point, the effect becomes positive, and the quadratic shape means that the inefficiency of HEIs with respect to

[22] To complete the set of findings, we find decreasing return to scale (confirming the findings of [10] suggesting that Italian universities are too big and that economies could be achieved by splitting (some of) them up into smaller units. In other words, there are universities in Italy that are too big and are experiencing diseconomies owing to their size.

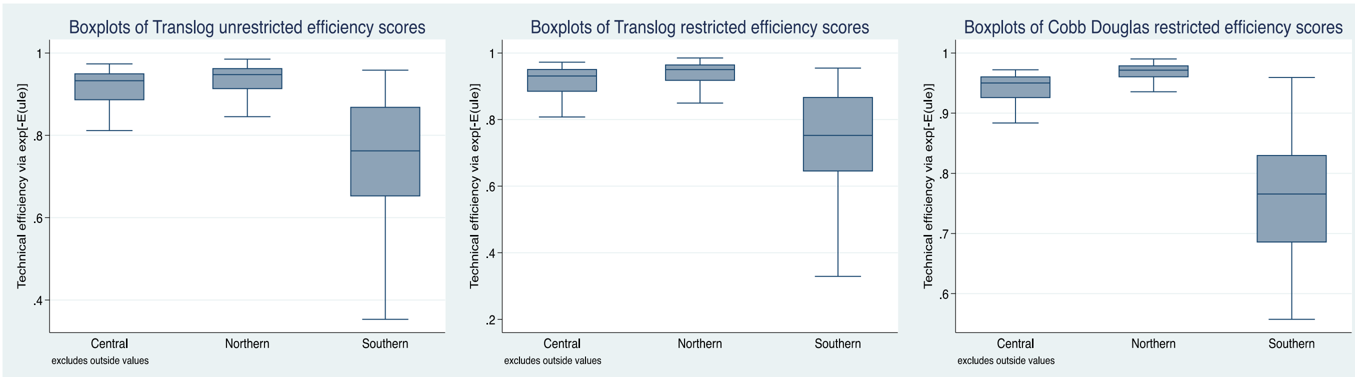

Fig. 1. Efficiency scores' estimates, by macro-area (different functional forms). Note: Central area: 40 observations; Northern area: 88 observation (44 in the North-Western and 40 in the North -Eastern area); Southern area: 88 observations.

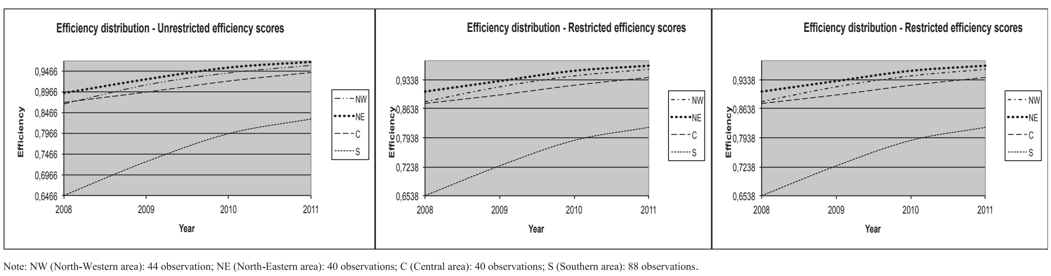

Fig. 2. Efficiency scores' distribution over time, by macro-area (different functional forms). Note: NW (North-Western area): 44 observation; NE (North-Eastern area): 40 observations; C (Central area): 40 observations; S (Southern area): 88 observations.

Table 5
Pearson's correlation.

	North-Western	North-Eastern	Central	Southern	All
a. Unrestricted (translog) vs Separable (translog)					
	0.9938 (0.0000)	0.9919 (0.0000)	0.9904 (0.0000)	0.9960 (0.0000)	0.9965 (0.0000)
b. Unrestricted (translog) vs Cobb Douglas					
	0.7316 (0.0000)	0.8143 (0.0000)	0.8516 (0.0000)	0.8439 (0.0000)	0.8731 (0.0000)
c. Separable (translog) vs Cobb Douglas					
	0.7528 (0.0000)	0.8400 (0.0000)	0.8651 (0.0000)	0.8553 (0.0000)	0.8970 (0.0000)
Obs	44	40	40	88	212

the measure of market concentration is increasing as concentration increases (i.e. universities are less efficient), and the results can be due to the finishing incentives in becoming efficient when concentration arises indeed. Overall, these findings suggest that differences in performances might be due to the market structure of higher education, in the direction that a more competitive environment could lead to higher efficiency.[23] We also find a negative and statistically significant coefficient on the FPS variable; this indicates that the higher levels of fees per capita are associated with lower levels of universities' inefficiency. This finding is also consistent with the interpretation that when market forces operate, there are benefits for HEIs' efficiency – an analogous finding about the positive association between efficiency and fees of Italian universities is in Ref. [4]. They underline that this result could depend on the fact that those universities "are more responsive towards students' needs and use the money in a more efficient way (for instance, on teaching services that are able to help "producing" more graduates)". The potential explanation for this general result resides in the traditional economic argument that competition can stimulate the ability of institutions of maximizing the outputs for any available input level; the series of reforms that, since 1990s, provide incentives to Italian universities in this direction, can be then judged as potentially useful in improving the efficiency of the overall HE system. A negative and statistically significant coefficient has been found on the variable value-added (AV), meaning that the higher is the value added per capita the lower is the technical level of inefficiency; operating in more economically developed areas is

[23] Using the results in Table 3, the turning point is at a market share of 0.29. Given that mean market share is 0.27, 0.30, 0.40 and 0.36 (Table 1) for the North-Western, North-Eastern, Central and Southern regions, respectively, this suggests that most universities are actually on the upward sloping part of the relationship. Only when we take into account the North-Western regions, most universities are on the downward part of the relationship. It is also useful to highlight here that the maximum value of MK is 1, and its standard deviation is 0.29. Therefore, the predominant relationship between inefficiency and market share is switching among macro areas of the country (since some means are below the turning point and some are above); in other words, the empirical evidence suggests that, on average, for the universities located in the North-Eastern, Central and Southern regions the efficiency is boosted by increasing competition. On the other hand, for the universities located in the North-Western regions, having additional students initially increases efficiency (at low level of concentration) and only after a certain point, their efficiency will be boosted by higher competition with their peers.

Table 6
Parameters' estimation, baseline model SFA with macro-area dummies in the frontier.

	(a)	(b)	(c)
	Translog		Cobb Douglas
	Unrestricted	Separable	
X_1	0.396 (0.038)*** [0.081]***	0.380 (0.036)*** [0.068]***	0.471 (0.031)*** [0.071]***
X_2	0.479 (0.047)*** [0.111]***	0.502 (0.043)*** [0.096]***	0.410 (0.040)*** [0.102]***
Y_2	−0.723 (0.033)*** [0.069]***	−0.703 (0.030)*** [0.070]***	−0.723 (0.031)*** [0.094]***
Y_2*Y_2	0.360 (0.063)*** [0.109]***	0.361 (0.060)*** [0.113]***	
X_1*X_1	−0.390 (0.109)*** [0.197]**	−0.277 (0.041)*** [0.058]***	
X_2*X_2	−0.219 (0.152) [0.397]	−0.073 (0.096) [0.192]	
X_1*X_2	0.690 (0.251)*** [0.574]	0.424 (0.107)*** [0.182]**	
X_1*Y_2	0.076 (0.076) [0.154]		
X_2*Y_2	−0.104 (0.083) [0.180]		
T_1	−0.251 (0.051)*** [0.064]***	−0.263 (0.045)*** [0.066]***	−0.229 (0.053)*** [0.063]***
T_2	−0.048 (0.033) [0.019]**	−0.054 (0.031)* [0.020]***	−0.047 (0.037) [0.026]*
T_3	−0.036 (0.026) [0.0140]***	−0.038 (0.026) [0.010]***	−0.033 (0.031) [0.011]***
North-Western	0.017 (0.033) [0.029]	0.017 (0.032) [0.030]	0.033 (0.039) [0.042]
North-Eastern	−0.029 (0.033) [0.044]	−0.024 (0.033) [0.036]	−0.001 (0.040) [0.045]
Southern	−0.229 (0.041)*** [0.050]***	−0.266 (0.039)*** [0.044]***	−0.249 (0.043)*** [0.050]***
Inefficiency effects δ			
MK	−6.263 (1.530)*** [1.719]***	−5.495 (1.306)*** [1.197]***	−4.540 (1.292)*** [1.238]***
MK^2	11.769 (3.554)*** [4.457]***	9.857 (2.902)*** [3.066]***	8.263 (3.174)*** [3.753]**
AV	−0.043 (0.048) [0.047]	−0.045 (0.045) [0.034]	−0.044 (0.047) [0.035]
FPS	−0.002 (0.0009)** [0.008]**	−0.003 (0.0008)** [0.0008]**	−0.002 (0.0009)** [0.0007]***
Time trend	−0.691 (0.306)** [0.430]	−0.644 (0.241)*** [0.337]*	−0.618 (0.311) [0.409]
Log Likelihood	100.933	100.172	75.463
Wald	4551.96 [23331.33]	4688.48 [14254.32]	4022.16 [5808.23]
Observations	212	212	212

Standard errors in round brackets are not clustered.
Standard errors in squared brackets are clustered at regional level.
(a)–(b): Results are obtained through a Translog functional form for the output distance function, without and with input-output separability property.
(c): Results are obtained through a Cobb-Douglas functional form for the output distance function.
*, **, *** stand for significant at 10%, 5% and 1%, respectively.

Table 7
Technical efficiency – directional output distance efficiency scores by geographical areas – SFA with macro-area dummies in the frontier.

	Unrestricted (translog)					
	Obs	2008	2009	2010	2011	All years
Geographical areas						
North-Western	44	0.8468	0.9007	0.9253	0.9472	0.9050
North-Eastern	40	0.8981	0.9324	0.9556	0.9680	0.9385
Central	40	0.8598	0.8880	0.9157	0.9390	0.9006
Southern	88	0.7358	0.8432	0.8899	0.9162	0.8508
Total	212	0.8351	0.8910	0.9216	0.9426	0.8987
Separable (translog)						
North-Western	44	0.8434	0.8935	0.9138	0.9399	0.8977
North-Eastern	40	0.8861	0.9233	0.9478	0.9609	0.9295
Central	40	0.8562	0.8799	0.9081	0.9322	0.8941
Southern	88	0.7433	0.8327	0.8785	0.9031	0.8394
Total	212	0.8322	0.8823	0.9120	0.9340	0.8901
Cobb Douglas						
North-Western	44	0.8606	0.9078	0.9339	0.9522	0.9136
North-Eastern	40	0.8970	0.9299	0.9539	0.9665	0.9368
Central	40	0.8646	0.8886	0.9176	0.9383	0.9023
Southern	88	0.7913	0.8487	0.8877	0.9129	0.8602
Total	212	0.8533	0.8937	0.9232	0.9424	0.9032

associated, on average, with higher efficiency. Given that there is a gap in economic development between Northern and Southern Italy, this result raises serious social issues under the equity profile. Indeed, all else equal, HEIs that are operating in South Italy are required to provide extra-effort to produce the same level of output; indeed, in weak and backward economies, like those of the South of Italy, where the main producer of knowledge is public university, the implication of this sentence is a reduction of knowledge production and local knowledge spillovers. Furthermore, university research published on high ranked journals can even turn out to be detrimental to innovation in sectors highly dependent on public R&D (i.e., [55]. Even in presence of a university efficiency gap, the prescription in terms of science policy should be not to cut university funding but to link this funding to stricter scholar recruitment rules, i.e., in terms of scholar scientific profiles.

Taken together, our results suggest the promotion of pro-competitive policies, which in turn can foster universities' efficiency. Nevertheless, the implementation of such actions would not reduce the gap between universities operating in the North and South of Italy, a topic that remains at the edge of the policy debate.

5. Concluding remarks and lesson learned

This paper estimates the efficiency of the Italian higher education system through a multi-output parametric distance function, using data over the four-years 2008–2011. Italy is a very interesting case of analysis as substantial reforms have been taken place in the last years in the tertiary education system with the aim of reaching higher standards quality; public funds to higher education institutions are now related to performance indicators according to which evaluate their management and productivity. Borrowing an expression made in an OECD report [58], which fits very well to describe also the situation the Italian universities started to deal with, "higher education institutions have become increasingly accountable for the use of public funds and are required to demonstrate value for money" and "the university becomes responsible for decisions on the composition of its teaching personnel"; moreover, "formal linkages between the performance assessment and the resource allocation have been settled up" [60]. As a consequence the need of measure efficiency of HEIs has never been more actual.

A very important issue, when estimating economic performances of decision making units, is that the efficiency scores may suffer from the presence of incidental parameters or time-

Table 8
Parameters' estimation, baseline model – SFA with regional dummies in the frontier.

	(a)	(b)	(c)
	Translog		Cobb Douglas
	Unrestricted	Separable	
X_1	0.310 (0.053)** [0.128]**	0.319 (0.052)*** [0.125]**	0.558 (0.030)*** [0.070]***
X_2	0.472 (0.052)*** [0.126]***	0.471 (0.052)*** [0.125]***	0.237 (0.042)*** [0.120]**
Y_2	−0.868 (0.031)*** [0.067]***	−0.866 (0.026)*** [0.045]***	−0.853 (0.029)*** [0.080]***
Y_2*Y_2	0.117 (0.044)*** [0.077]	0.132 (0.042)* [0.075]*	
X_1*X_1	−0.287 (0.097)***[0.154]*	−0.228 (0.033)*** [0.062]***	
X_2*X_2	−0.070 (0.139) [0.266]	−0.006 (0.078) [0.114]	
X_1*X_2	0.401 (0.226)* [0.411]	0.275 (0.093)*** [0.144]*	
X_1*Y_2	0.043 (0.058) [0.093]		
X_2*Y_2	−0.024 (0.060) [0.106]		
T_1	−0.234 (0.028)*** [0.049]***	−0.232 (0.026)*** [0.042]***	−0.233 (0.029)*** [0.049]***
T_2	−0.104 (0.019)*** [0.030]***	−0.100 (0.019)*** [0.023]***	−0.072 (0.025)** [0.028]**
T_3	−0.046 (0.017)** [0.015]***	−0.045 (0.018)** [0.012]***	−0.031 (0.024) [0.015]**
Inefficiency effects δ			
MK	−10.730 (2.245)*** [1.611]***	−10.656 (2.136)*** [1.328]***	−8.270 (1.932)*** [2.720]***
MK^2	17.233 (7.488)** [6.917]**	17.910 (7.259)** [6.849]***	10.900 (6.140)* [6.536]*
AV	0.016 (0.032) [0.038]	0.016 (0.032) [0.034]	0.050 (0.035) [0.047]
FPS	−0.001 (0.0006)** [0.0009]*	−0.001 (0.0006)** [0.0008]**	−0.001 (0.0006)*** [0.0006]***
Time trend	0.036 (0.128) [0.125]	0.020 (0.125) [0.106]	0.023 (0.142) [0.179]
Log Likelihood	135.634	135.071	109.564
Wald	19692.04 [7.62e+06]	18733.42 [3.17e+07]	10319.67 [277218.96]
Observations	212	212	212

Standard errors in round brackets are not clustered.
Standard errors in squared brackets are clustered at regional level.
(a)–(b): Results are obtained through a Translog functional form for the output distance function, without and with input-output separability property.
(c): Results are obtained through a Cobb-Douglas functional form for the output distance function.
*, **, *** stand for significant at 10%, 5% and 1%, respectively.

Table 9
Technical efficiency – directional output distance efficiency scores by geographical areas – SFA with regional dummies in the frontier.

	Unrestricted (translog)					
	Obs	2008	2009	2010	2011	All years
Geographical areas						
North-Western	44	0.8055	0.8290	0.8072	0.8170	0.8147
North-Eastern	40	0.8494	0.8763	0.8682	0.8540	0.8620
Central	40	0.8828	0.8659	0.8234	0.8205	0.8481
Southern	88	0.7936	0.8164	0.8170	0.8200	0.8117
Total	212	0.8328	0.8469	0.8289	0.8278	0.8341
Separable (translog)						
North-Western	44	0.8057	0.8330	0.8101	0.8221	0.8177
North-Eastern	40	0.8504	0.8790	0.8728	0.8601	0.8656
Central	40	0.8825	0.8668	0.8271	0.8260	0.8506
Southern	88	0.7927	0.8185	0.8200	0.8232	0.8136
Total	212	0.8328	0.8493	0.8325	0.8328	0.8368
Cobb Douglas						
North-Western	44	0.7846	0.8222	0.8036	0.8165	0.8067
North-Eastern	40	0.8476	0.8762	0.8767	0.8688	0.8673
Central	40	0.8547	0.8337	0.8135	0.8238	0.8314
Southern	88	0.8174	0.8382	0.8409	0.8459	0.8356
Total	212	0.8260	0.8425	0.8336	0.8387	0.8352

invariant, often unobservable, effects; indeed, do not separate inefficiency and fixed individual effects and thus do not distinguish between unobserved individual heterogeneity and inefficiency, forcing all time-invariant individual heterogeneity into the estimated inefficiency, would distort the estimates. Thus, the first contribution of the paper is to apply a procedure developed by Ref. [67] imposing on the data a within transformation such that the sample mean of each panel is subtracted from every observation in the panel and the estimated efficiency is net of the influence of unobserved heterogeneity. The coefficients show that all the inputs variables have a positive and statistically significant effect on the various outcomes of the universities and their statistical significance is not majorly affected by clustering the production function at regional level. Furthermore, consistently with previous evidence [6], the findings show that institutions in the Central-North area (North-Western, North-Eastern and Central) outperform those in the Southern area. More importantly, the empirical evidence suggests the importance of removing time-invariant individual effects from the model; indeed, when we replicate the analysis without taking into account the above mentioned unobserved heterogeneity, a bias is found in our estimation. More specifically, when bias corrected efficiency estimates are taken into account, the differentials between geographical areas (especially between Southern and Northern Italy) tend to be reduced. Important managerial considerations could be drawn in using these efficiency models for policy-making; our main claim is that maintaining State-level policies in the field can be detrimental for overall efficiency, and instead special interventions for universities in the South should be designed.

The second contribution of the paper is analyzing whether and how some characteristics of the marketplace in which the higher education institutions operate affect their inefficiency. The empirical evidence reveals the validity of the heteroscedastic assumption, giving credit to the use of such variables according to which the inefficiency is allowed to change; indeed, the results show that inefficiency is U-shaped relationship with respect to the measure of market competition: a university's inefficiency is reduced by increasing its market share, at lower levels of concentration (at regional level), then after a certain threshold the efficiency is boosted by increasing competition, i.e. reducing market concentration at regional level. The specific coefficients attached to the variable(s) measuring MK and its square demonstrate that most universities are in the upward sloping part of the relationship.

Our findings reveal that the higher is the level of fees per capita the lower is the universities' inefficiency as well as that the higher is the value added per capita the lower is the technical level of inefficiency. Again, as for the inputs variables used in the production function, the statistical significance of the exogenous variables is not majorly affected by clustering the production function at regional level. These findings should provide a clue towards the expansion of pro-competitive policies in the Italian HE sector, for example stimulating the students' freedom of choice through additional grants, loans and vouchers. Indeed, these results are in line with the realization of both a decentralization of powers from the State to the universities and of the following attempts to set up an evaluation system, as a result of the implementation of a series of reforms the Italian university system has gone through since the beginning of the 1990s. These interventions led to a concession of a certain degree of autonomy to the universities by letting them having their own statutes, allocating the central funding and creating new faculties and courses, encouraging a higher degree of autonomy in management of resources and in the teaching processes. The higher education institutions are now allowed to autonomously allocate the funding from the central government and work a more performance-oriented system of resources allocation, in which each university is in competition with others for the assignment of public funds. Indeed, universities have started to be funded according to their level of virtuosity and both quantitative and qualitative indicators were developed to accurately evaluate their productivity in research and teaching. All hints pointing at a development of a quasi-market in the provision of education where, as [3] have underlined, students are free to choose the university to attend, institutions are allowed to compete for students, since public funding is associated with the number of students, control over financial resources is delegated to universities, all institutions have to meet the requirements of a national curriculum, but also have to leave their formative offer to be determined by market forces, freedom of entry into the market, universities' freedom in the setting of fees and availability of relevant information.

Finally, a third contribution of the paper regards the not secondary issue of identifying the more appropriate functional form of higher education institutions' production processes. We firstly consider a translog functional form for the output distance function with input-output separability; then, for robustness, we firstly relax the separability assumption by assuming a translog functional form without input-output separability property and secondly by considering a Cobb-Douglas formulation. The estimates are quite stable across all the specifications, suggesting that the functional form of the production (cost) educational function of the Italian universities does not affect the quality of final judgments.

Although we are aware of the limit of external validity allowed by operating within a national higher education environment, the empirical evidence do offer an important instrument to the university and governance structures. It is very important being aware of the possible source of inefficiency in order to increase the university productivity and to make more accurate resource allocation decisions; indeed, as pointed out by Refs. [19]; failing to make efficiency analysis a standard practice would certainly lead to less than efficient allocation of educational resources. Regulators operating in this sector might take advantage of these studies and make, through appropriate policy decisions (i.e. focusing on the distribution of available additional resources either among the more efficient units, as reward, or the more inefficient units, helping them to improve their efficiency), the tertiary education system more effective.

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