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THE INFLUENCE OF REGIONAL CONTEXTUAL FACTORS ON PUBLIC UNIVERSITY EFFICIENCY IN ITALY

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The influence of regional contextual factors on public university efficiency in Italy

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Abstract

This study contributes to the ongoing debate on the assessment of university performance, a critical issue in light of increasing global competition in education and the growing demand for accountability as universities rely on taxpayer funding, particularly when public budget constraints are tight. Using a two-stage approach, we examine the evolution of productivity levels of public universities in Italy from 2010 to 2017, following the introduction of university reform in 2010. In the first stage, we apply the nonparametric bootstrap Data Envelopment Analysis (DEA) method to calculate universities' internal technical efficiency scores, considering two outputs (teaching and research) and four inputs (students, academic staff, technical staff, and financial resources). In the second stage, we use linear and fractional response models to assess how the socio-economic characteristics of the regions where universities are located impact their internal efficiency. The first stage results reveal a general increase in relative technical efficiency between 2010 and 2017, accompanied by a notable reduction in efficiency dispersion, largely due to improvements among Southern universities. This suggests that universities have responded effectively to the reforms and the specific incentives they introduced. In the second stage, we find convincing evidence that regional contextual factors such as per capita income, student competencies, and the quality of local institutions significantly influence university efficiency. The paper, by suggesting to decision-makers and practitioners an easy procedure to calculate the universities' internal efficiency and the impact of contextual factors, offers valuable tools and insights to inform the design of more balanced policy measures to finance the public university system.

Keywords: University, Contextual factors, Data envelopment analysis, Fractional responses models, Italy
JEL codes: D24, I23, R10
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1. Introduction

There is a broad consensus among economists and policymakers on the positive role of human capital and technological innovation in fostering growth processes globally and locally. All over the world, the universities, particularly the public ones, are the institutions that pursue the key functions of endowing people, especially youth, with advanced knowledge and skills, developing basic research and technological innovation, and exchanging knowledge with the society as a whole (Varga, 2009; Uyarra, 2010; Brekke, 2021 for a recent review). Universities are nowadays more and more engaged in providing innovative and creative solutions to both global and local challenges thus enhancing the economic performance of countries and regions (Drucker and Goldstein, 2007; Valero and Van Reenen, 2019; Marrocu et al., 2022). Universities are also central to advancing initiatives and solutions to overcome challenges related to health issues, economic recession, rising poverty and inequality (Uyarra, 2010).

In the last decade, universities faced funding reductions due to public budget constraints following the 2008 great recession. This has revived the debate on the assessment of university performance, emphasizing the need to accurately measure universities' internal capacities to produce teaching and research while considering the influence of their regional contexts. This issue has relevant and direct policy implications, given that most university funding comes from taxpayers, necessitating a high degree of accountability.

The issue of efficiency is particularly pertinent in the Italian university system, which has become more competitive due to the degree course reform introduced in 1999 as part of the European Bologna Process (Donina et al., 2015). Italian universities now compete for limited and shrinking public financial resources while striving to attract the best students and staff. In Italy, the primary source of universities' financial revenue is the Ordinary Financial Fund (*Fondo di Finanziamento Ordinario,* FFO), which is allocated annually by the central government. For the purposes of our analysis, it is crucial to remark that since 2009, the FFO has included an increasing performance-based component, which started at 9% and is expected to reach a maximum of 30%. The amount of this performance-based funding received by each university primarily depends on the quality of scientific research, as periodically evaluated by the Quality Research Assessment (*Valutazione della Qualità della Ricerca*, VQR) for all academic staff and newly recruited faculty. Another factor influencing FFO distribution is teaching performance, measured in terms of graduation and completion rates. As we will discuss in Section 3, these two regulatory provisions - focused on research and teaching outcomes - have effectively incentivized universities to improve their internal efficiency throughout the 2010s and secure more public funding.

The economic literature has extensively examined the efficiency of Italy's university system focusing on periods ending in 2011 and using both parametric and nonparametric techniques with different inputs and outputs (Agasisti and Dal Bianco, 2009; Guccio et al., 2016; Agasisti and Ricca, 2016; Barra et al., 2018).

This study seeks to fill several gaps in the existing literature from both methodological and empirical standpoints. The main objective is to analyze the efficiency levels of public universities in Italy, subsequently to the university reform, and examine how these are influenced by the regional socio-economic context, using a two-stage approach. In the first stage, we apply a nonparametric bootstrap Data Envelopment Analysis (DEA) to estimate the internal technical efficiency (TE) scores of each university. In the second stage, we investigate the effects of the socio-economic characteristics of the regions where the universities are located on their TE scores.

Unlike previous studies that examined periods until 2011, our analysis is carried out for the years 2010 and 2017, allowing us to examine how universities' efficiency scores have evolved following the introduction of various university reforms in the early 2010s. The most relevant of these reforms, the so-called *Riforma Gelmini* (Law 240/2010), was enacted in 2010 and introduced changes in institutional governance, internal organization, and recruitment procedures. Additionally, as noted earlier, a specific reward scheme based on research and teaching outcomes was introduced in 2009, influencing the distribution of public financial resources to universities.

In this study, we have chosen to focus exclusively on the pre-COVID-19 period, as the normal operations of universities were significantly disrupted by the pandemic, with over 90% of students affected by school and university closures. Future research could benefit from a comparative analysis of the pre- and post-COVID performance of the university system, particularly in relation to its role in addressing the pandemic's adverse effects on the education system.

Our study emphasizes the importance of accurately defining the inputs and outputs of the production process, clearly distinguishing internal variables from external factors, which are beyond the control of universities. This distinction is crucial for correctly specifying the universities' production function and obtaining reliable efficiency estimates, yet it is often neglected in the literature. To address this gap, we leverage, for the first time, a comprehensive database on revenues and expenses for each public university, provided by the Central Nucleus of Territorial Public Accounts and based on the State General Accounting Office database. Additionally, we develop a novel measure of universities' research activity by collecting data on the number of articles published annually in scientific journals, using the Institutional Research Information System (IRIS).

From a methodological perspective, we offer an original contribution by applying fractional response models for the first time to assess the impact of contextual factors on university efficiency scores. Given that the scores are proportional data resulting from a normalization process, it is inappropriate to apply models such as the one- or two-limit Tobit models, which are suitable only for censored or corner solution data and may produce inconsistent estimators in second-stage efficiency analysis. Following the recommendations of McDonald (2009), we employ both linear regression models estimated by the least squares method and "the gold standard" quasi-maximum likelihood estimation procedure proposed by Papke and Wooldridge (1996) and further developed in Wooldridge (2002) for proportional data.

The main results from the first-stage analysis – based on a two-output model that accounts for the complex academic production process, where teaching and research activities are highly intertwined – indicate an increasing average efficiency score and a significant decrease in dispersion over time. This finding suggests that universities have effectively responded to the specific measures and incentives introduced by the aforementioned reforms, which have fostered a more competitive environment within the Italian university system. In the second stage, both linear and fractional response models highlight the crucial role of economic, social, institutional, and geographical factors in either enhancing or hindering university performance. Moreover, although the fractional responses model is the most adequate specification to represent the data intrinsic nonlinearity, our results show that linear models perform sufficiently well when compared to the nonlinear counterparts. This is a valuable result, especially from a practitioners' perspective, which allows combining the flexibility of the DEA approach with the familiar and easy to apply linear regression analysis.

The paper is organised as follows. In section 2 we review the relevant literature on the universities role and efficiency measures and its main drivers. Section 3 presents the empirical strategy, while Section 4 describes the data on the output and input variables included in the first stage of this study. In Section 5 we discuss the estimated universities' efficiency scores, while in section 6 we analyse how they are affected by territorial context factors. Section 7 concludes.

2. Literature background

In the contemporary knowledge society, universities' functioning, role, and socio-economic impact have attracted considerable attention in both academic and policy discussions. A body of literature has focused on the multifaceted roles of universities (Uyarra, 2010), highlighting their crucial contribution to generating high-level human capital through teaching, creating and disseminating knowledge and innovation through research, and fostering the socio-economic development of the regions where they are located - referred to as the "third mission" (Compagnucci and Spigarelli, 2020). See the recent contribution by Brekke (2021) for a comprehensive review.

Several studies have explored the impact of higher education institutions (HEIs) on regional economic performance. Drucker and Goldstein (2007) provide a comprehensive review of various approaches to this topic. Cross-country comparisons of universities' effects on regional GDP per capita growth include the seminal contribution by Valero and Van Reenen (2019), who examine 1,500 global regions worldwide. At the European level, the relationship between HEIs and economic growth in NUTS2 regions has been investigated by Lilles and Roigas (2017) and Agasisti and Bertoletti (2022). Marrocu et al. (2022) examined universities' direct and indirect effects on total factor productivity across 270 EU regions. Other studies have focused on specific countries, such as Lendel (2010) and Drucker (2016) on U.S. counties and states, Schubert and Kroll (2016) on Germany's NUTS3 regions, and Agasisti et al. (2019) on Italian labor market areas. Generally, these studies indicate that local economies benefit from the presence of HEIs, although there are notable differences depending on the socio-economic characteristics of the regions.

Another stream of literature examines the role of universities in attracting talented students from other regions and their impact on local economic performance. These mobile students contribute to local development by increasing demand (Breznit et al., 2022), supporting labor supply (Carrascal Incera et al., 2022), and enriching entrepreneurial culture (Bergmann et al. 2016, Wu and Eesley, 2022; Kitagawa et al., 2022), thereby enhancing the economic performance of host regions (Etzo et al., 2024).

A different body of research – related to the aim of the present contribution – focuses on the efficiency of universities in various countries, employing both parametric and non-parametric techniques. This approach aims to assess universities' internal capacity to generate outputs based on the inputs available in their production processes. In this section, we provide a brief overview of these contributions, while a more detailed discussion on how to select the input and output variables that enter the university production function is presented in Section 4 where we compare our key choices with those present in the extant literature.

Focusing specifically on studies of Italian universities, different approaches have been adopted in defining the outputs and inputs of the university production function. Some studies concentrate solely on teaching activities (Guccio et al., 2016; Agasisti and Dal Bianco, 2009), while others, more appropriately, examine the joint production of both teaching and research outputs, considering the effects of local contexts on efficiency levels. Agasisti and Ricca (2016), for example, analyzed the technical efficiency of 74 Italian public and private universities from 2007 to 2011. In their study, the outputs included the total number of graduates and research revenues, while the inputs comprised the total number of students and faculty staff. Their findings suggest that private universities are relatively more efficient than public ones, and universities in Northern Italy are more efficient than those in the Center and South.[1]

Barra et al. (2018) analyzed the efficiency of 53 Italian public universities between 2008 and 2011, using both parametric and non-parametric methods. Their production function included two outputs (graduates and research grants) and four inputs (academic staff, the share of enrollees with high secondary school scores, the percentage of enrollees from lyceums, and the total number of students). In a more recent contribution, Agasisti and Bertoletti (2022) introduced a partial measure of universities' third mission, considering the percentage of research publications co-authored with industry partners. result

Other studies have focused on the efficiency of universities in different countries. Among the most recent contributions, Martínez-Campillo and Fernández-Santos (2020) measure the technical efficiency of Spanish public universities from 2002 to 2013, comparing the situation before and during the economic crisis and assessing the direct impact of the global crisis. Crespo et al. (2022) show that university efficiency in Spain positively influenced labour productivity growth for Spanish provinces from 2009 to 2016. Agasisti et al (2023) investigate how the efficiency of universities in Russia is affected by the characteristics of the territory in which they operate.

In conclusion, two key issues emerge from the literature. First, the accurate definition and measurement of the input and output variables in a university's production function are essential for properly estimating its internal efficiency. Second, universities are deeply intertwined with their surrounding environments: not only are they shaped by local conditions, but they also play a critical role in driving regional development. Given this mutual influence, it is crucial to account for the substantial heterogeneity in regional socio-economic factors when assessing the overall efficiency of universities. Our study contributes to the existing literature by accurately selecting the relevant input and output universities' variables and evaluating, with the most adequate models for proportional data, the impact of contextual variables on their efficiency scores.

3. Empirical strategy

The efficiency of Italian public universities is analysed by applying a two-stage procedure. In the first stage, the nonparametric DEA method is used to compute the

[1] D'Ippoliti and Zacchia (2017) criticise the results and, especially, the policy implications reached by Agasisti and Ricca (2016), indicating that their conclusions are based on inadequate empirical methodology.

"technical" efficiency score for each university.[2] In the second stage, we assess the effects exerted on the efficiency scores by the socio-economic contextual factors of the area in which the university is located. Although some procedures have been proposed that account for such effects within the DEA method (see Cooper et al., 2000; Coelli et al., 1999; Fried et al., 1999; Grosskopf, 1996), the two-stage procedure, as argued by McDonald (2009), remains very attractive for its simplicity and the direct interpretation of conditional efficiency measures.

DEA allows identifying the best performing universities among the set of 56 entities considered in this study, whose common objective is to convert multiple inputs into possibly multiple outputs. The best performing universities define the efficient frontier, which "envelopes" all the other units. These latter units are then evaluated by calculating their *relative* efficiency in terms of distance from the frontier. Because DEA is a nonparametric method, it does not require to specify a functional form for describing the relationship between inputs and outputs or to formulate specific distributional assumptions on the efficiency scores. These are noteworthy advantages with respect to the approach based on the estimation of Stochastic Production Frontiers (SPF). The latter requires advanced technical competences not always within reach of practitioners, such as managers or policymakers alike. Another significant advantage is that DEA allows to easily analyse the case of multiple outputs, which is the most recurrent case when the production process is carried out by complex organisations, like universities.

We apply the DEA method under the assumption of variable returns to scale (VRS). As a matter of fact, the assumption of constant returns to scale (CRS) is appropriate only when all decision-making units (DMU) operate at an optimal scale, without imperfections or externalities deriving from the surrounding environment. In the case under consideration – public universities – this seems a highly restrictive assumption, unlikely to hold with actual data. Therefore, we have chosen not to impose the strong restriction of constant returns but to allow more flexibility in the model, assuming that there may be variable returns to scale. This approach is the most widely applied in the literature. It is important to emphasise that the use of CRS when not all DMUs operate on an optimal scale, implies that the estimated technical efficiency (TE) measures are confounded by scale efficiency (SE) ones. Under CRS an inefficient unit can be benchmarked versus other units of substantially different size, whereas under VRS inefficient units are compared only with other units of similar size.

Efficiency scores can be obtained by following either an *input*-oriented or an *output*-oriented DEA approach. As it is well-known, the first approach entails a minimisation of the amount of inputs used given a certain level of output, whereas following the second approach output is maximised given a certain level of available inputs. The output-oriented approach is more adequate in the case of public universities as, especially in the short-run, they are constrained by institutional factors in choosing the amount of inputs (financial resources, enrolled students, staff).[3] If we consider financial resources, it is worth recalling that in Italy

[2] When data on costs and prices are available the DEA method also allows to measure allocative efficiency, which is informative for productive units such as firms or hospital, but it is less appropriate for regions.

[3] Most studies on Italian universities adopted the output-oriented approach (Bonaccorsi et al. 2006, Agasisti and Dal Bianco 2009, Barra et al. 2018). Di Giacomo and Silvi (2019) represent an exception as they adopt the input-oriented approach, without providing a clear motivation for such a choice.

the primary source of public financial resources (the FFO) is set by the central government on a yearly base. As far as enrolled students are concerned, each public university has a limited ability to affect the number of enrolments since in Italy it is not possible to impose a maximum number of first-year enrolled students in all degree courses. Finally, there are legal constraints on both new hires and dismissals for which even the number of employees is hardly a variable under the control of the university management. However, it should be noted that universities are starting to practice active policies of attracting academic staff or acquiring forms of financing other than the State FFO. In general, it seems reasonable to assume that the universities' strategic choice to achieve efficiency is to try to increase the output given the available inputs rather than reduce the inputs given the output as assumed in the input-oriented approach. Input and output orientations provide the same results under CRS but differ under VRS; however, as emphasised by Coelli and Perelman (1999), the choice of orientation only marginally influence the scores obtained.

Considering a set of *N* DMUs that use *M* inputs ($x_{m,i}$) to produce *K* outputs ($y_{k,i}$) for an output-oriented VRS-DEA model, the maximum output (ϕ_i) of the *i*th unit is maximised by solving the following linear programming problem (Coelli et al., 1999):

$$\max_{\lambda,\phi} \phi_i$$

$$\text{s.t.} \quad -\phi_i y_{k,i} + \textstyle\sum_{j\neq i}^{N} \lambda_{j,i} * y_{k,j} \geq 0$$

$$x_{m,i} - \textstyle\sum_{j\neq i}^{N} \lambda_{j,i} * x_{m,j} \geq 0$$

$$\textstyle\sum_{j=1}^{N} \lambda_{j,i} = 1$$

$$\lambda_{j,i} \geq 0$$

The unit sum of the DEA weights, $\lambda_{i,j}$, represents the convexity constraint which ensures variable returns to scale. The resulting convex hull of intersecting facets envelops the data point more tightly than in the CRS case, and this is the reason why VRS scores are equal to or greater than those obtained from the CRS model. $1 \leq \phi \leq \infty$ and ϕ-1 is the proportional increase in outputs that can be achieved by the *i*th unit given its inputs. Technical efficiency is given by TE=1/ϕ, and it varies in the interval]0; 1]. Efficient units are those that cannot further increase one of their outputs without reducing the amount of the others or without increasing the level of their inputs.

It is evident, as also clearly remarked by McDonald (2009), that TE scores are the result of a normalisation process: in output-oriented models, the TE score is the ratio between the actual output of the focal unit and the frontier output corresponding to the level of its inputs. Thus, they are not censored or corner solution data, even though in specific applications there could be many units with scores equal to 1. The normalisation process generates a kind of fractional or proportional data. This aspect of the data is particularly relevant for selecting the appropriate regression model to assess how contextual factors affect efficiency scores. We will discuss this issue in more detail in section 6.

In recent years, it has become common practice to provide bootstrapped efficiency scores after Simar and Wilson (2000). In the context of the DEA analysis, bootstrap methods are designed to account for sample variability when efficiency scores are seen as *estimates* of the *true* scores and not just as a descriptive measure of the relative performance of the sample units (McDonald, 2009, provide a very valuable discussion on such a distinction). It is worth recalling that due to the one-sided nature of the scores' distribution, the bootstrapping resampling rests on some specific assumptions (Simar and Wilson, 2000 and 2007), which make unreliable and inadequate naïve mechanical applications of general bootstrap methods. Moreover, bootstrap is not necessary, and therefore inappropriate, when data on the whole population of the units under investigation is available, since, in such a case, the production frontier is measured and not estimated (Coelli et al., 1999).

In the analysis of the Italian public universities, we were forced to exclude three of them because of missing data for some relevant inputs, as detailed in section 4. For this reason, our set of universities does not coincide with the entire population and, thus, also in our case, sampling variability could be an issue. Following the suggestion in Coelli et al. (1999), we apply the bootstrap method, using Wilson (2008) FEAR 1.15 software, to assess the sensitivity of DEA efficiency estimates with respect to sample composition. For all the models considered in this study we find that the bias detected by applying the bootstrap method is very contained with an average value of 0.05 and a range defined by a minimum of 0.02 and a maximum value of 0.11 depending on the model considered.

4. Data on universities

In this section, we provide a descriptive analysis of the variables used for the DEA computation of universities' efficiency scores in the years 2010 and 2017. We pay specific attention to accurate identification of outputs and inputs of the production process since it is essential to select only variables over which the university, at least in part, can exert control in order to pursue its objectives. This is a very crucial but often overlooked aspect in the specification of the university production function with the DEA approach. As highlighted by Coelli et al. (1999), the exclusion of some inputs or outputs can yield biased efficiency scores. The main variables, along with some descriptive statistics, are listed in Table 1.

4.1 The set of public universities

We start by defining the set of universities analysed in this study. In Italy, there are 97 HEIs recognised by the Ministry of University and Research (MUR). Among these, 30 are private institutions, which include 11 online universities. We have carried out numerous preliminary analyses on the entire population, which have highlighted how private universities and, in particular, online ones, show very different behaviours compared to the general public universities that pursue the joint objective of teaching and research in a broad spectrum of disciplines. The inclusion of these institutions in the DEA analysis would make the set of DMUs strongly heterogeneous yielding an unreliable estimation of the efficiency frontier and the scores of the universities. Therefore, in our analysis, we preferred to exclude private and online universities, which are mostly small institutions specialised in specific disciplines. Among the 67 public structures, we have also excluded some institutions that have specific purposes, such as the two Universities for Foreigners and the six Specialized High Schools. Finally, we had to exclude three small universities (Tuscia, Foro Italico Rome and Mediterranea

Reggio Calabria) because of missing data on the main output related to research activity. In the end, we focused on a very homogeneous set of 56 State-owned HEIs. It is worth noting that such a set, when compared with the total of 97 HEIs operating in Italy, accounts for a considerable proportion of enrolled students (90% in 2010 and 87% in 2017), graduates (90% and 86%) and teaching staff (94% and 92%).

4.2 The outputs

It is universally recognised that the two fundamental tasks of the universities are teaching and scientific research which constitute two goods generated jointly and simultaneously by the same inputs within the universities' production process.[4]

Following consolidated literature (Madden et al. 1997, Bonaccorsi et al. 2006), we use as an indicator of the teaching activity the "number of graduates" per year of graduation, which is a very general measure that fully represents the teaching result of the university. Other studies, to account for the quality of the teaching output, have considered specific types of graduates such as the number of "regular" graduates [5] (Agasisti and Dal Bianco, 2009) or the number of graduates weighted by the grade achieved in the degree (Johnes, 2006; Barra et al., 2018). However, Nordin et al. (2019) show that the "grade inflation" effect distorts the distribution of graduation scores among universities and over time. Therefore, it does not always correctly represent the actual quality of graduates.

As we have already remarked, the FFO reward quota is based on the graduate's completion rate and not on the final grade level. It means that the universities have the incentive to increase the number of graduates regardless of their final grade. More generally, the principal aim of public universities is to graduate the largest number of students, given their heterogeneous skills and, consequently, their differentiated final marks. Certainly, some students graduate with lower marks or take longer than the standard duration of the degree program. However, from the university's perspective, these graduates still represent a successful outcome. Taking this into account, and to avoid any arbitrary decisions regarding the classification and weighting of graduates, we chose to use the absolute number of graduates in our analysis.[6]

In 2017, over 270 thousand students graduated from the 56 institutions considered, mainly located in the universities of the Northern regions (47%). Compared to 2010, graduates in Italy increased by 5.9% with a particularly pronounced dynamics in the North of the country

[4] In recent years, the so-called "third mission" has also been recognised among the objectives of the universities, i.e. the contribution that single faculty members and the institution as a whole make to society and the territory through knowledge exchange. However, this function has yet to be fully developed and, most importantly, there are not homogeneous indicators that measure the third mission output. Therefore, it is not possible to include it in our analysis.

[5] Regular graduates are those who have obtained the degree within the legal duration of the academic courses. However, the Italian system allows students to legitimately graduate also after the courses formal length period.

[6] Barra et al. (2018) remark that the results of the efficiency estimates do not change if one considers the absolute number of graduates instead of the number weighted by degree grade.

(16.4%), polytechnics (36%) and large universities (8%).[7] On the contrary, for small universities, the decrease is generalised throughout the national territory, with an overall decrease of 9%. A first measure, albeit crude, of the universities' performance is given by the ratio between the number of graduates at time *t* and those enrolled in their first year at time *t-3*. In 2017, such a ratio was 66%, a sharp increase compared to 2010 (55%). This increase is generalised across the country with universities in the South showing the best performance (from 49% in 2010 to 64% in 2017), thus reducing the gap compared to those in the North (69% in 2017). This effect of reducing disparities is confirmed by the coefficient of variation, which dropped from 0.18 in 2010 to 0.13 in 2017. The ratio of graduates to teachers also recorded a slight increase in the period considered, going from 4.8 graduates per teacher to 5.6. This trend is confirmed both at the local level and for the different types of universities.

The second output is represented by scientific research, which is the most controversial element to be measured. The literature has extensively debated the choice of the most suitable indicators for evaluating research activities: bibliometric measurements (De Groot et al., 1991), scientific articles (Johnes and Johnes 1993, Halkos et al. 2012), research funding (Agasisti and Johnes 2010, Barra et al. 2018). The final choice is often dictated by data availability (see recent contributions by Frey and Rost, 2010; Rhaiem, 2017, Gralka et al., 2019). In this study, we use the "number of articles published in scientific journals", which constitutes a relevant research outcome in most disciplinary areas. The advantage of this indicator is that it can be collected directly from the IRIS database maintained by each university and is available for the time considered in this paper.

In 2017, the number of articles published in scientific journals was approximately 116 thousand, with an average of over 2 thousand articles per university. In 2017, the number of publications per researcher at the national level reached 2.4, marking a significant increase from 1.8 in 2010. The highest values are found in the North (2.7) compared to the South (2.4), which nevertheless shows the most significant growth. In the last decade, the Italian university system has exhibited a decrease in the disparities in terms of scientific production (the coefficient of variation declined from 0.27 in 2010 to 0.22 in 2017).

We are aware that the evaluation of scientific articles' quality is a very complex issue, and it is not easy to find a shared metric, especially in non-bibliometric areas. The number of articles, being a pure count, does not distinguish among different journal outlets and does not allow for evaluation of the quality of the publications.[8] Therefore, in our robustness analysis, we considered an alternative indicator for research activity, i.e. the VQR average mark computed for each university. This is a synthetic measure of the university's research quality given by the ratio between the overall score obtained by the scientific products submitted by each university and their expected number. This indicator, notwithstanding some limits of the assessment exercise, represents an adequate approximation of the quality level of the research

[7] We consider four size classes: mega (over 40 thousand students), large (20-40 thousand), medium (10-20 thousand) and small (up to 10 thousand) universities. The classes are based on students enrolled in the 2017-2018 academic year collected by the MIUR, National Registry of University Students.

[8] For the bibliometrics areas (hard sciences, medicine) it may be possible to adjust the number of scientific articles according to the quartiles of their ranking. However, this solution is not feasible for other areas (humanities, social sciences) where many journals are not included in the international rankings.

activity in all scientific areas. The disadvantage of this measure is that, with respect to the years considered in this analysis, 2010 and 2017, the Italian evaluation exercise is available only for the periods 2004-2010 and 2011-2014. It is worth noting that the correlation coefficient between the two research indicators (scientific articles and VQR average marks) is equal to 0.4. Therefore, while indicating a positive and significant association between the two measures, it signals crucial differences in the two research output variables. The national average value of the latest available VQR average mark was 0.58, with a slight increase compared to 2010. The territorial distribution shows a gap between the performance of Northern (0.62 in 2014) and Southern (0.54) universities, even if the disparity is significantly reduced over time (Checchi et al. 2020). Again, this convergence process may be induced by the new rules on public financing of the university system, which has linked an increasing share of FFO to the VQR research results.

Some authors (Agasisti and Johnes, 2010; Barra et al., 2018) in evaluating the efficiency of Italian universities use as an indicator for the scientific research output, the research funding obtained by each university. However, this measure seems less general than scientific publications and, most importantly, it can be considered more as an input to the production process, rather than an output.[9]

4.3 The inputs

As the main set of inputs of the university production function, we consider financial resources, academic staff, technical and administrative (TA) staff and students. Data on the expenses of each public university were provided by the Central Nucleus of Territorial Public Accounts and were retrieved from the database of the State General Accounting Office. University financial resources are proxied by "total expenditure", which includes both current and capital expenditures. In 2017, the total expenditure amounted to € 10.9 billion, with an average of 195 million per university and the largest share of expenditure concentrated in the North (46.5%). Compared to 2010, total expenditure has increased (17%), especially in the Northern universities (22.8%), while the South (9.1%) is well below the national average. A share of 94% is made up of current expenses, while the remaining 6% is allocated to capital account investments; this proportion remains substantially unchanged if we break it down by macro-region or university size. The current component of personnel expenditure has been increasing over time, reaching 63% in 2017. It is worth mentioning that total expenditure contains all universities' revenues, including the research grants obtained by researchers or departments since they are all consolidated in the university budget.

Concerning university staff, we considered both the total number of academics (full and associate professors, permanent and fixed-term researchers)[10] and the total number of TA staff as both categories of employees, despite their distinct roles, perform essential tasks for the pursuit of teaching and research outcomes. Therefore, both must be considered as inputs in the university production process. In 2017 over 98 thousand academics and TA were

[9] Gralka et al. (2019) show that the correlation between university efficiency levels based on the number of scientific articles and the number of research funding is very high.

[10] Barra et al. (2018) assign a weight to each category of academic staff; they also try different weights concluding that the results are similar. Since the weights' choice may be arbitrary, we prefer to attribute the same weight to all categories.

employed, a number in a sharp decrease (-10.5%) with respect to 2010. Employees are divided almost equally between academics and TA, and this composition is stable over time as the number of both categories decreases at a similar rate. There are substantial territorial disparities in the dynamics. The reduction appears more contained in the North, while it is sizeable in the South, especially for the TA component (-23%) and in the Centre for academic staff (-13.7%).

Finally, for the students' input, we have chosen the "number of students enrolled in the first year" (undergraduate, postgraduate and single-cycle degree courses) as this is the indicator that best describes the annual flow of incoming students who may become graduates. There are two other measures available which are less suitable for our purposes. The first is the "matriculated students", that is, the students at their first enrolment in the university system; this indicator, therefore, does not include students who enrol in postgraduate degree courses or students that change either degree course or university within the Italian academic system. The second indicator is the "total number of students enrolled in universities" used by Agasisti and Dal Bianco (2009) and Barra et al. (2018). However, this is a stock variable less suitable to be included in the production function where a flow variable represents the graduate output.

Students' input is considered three years in advance of graduates, in order to allow for the average period required for graduation. The number of 1st year-enrolled students in 2014 was approximately 420 thousand, with 45% concentrated in the Northern universities. Between 2007 and 2014 the number of students exhibits a remarkable decrease of -11.3%. The reduction concerns all the macro-regions, but it is more sizeable in the South (-22%) mainly affected by the reduction in mega universities (-25%). This contraction of students enrolling at Southern universities is a very critical phenomenon that induces a further impoverishment of the social and economic fabric of the South (Ciriaci, 2005; Dotti et al., 2013).

In the robustness analysis we have also accounted for the quality of the incoming students (Usala et al., 2023). More specifically, we have estimated a model in which first-year students are disaggregated into two groups according to their secondary school final mark: up to 90 points and from 90 to 100 points (100 is the maximum mark). However, this indicator is not without limitations because it is subject to strong grade inflation: a high mark in the diploma does not always reflect high levels of knowledge and skills but may be the result of benevolent attitudes in the evaluation by the sending school. This hypothesis is partly confirmed by the examination of the territorial distribution of this indicator. The highest value is found in the South (25.5% of university students in the first year have a diploma mark greater than 90) while the lowest share is in the Northern regions (19.2%). A very different picture emerges when one considers the territorial indicators of competencies and skills acquired by the students based on the INVALSI standardised tests.[11]

Finally, in two extensions of the baseline DEA model, we have included other indicators that can be considered as inputs of the production process. The first is the complexity of the universities' teaching offer measured by the total number of degree courses taught in each university. The second is the quality of the infrastructure measured by the degree

[11] INVALSI stands for Istituto per la Valutazione del Sistema Educativo di Istruzione e Formazione (Institute for the assessment of the education and training system). The INVALSI test are the Italian counterpart of the OECD-PISA tests.

of satisfaction with classrooms, libraries and equipment expressed by students in the Almalaurea survey. [12]

5. Results on technical efficiency

5.1 The preferred model

In this section, we present and discuss the results of technical efficiency obtained by applying the bootstrap-DEA method to our preferred model considering two specific years before (2010) and after (2017) the introduction of the universities' reforms. Our main model (M1) was specified by considering two outputs: teaching activities (number of graduates) and research activities (number of published articles in scientific journals), and four inputs; namely, first-year enrolled students, number of academic employees, number of TA employees and financial resources. All variables are considered at time *t* except the number of incoming students which enters with a time lag of three years (*t-3*).

Featuring two outputs, M1 can account for the economies of scope which characterise the complex academic production process. Teaching and research activities are so intertwined in higher education processes that it is almost impossible to imagine two separate production lines with each one assigned a specific amount of inputs.

Table 2 shows the main aggregate results of unbiased DEA scores while the TE scores for each university are reported in Table A1 in the Appendix. In 2010, the mean value of the efficiency scores was 0.87, with a standard deviation equal to 0.071. In 2017 we note a slight increase in the average score level (0.89) and a remarkable decline in the variance (0.056). The improvement in the level of productivity, coupled with less dispersion, indicates the existence of a converging process in the efficiency of the Italian university system, which may be explained by the incentives related to the reward quota and by the more competitive environment of the national university system.

Looking at the university rankings, in 2010, the highest score (0.95) was shown by Pavia, followed by Catania, Trento, Roma 3 and Macerata. It is interesting to remark how these most efficient universities differ in terms of both geographical location (they are in the North, Centre and South) and dimension (mega, large, medium universities). In the lower part of the efficiency ranking, there are three universities located in the islands: Cagliari, Messina and Sassari. The insularity condition and the resulting reduced external relationships appear to limit the ability to operate efficiently, especially for a university located on a remote island like Sardinia. The ranking in 2017 highlights remarkable changes in the universities' relative positions. The most efficient university is now Perugia (it was 34th in 2010), followed by Trieste (40th in 2010). Pavia, the best performer in 2010, has declined to the 33rd position; similarly, Catania declined from the 2nd to the 35th position. Thus, there emerges a substantial variability in the distribution; rankings tend to change, and universities that start from high-efficiency conditions can lose positions over time and vice versa.

Overall, the M1 results show a high and increasing average level of efficiency for the Italian public universities featuring, at the same time, high variability in the ranking. In comparison to 2010, the TE scores distribution in 2017 is more concentrated around higher efficiency values, thus exhibiting higher skewness and kurtosis. The Pearson (0.33) and the

[12] Almalaurea is an interuniversity consortium (www.almalaurea.it), which runs surveys addressed to graduates with the main aim of facilitating the matching between them and available jobs.

Spearman (0.31) correlation coefficients reveal a modest positive association over time. Based on these results, we can argue that the low persistence is yielding a convergence process towards higher efficiency in the Italian university system, which is primarily due to a relevant improvement in the efficiency levels of the Southern universities. In 2017, the average TE of universities in the eight regions in the South and islands (the so-called Mezzogiorno) was 0.89, almost equal to the level of the Northern regions (0.90). This positive tendency is likely to be the result of the specific incentive policies that were introduced over the last two decades in Italy in the evaluation and funding processes of the university system, such as the reward quota of the FFO and the exercise for assessing the quality of the scientific research (VQR).

It is not possible to compare our results with the previous literature mainly because the period considered is different. Agasisti and Ricca (2016) and Barra et al. (2018) refer to periods ending in 2011 before the reforms of the Italian university system could affect the behaviour of the universities and, consequently, their technical efficiency. On the other hand, our analysis starts in 2010 and has the goal of examining how the universities' efficiency has changed over the decade as a result of the reforms. A stylised fact common to all the studies is the presence of an efficiency gap between universities in the North and in the South in the early 2010s. However, if we look at the evolution of the efficiency scores in 2017 the gap has been largely reduced.

5.2 Robustness analysis

The results obtained from M1 have been subject to a thorough robustness analysis to check their sensitivity with respect to different combinations of the input and/or the output set. In Model 2 (M2), we keep the same set of inputs while including an alternative indicator for the research output based on the university research assessment exercise, which allows us to consider the quality of the academic publications.

The subsequent models M3-M6 consider alternative choices for some inputs. In M3 financial resources are considered net of personnel costs to check possible double-counting issues related to personnel wages since the number of academics and TA staff are included among the inputs. In M4, we try to account for the quality of incoming students by splitting the number of enrolled students into two groups: students who obtained a low-grade diploma (final mark up to 90 points) and students with a high-grade diploma (final mark in the range 91-100 points). In M5 we add the number of the degree courses provided by the university as an additional input. A more diversified set of degrees is expected to yield a better matching between first-year students and the chosen degree and as a result, enhance the ability of the university to employ its resources efficiently in the "production" of graduates. Finally, in M6 we augment M1 with an indicator derived from the Almalaurea survey on the students' satisfaction with classrooms, libraries and equipment. More specifically, we consider the percentage of classrooms assessed "always or almost always adequate" in the survey. This additional indicator allows us to partly account for the infrastructure input, whose actual data are not readily and consistently available for all universities considered in this study. Table 4 reports the main results of these alternative models and their correlations to the general model M1.

Results from M2, in which the average VQR score replaces the number of scientific articles, are in line with those obtained from M1 for both years. We find a slight reduction in variance, which indicates that universities are gaining in efficiency to adapt to changes induced in high quality publication attitudes by the VQR. The efficiency score correlation between M1 and M2 was relatively high in 2010 (0.83), but it sharply decreased in 2017 (0.55); the same happens to the ranking correlation, although to a minor extent (0.78 in 2010 and 0.61 in 2017). A possible explanation for the low correlation between M1 and M2 in 2017 is that the indicator of research articles refers to 2017 while the VQR measure refers to scientific products published in 2011-2014, when the universities' adaptation process to the new rules was still ongoing.

Focusing on models M3-M6, it turns out that differences in average TE scores are negligible with respect to M1 in 2010, only model M4 (includes enrolled students disaggregated in low vs high secondary school grade group) and M6 (includes quality of infrastructure) exhibit an average higher than 0.01 point. Correlations with M1 are very high, ranging from 0.91 for models M3 (expenditures are included net of personnel costs) to 0.98 for M5 (number of degree courses added to the input set of M1). As it is evident from Table 4, similar results are also found with respect to 2017 for both scores and rankings.

Overall, we can argue that our preferred model, M1, is remarkably robust to a wide range of alternative specifications for the set of input and output variables. For this reason, the second stage analysis will be entirely based on M1 efficiency scores.

6. The effects of the territorial context on university efficiency

6.1 Methodological issues

As stated in section 3, TE scores are the outcome of a normalisation data generating process. They are proportional data defined in the range]0; 1], although they may exhibit several observations with the limiting value of 1, they cannot be considered censored or corner solution data. For this reason, in regression analyses aimed at assessing the role of contextual factors in influencing efficiency, it is not appropriate to apply the Tobit model since it may yield inconsistent estimators of the conditional expectation of the scores variable that has a continuous distribution (Woodridge, 2002). On the contrary, Least Square (LS) estimators are consistent, and the less demanding linear specifications have been proven to provide reliable results and robust inference when standard errors are computed to account for the heteroskedasticity of the error term (McDonald, 2009). It is worth highlighting that the application of the LS method to proportional data is analogous to the estimation of linear probability models in the case of binary dependent variables. Depending on the values assumed by the explanatory variables, linear specifications may result in estimated values outside the range of admissible data. In the case of proportional data, this limit of the LS-linear model can be overcome by applying fractional responses models when the main interest is to estimate the partial effects of the covariates on the conditional mean of the analysed process (Papke and Wooldridge, 1996; Wooldridge, 2002, Buis, 2020). The latter can be specified as a logistic or as a probit function:

$$E(y|\boldsymbol{x}) = exp(\boldsymbol{x\beta})/[1 - exp(\boldsymbol{x\beta})]$$

$$E(y|\boldsymbol{x}) = \Phi(\boldsymbol{x\beta})$$

where *y* is the fractional process, in our case the TE scores, $\boldsymbol{x}$ is the set of explanatory variables, $\boldsymbol{\beta}$ is the parameters vector and Φ is the cumulative normal distribution function.

Both specifications return predicted values in the interval (0,1), while the dependent variable is allowed to assume any value in the interval [0,1]. As in the case of logit or probit models, average partial effects can be computed and compared with the coefficients of linear models. Papke and Wooldridge (1996) suggest the estimation of fractional response models using the quasi-likelihood approach based on the Bernoulli log likelihood, which belongs to the linear exponential family, so that it becomes a standard estimation problem as it is the case when estimating binary response models. The models are called *fractional logit regression* or *fractional probit regression*.

As highlighted by Wooldridge (2002), the fractional probit specification also allows to account for endogenous explanatory variables by applying the control function approach in two steps. In the first step, the endogenous variable is regressed on the whole set of exogenous variables (instrumental variables and main model exogenous explanatory variables); the residuals are then included as an additional variable in the argument of the cumulative normal distribution function. In section 6.3 we present the main results obtained by applying both linear and fractional response models, while in the next section, we present a brief description of the key contextual factors considered in our study.

6.2 Contextual variables

The production process of the universities, as it happens for companies, is influenced by the characteristics of the external environment in which each university is located, such as the level of per capita income and related purchasing power, the opportunities to enter the labour market, the skills acquired by students in secondary school and the quality of the local institutions. In the case of Italy, it is mostly important to account for the local context, given the well-known territorial divide that still characterises the country's development process. More specifically, the eight regions in the Mezzogiorno show socio-economic indicators well below those of the North and Centre areas.

Therefore, in the second stage of the analysis, we assess how the territory's economic, social and institutional features affect the universities' efficiency levels and derive TE scores adjusted for contextual factors. Particular attention is devoted to identifying effectively exogenous elements which, therefore, do not enter directly into the production function of universities. As mentioned in section 3, if a variable is indeed a production factor rather than a contextual one, the first stage efficiency scores are biased. Moreover, it is also required that first stage inputs and second stage contextual variables are not correlated. This is the case for the environmental factors we included in our analysis.

One of the most prominent local factors is related to economic conditions and labour market dynamics. A sluggish economic performance in the region coupled with high unemployment can persuade the best and most motivated local students to move to universities located in other areas where job opportunities are more promising. The resulting brain drain is likely to induce an adverse selection problem as universities in disadvantaged areas will receive relatively less motivated students determining a further worsening in their productivity.

Additionally, the social and cultural context plays a major role in shaping the overall skill level of the population. INVALSI tests, which assess the abilities of secondary school students, reveal significant territorial differences: students from the Centre-North consistently outperform their Southern counterparts in both reading and mathematics. These regional disparities likely influence the performance of local universities, although universities themselves have no direct control over these external factors. Southern universities face challenges as they admit students with generally lower skill levels compared to those in the North, making it harder for these students to complete their degrees. Additionally, the brain drain effect described above further lowers the average skill level of students attending Southern universities, worsening the situation compared to the population's performance as measured by the INVALSI tests.

Finally, university efficiency, like other socio-economic outcomes, is influenced by the quality of local institutions. The presence of high-quality institutions fosters greater trust in political institutions and public administrations, as they are perceived to prioritize the public interest over the demands of specific interest groups. This, in turn, increases the level of trust, reduces transaction costs, facilitates smoother functioning of public administrations - including public higher education institutions - and enhances their efficiency and responsiveness to stakeholder needs.

The local context indicators refer to the region in which the university is located. This choice is more appropriate than the provincial level since the intra-regional migration of university students is very accentuated also because many Italian provinces do not have public universities. The variable included to account for the economic domain is the per capita gross domestic product (GDP) level.[13] In 2010, Mezzogiorno's GDP per capita only reached 67% of the Italian average; the economic gap further widened during the crisis to a value of 65% in 2017.

For the social and cultural domain, we considered the average score obtained by second-year secondary school students in the INVALSI tests that assess the acquisition of literacy and numerical skills. The scores at the regional level of the two competencies are closely linked (correlation coefficient around 0.95). Therefore, we have constructed a synthetic indicator given by the average of the two simple indicators. This indicator confirms the territorial differences in Italy. In 2010, the average literacy and numerical skills of students in the Mezzogiorno's regions were 93% of those in the rest of the country, and, also in this case, there is a tendency to increase the divide (92% in 2017). We are aware that this variable can be considered just an approximation for the actual level of ability of students enrolling in local universities because (i) not all high school students enrol in university and (ii) students enrolled in a specific university may come from other regions. In general, northern universities attract students from the South and movers are, on average, more talented than stayers (Tosi et al., 2019; Ballarino et al., 2022). However, most students enrolled in universities come from the same region; stayers are, on average, 75% in Southern regions, above 90% in the Centre and 98% in the North (Columbu et al., 2020). Therefore, we believe that the indicator based on INVALSI test can represent a reliable proxy of the actual quality of human capital entering the universities.

Finally, we account for institutional capital using the European Quality of Government Index (EQI) which is a composite index based on three main dimensions, namely

[13] The GDP per capita level is highly correlated with the employment or the unemployment rate (correlation coefficients greater than 0.9), and therefore, the latter two variables are not included in the regression analysis.

high impartiality, quality of public service delivery and low corruption.[14] For this variable, the territorial divide appears even wider, with the Southern and island regions reaching a level of institutional quality equal to 52% of the regions in the North and Centre of Italy.

6.3 Second stage results

The main results are reported in Table 4 and Table 5 for the two years considered in this study. Building on the arguments advanced by Banker and Natarajian (2008), McDonald (2009) and Huguenin (2015) on the adequate approximation provided by linear models in most empirical applications, we first propose the results based on the estimation of three linear regressions in which the main contextual variables are included one at a time to avoid multicollinearity. It is worth noting that they are highly correlated in both years[15]; this is reasonable since they share most of the underlying information on the latent structural features shaping the regional context.

Significant effects are found for all three explanatory variables, with the level of per capita GDP being the most significant one, followed by school competencies. The income effect, 0.0037, entails an elasticity of 0.11% computed at mean values. Efficiency scores turn out to be most responsive to school skills as for this variable the elasticity is 0.65% (estimated coefficient 0.0028). In contrast, institutional capital implies a very low elasticity of just 0.05% (estimated coefficient 0.0011).

As the GDP per capita is the most comprehensive indicator, we maintain equation 1 as the baseline specification. In column 4 (Table 4), we check for the effects determined by the existence of medical schools by including a dummy variable taking the value of 1 for universities with a medical school (31 out of the 56 HEI included in this study). As in previous contributions (Thursby and Kemp 2002, Chapple et al. 2005, Anderson et al., 2007; Agasisti and Johnes 2010, Curi et al. 2012), we find a negative effect. This finding does not imply that universities with medical schools are less efficient than the other ones, but it signals the need to control this relevant aspect. Medicine schools are not just academic entities; they also include hospitals operating within the national health system, so that their universities feature a specific production process that entails an additional objective, namely health care for citizens. Ideally, it would be preferable to account for such output in the first stage DEA. However, this is not possible because data is not available given the very complex measurement challenges that such a comprehensive health outcome poses. In general, the existence of medical schools, while representing a crucial function for the whole territory, constitutes an additional burden in terms of human and financial resources and, therefore, reduces the relative productivity of the university.

To assess how linear models fare with respect to their more accurate nonlinear counterparts, we refine our analysis by re-estimating model 4 using probit fractional response

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[14] This index is computed by the Quality of Government Institute, of Gothenburg University (Charron et al. 2015).

[15] When all three variables are included in the regression only GDP per capita is significant. In 2010 the correlation coefficient is 0.73 between GDP and school competence and between the former and the EQI variable, while school competences and EQI have a correlation of 0.68. In 2017 all correlation coefficients increase to around 0.80.

models.[16] Results confirm previous evidence on the relevance of the contextual variables in explaining differences in efficiency levels across universities.[17] The marginal effects reported in column 5 are very similar to the estimated coefficients obtained from the linear specification (0.0036); the only noticeable difference is that the medicine dummy is now significant at the 5% level. These findings confirm and generalise the adequateness of linear models in second stage analysis, even when the most appropriate model for the data generating process of technical scores is applied.

In column 6 (Table 4) we address the issue of possible endogeneity of per capita GDP, which might be due to reverse causality issues, by applying the control function approach suggested by Wooldridge (2002) for the probit specification. First step residuals are obtained by regressing the endogenous variable on the whole set of exogenous variables, which now include also spatial variables, namely dummy variables taking the value 1 if the university is located in a Centre or Southern region, respectively. Results in column 6 indicate a larger effect for per capita GDP (0.0046, implied elasticity at mean value 0.135%), whereas the effect of hosting a medical school is unchanged.

Finally, we check whether being a university located on an island has some adverse effects on technical efficiency, which might be caused by being more peripheral with respect to scientific and academic networks (reduced student and staff mobility, limited connectedness). Results show that when we consider both main Italian islands, Sicily and Sardinia, there is no significant effect. However, when we consider the two islands separately, Sicily universities remain unaffected by their insularity condition. In contrast, the Sardinia ones exhibit a sizeable and significant negative effect, as reported in column 7 (Table 4). This result is relevant as it highlights that it is not being on an island per se, which could be detrimental for a university, but rather the insularity condition coupled with remoteness from the mainland. In the case of Italy, this is a problematic issue since part of the FFO is allocated based on the students' attractiveness criterion. Hence, Sardinia universities are financially at a disadvantage for being "geographically unattractive", a factor which is out of their control and that can be hardly counterbalanced with less available financial resources.

In Table 5 we replicate the analysis for the year 2017. Based on the evidence provided by the single contextual variable models (1-3), it turns out that only school competencies are relevant in explaining technical efficiency. However, the effect is remarkably lower, almost half (0.0017) the one found for 2010 (0.0028). Per capita GDP turning insignificant might be due to the convergence process already discussed in section 4, with the initially less efficient universities, in general, those in the South and the islands, reaching the highest efficiency gains. Models in columns 4, 5 and 6 in Table 5, now replace per capita GDP with school skills as the main contextual variable. The results for 2017 provide additional evidence on the negative effects related to the presence of medical schools and specific and persistent geographical conditions. However, it is worth highlighting that their effects are less sizeable than the ones reported for 2010.

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[16] Estimation is carried out by using STATA GLM routines. See also http://maartenbuis.nl/software/index.html.

[17] Logit fractional response models, estimated for robustness reasons, yielded very similar results.

6.4 Context-adjusted TE scores

Following previous contributions (Huguenin, 2015; Tupper and Resende, 2004; De Witte and Moesen, 2010), we finally computed the adjusted efficiency scores, which, accounting for the effect of contextual factors, allow for a more rigorous comparison across universities.[18] This way, they are no longer considered as totally independent entities that could operate anywhere regardless of their actual location. Table 6 compares the TE summary statistics for the unbiased DEA estimation (model 1 in Table 2) with those computed from the fractional response probit specifications (model 7 in Table 4 for 2010 and model 6 in Table 5 for 2017). The most interesting results are that the dispersion in the TE values considerably declines when the influence of the external factors is correctly accounted for. Universities are more similar in their TE levels once the impact of the contextual factors is considered.

This is particularly remarkable for the universities located in the South (which includes the two islands of Sicily and Sardegna), as we can see in the bottom part of Table 6, where we compare the TE levels between unbiased DEA and context-adjusted estimation. Universities located in the South are those that, consistently across time, exhibit the highest efficiency gains. In contrast, the opposite is the case for Northern universities, albeit with some slight differences in the rankings. Focusing on 2010, when the adjustment accounts for differences in GDP per capita and the presence of medical schools and insularity conditions, gains are remarkable for the two universities located in the peripheral island of Sardegna (Sassari with 23.6% gain, and Cagliari with 22%). Efficiency gains are still sizeable in 2017 (around 16% for Sassari and Cagliari) when the competencies are the most relevant contextual variable. However, as emphasised in the previous sections, the relevance of regional factors tends to decrease over the period analysed.

In general, being located in a wealthy region such as Lombardy or Veneto (or in the North of Italy in general) and not having the burden of healthcare provision allows universities to more easily reach high levels of internal efficiency. Once the external context is considered, these universities see their net efficiency reduced. Conversely, universities that suffer from geographical isolation, less favourable economic conditions and must also contribute to the healthcare system have a lower internal efficiency than they would have considering the penalising effects of these external factors.

Our results show a general reduction in disparities across Italian public universities which may be induced by the incentives brought about by recent university rules such as the FFO reward quota and the research evaluation system. At the same time, it is worth remarking that the local context is still playing a role in acting as a penalising element for the Mezzogiorno universities, as shown by the variation in the adjusted TE ranking.

7. Concluding remarks

The paper analyses the TE scores of Italian public universities in 2010 and 2017 using a two-stage DEA approach. In the first stage, the internal TE of each university is calculated using a nonparametric bootstrap-DEA method, with careful attention to selecting appropriate output and input variables. In the second stage, linear and fractional response models are used

[18] Adjusted efficiency scores are computed as $TE_i^{adj} = e_i + [1 - max(e_i)]$, where e_i are the response residuals obtained from the fractional responses probit regressions.

to assess the impact of the socio-economic characteristics of the area where each university is located on internal TE.

From a methodological perspective, our study provides a twofold contribution to the extant literature. First, we provide further support for the use of the DEA nonparametric method, which outperforms alternative approaches for being more flexible and much easier to apply, especially for non-academics, such as managers or policymakers alike. Complexities related to the application of the advanced bootstrap method could be avoided when sample variability is not an issue. Second, for the first time, we have investigated local context determinants of efficiency scores by applying fractional responses models, which are the most adequate specification in the case of proportional data. Although such specification allows for a more rigorous assessment of the effects as they allow to take into proper account nonlinearities and possible endogeneity, comparison with linear specifications indicates that the latter perform adequately when the explanatory variables do not take extreme values. This, again, represent a relevant advantage from a practitioners' perspective.

The preferred model, with two outputs (teaching and research activities) and four inputs (first-year enrolled students, number of academic and TA employees, and financial resources), points out a general increase in relative technical efficiency from 2010 to 2017 along with a notable reduction in dispersion. In general, Northern universities tend to score higher, but the reduced variability and convergence among Italian HEIs is largely driven by improvements in Southern universities. Overall, universities seem to have responded to the specific measures brought about by the reforms from the last two decades (reward quota in the state financing fund based on the evaluation of the teaching and scientific research attainments) by improving their internal performance. These results are confirmed by a wide array of robustness checks based on alternative specifications of the main model.

This novel evidence offers a valid contribution to the debate on the efficiency of the Italian university system. In most studies, the analysis was carried out over periods ending in the years 2010 or 2011, when the implementation of the reforms was still in its infancy making it difficult to single out the converging effects which became evident in the subsequent years.

Notwithstanding the converging process, the local context still plays a crucial role in determining the universities' efficiency levels as shown by the results of the second-stage analysis. Both linear and fractional response models provide convincing evidence on how the level of per capita income, students' skills and the quality of local institutions affect universities' efficiency, although the effects decrease in size over time. As in previous studies, we have also found a negative effect due to the presence of medical schools. These entail an additional burden for universities in terms of human and financial resources which tend to reduce the relative productivity of the university. Differently from previous contributions, we also tackle the issue of "isolated" universities. Our results show that being a university located on a remote island like Sardinia has adverse effects on technical efficiency since it limits the degree of connectedness and makes more difficult the functioning of scientific and academic networks.

Efficiency scores adjusted for the local context effects, allowing for more accurate comparisons across universities, are much less dispersed than the unadjusted ones. The upward adjustment is particularly remarkable for the universities situated in the South and the islands. In general, universities located in rich regions like Lombardy or Veneto, and not including a medical school, typically achieve higher internal efficiency scores. These universities see their adjusted efficiency reduced when the external context is considered.

Conversely, universities that suffer from geographical isolation and poor economic conditions, like those situated in the South and the islands, have an internal efficiency lower than they would have considering the penalising effects of these external factors.

Overall, our findings indicate a general reduction in disparities across Italian public universities. While the economic gap between the Centre-Northern and the Southern part of the country persists and indeed has widened as a consequence of the great economic crisis, it appears that the local context has become less critical over time in determining the efficiency of universities as these seem to be more responsive to the pressure and incentives brought about by recent university reforms (FFO reward quota, research evaluation system, more accountability). However, the COVID-19 pandemic may have disrupted this trend. If the pandemic's negative effects on the education system and the economy persist, local context could once again become a major determinant of university outcomes, potentially leading to divergent paths based on regional strengths. Strong and effective policies are needed to preserve educational opportunities, support research and knowledge creation, and mitigate risks of exclusion and inequality. It is our intention to explore these issues in future research thoroughly.

There is broad consensus that Italy's public university system, which is almost entirely funded by taxpayers, requires a reliable accountability mechanism. Although it is generally accepted that a significant and growing proportion of public funding is linked to the universities' performances in teaching and research activities, the current allocation of state funding does not adequately account for the impact of regional socio-economic conditions on university internal productivity. If a balanced compensation for the adverse territorial conditions is not included in the national reward scheme, then a vicious circle is dangerously fuelled. Fewer resources to the universities operating in lagging Southern areas mean less capacity to generate human capital and technological innovation at the local level; this further worsens the local socio-economic conditions and the university efficiency. This paper, by suggesting to decision-makers and practitioners an easy procedure to calculate the universities' internal efficiency and the impact exerted by contextual factors, can be useful for defining more balanced policy measures to finance the public university system.

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Table 1. Variables and indicators

	2010				2017			
	mean	min	max	coeff. of variation	mean	min	max	coeff. of variation
Outputs								
graduates	4636	731	19782	0.81	4909	861	18392	0.82
articles in scientific journals	1725	165	6579	0.89	2071	240	7797	0.88
research quality average mark, VQR	0.57	0.36	0.71	0.13	0.58	0.47	0.71	0.09
Inputs								
total expenditures (mln euro)	167	27	622	0.77	195	34	722	0.80
teaching staff	969	166	4161	0.81	880	150	3405	0.78
technical and administrative staff	1002	167	4544	0.89	883	154	3906	0.84
1st year enrolled students (with 3 years lag)	8454	1650	35526	0.80	7497	1421	27345	0.79
Indicators								
graduates / 1st year students, %	55.7	24.2	87.8	0.18	65.2	48.4	90.4	0.13
graduates / teaching staff	5.0	2.6	9.5	0.26	5.7	2.8	9.9	0.28
articles / teaching staff	1.7	0.8	3.0	0.27	2.3	1.0	3.5	0.22
expenditure / graduates (thousands euro)	37.0	21.6	66.2	0.25	40.9	22.1	68.5	0.24
1st year students with high diploma score 90-100, %	26.2	14.8	41.1	0.21	21.1	8.9	41.8	0.30

Number of universities: 56

Data sources:

Graduates, students, staff: Minister of University (MUR)

Scientific articles: IRIS websites of each university (data collected in November 2019)

Research quality average mark, VQR: Agenzia Nazionale di Valutazione del sistema Universitario e della Ricerca (ANVUR)

Expenditures: Conti Pubblici Territoriali, Siope

Table 2. University technical efficiency, unbiased DEA estimations

Baseline model (M1):
two outputs: teaching (graduates), research (n. articles)
four inputs: total expenditure, teaching staff, TA staff, 1° year students

	2010	2017
TE summary statistics, Italy		
mean	0.869	0.889
st. dev.	0.071	0.056
max	0.955	0.961
min	0.683	0.720
Mean TE in macro areas		
North	0.892	0.903
Centre	0.890	0.869
South	0.834	0.886

Table 3. University technical efficiency, robustness analysis

Model	Changes in Output and Input with respect to M1 (bold vbl change; italics vbl addition)	2010			2017		
		Mean TE	St. Dev.	Pearson correlation	Mean TE	St. Dev.	Pearson correlation
M2	O: **VQR research quality**	0.877	0.067	0.83	0.895	0.055	0.55
M3	I: **expenditures net of personnel costs**	0.873	0.067	0.91	0.906	0.060	0.87
M4	I: **students with low grade diploma; and students with high grade diploma**	0.885	0.068	0.96	0.885	0.068	0.94
M5	I: *number of teaching courses provided*	0.873	0.070	0.98	0.892	0.056	0.99
M6 *	I: *quality of infrastructures*	0.884	0.068	0.92	0.901	0.056	0.93

Correlations are computed with respect to M1

* based on 55 observations (missing Milano Politecnico)

Table 4. University technical efficiency and regional context determinants, 2010

Dependent variable: unbiased technical efficiency levels from DEA estimation (M1)

	Linear Models				Fractional Probit Models		
	1	2	3	4	5	6	7
GDP pc (thousands euro)	0.0037 ***			0.0036 ***	0.0036 ***	0.0046 ***	0.00378 ***
	(0.0011)			(0.0011)	(0.0010)	(0.0014)	(0.0013)
School competence		0.0028 **					
		(0.0012)					
Institutional capital			0.0011 *				
			(0.0005)				
Dummy medicine				-0.0396 *	-0.0398 **	-0.0390 **	-0.0321
				(0.0215)	(0.0205)	(0.0203)	(0.0209)
Dummy Sardinia							-0.1108 ***
							(0.0161)
First step residuals							
r^2	0.1229	0.1358	0.0496	0.2007	0.2062	0.2688	0.3537

Number observations: 56
All regressions include a constant term
Marginal effects (ME) are reported for Fractional Probit models.
ME are computed at the mean of the continuous variables and for discrete change of dummy variables from 0 to 1
Standard Errors in parentheses are clustered at the regional level. In models 6 and 7 they are bootstrapped
r^2 is the squared correlation coefficient between TE and model's predicted values
Significance levels: *** 1%, ** 5 %, * 10%

Table 5. University technical efficiency and regional context determinants, 2017

Dependent variable: unbiased technical efficiency levels from DEA estimation (M1)

	Linear Models			Fractional Probit Models		
	1	2	3	4	5	6
GDP pc (thousands euro)	0.0007					
	(0.0011)					
School competence		0.0017 **		0.0016 **	0.0015 **	0.0010 *
		(0.0007)		(0.0007)	(0.0006)	(0.0006)
Institutional capital			0.0004			
			(0.0006)			
Dummy medicine				-0.0279 ***	-0.0278 ***	-0.0255 ***
				(0.0095)	(0.0092)	(0.0089)
Dummy Sardinia						-0.0491 **
						(0.0200)
r^2	0.0075	0.0913	0.0076	0.1534	0.1539	0.1858

Number observations: 56

All regressions include a constant term

Marginal effects (ME) are reported for Fractional Probit models.

ME are computed at the mean of the continuous variables and for discrete change of dummy variables from 0 to 1

Standard Errors in parentheses are clustered at the regional level

r^2 is the squared correlation coefficient between TE and model's predicted values

Significance levels: *** 1%, ** 5 %, * 10%

Table 6. Comparison between unbiased DEA TE and context-adjusted TE

	2010		2017	
	DEA (a)	Adjusted (b)	DEA (c)	Adjusted (d)
TE summary statistics, Italy				
average	0.869	0.868	0.889	0.925
st. dev.	0.071	0.057	0.056	0.050
max	0.955	1.000	0.961	1.000
min	0.683	0.727	0.720	0.743
Mean TE in macro areas				
North	0.892	0.866	0.903	0.928
Centre	0.890	0.874	0.869	0.903
South	0.834	0.868	0.886	0.935

(a) (c): unbiased DEA estimation, Model 1, Table 2

(b) (d): adjusted efficiency levels (eq 7 Tab 5, eq 6 Tab 6)

Table A1. University Technical Efficiency: unbiased DEA and context adjusted levels (Model 1)

University	Region	Macro-region	University size	Medical school	TE 2010 DEA (a)	TE 2010 Adjusted (b)	TE 2017 DEA (c)	TE 2017 Adjusted (d)
Bari	Puglia	South	Mega	1	0.77	0.81	0.84	0.89
Bari Politecnico	Puglia	South	Small	0	0.73	0.73	0.92	0.94
Basilicata	Basilicata	South	Small	0	0.83	0.82	0.92	0.94
Bergamo	Lombardia	North	Medium	0	0.90	0.85	0.92	0.93
Bologna	Emilia-R.	North	Mega	1	0.90	0.89	0.92	0.96
Brescia	Lombardia	North	Medium	0	0.84	0.80	0.89	0.91
Cagliari	Sardegna	South (Island)	Large	1	0.73	0.89	0.81	0.94
Calabria	Calabria	South	Large	0	0.93	0.93	0.86	0.90
Camerino	Marche	Centre	Small	0	0.89	0.85	0.92	0.94
Cassino	Lazio	Centre	Small	0	0.94	0.91	0.72	0.74
Catania	Sicilia	South (Island)	Mega	1	0.95	1.00	0.90	0.97
Catanzaro	Calabria	South	Medium	1	0.89	0.93	0.92	0.98
Chieti e Pescara	Abruzzo	South	Large	0	0.89	0.90	0.92	0.94
Ferrara	Emilia-R.	North	Medium	1	0.92	0.91	0.92	0.96
Firenze	Toscana	Centre	Mega	1	0.93	0.93	0.80	0.85
Foggia	Puglia	South	Medium	1	0.94	0.98	0.82	0.87
Genova	Liguria	North	Large	1	0.77	0.76	0.84	0.88
Insubria	Lombardia	North	Medium	0	0.91	0.87	0.87	0.88
L'Aquila	Abruzzo	South	Medium	0	0.77	0.78	0.92	0.94
Macerata	Marche	Centre	Medium	0	0.95	0.90	0.95	0.97
Marche	Marche	Centre	Medium	1	0.85	0.85	0.85	0.89
Messina	Sicilia	South (Island)	Large	1	0.73	0.77	0.85	0.91
Milano	Lombardia	North	Mega	1	0.89	0.89	0.92	0.95
Milano Bicocca	Lombardia	North	Large	0	0.89	0.85	0.93	0.94
Milano Politecnico	Lombardia	North	Mega	0	0.91	0.87	0.92	0.93
Modena e R.E.	Emilia-R.	North	Large	1	0.84	0.82	0.83	0.87
Molise	Molise	South	Small	0	0.92	0.93	0.93	0.95
Napoli Federico II	Campania	South	Mega	1	0.84	0.89	0.94	1.00
Napoli L'Orientale	Campania	South	Medium	0	0.91	0.90	0.92	0.94
Napoli Parthenope	Campania	South	Medium	0	0.92	0.92	0.92	0.95
Napoli Vanvitelli	Campania	South	Large	1	0.75	0.79	0.91	0.96
Padova	Veneto	North	Mega	1	0.94	0.92	0.94	0.97
Palermo	Sicilia	South (Island)	Mega	1	0.80	0.84	0.87	0.93
Parma	Emilia-R.	North	Large	1	0.78	0.77	0.91	0.94
Pavia	Lombardia	North	Large	1	0.95	0.95	0.91	0.94
Perugia	Umbria	Centre	Large	1	0.86	0.85	0.96	1.00
Piemonte Orientale	Piemonte	North	Medium	1	0.95	0.93	0.82	0.86
Pisa	Toscana	Centre	Mega	1	0.82	0.82	0.84	0.88
Roma La Sapienza	Lazio	Centre	Mega	1	0.89	0.90	0.92	0.97
Roma Tor Vergata	Lazio	Centre	Large	1	0.76	0.77	0.73	0.78
Roma Tre	Lazio	Centre	Large	0	0.95	0.92	0.95	0.97
Salento	Puglia	South	Medium	0	0.85	0.84	0.85	0.88
Salerno	Campania	South	Large	1	0.79	0.84	0.86	0.91
Sannio	Campania	South	Small	0	0.89	0.89	0.92	0.94
Sassari	Sardegna	South (Island)	Medium	1	0.68	0.84	0.78	0.91
Siena	Toscana	Centre	Medium	1	0.90	0.90	0.91	0.95
Teramo	Abruzzo	South	Small	0	0.84	0.84	0.94	0.96
Torino	Piemonte	North	Mega	1	0.94	0.92	0.93	0.97
Torino Politecnico	Piemonte	North	Large	0	0.92	0.86	0.92	0.94
Trento	Trentino A.A.	North	Medium	0	0.95	0.91	0.95	0.96
Trieste	Friuli V.G.	North	Medium	1	0.84	0.82	0.96	0.99
Udine	Friuli V.G.	North	Medium	1	0.84	0.82	0.80	0.83
Urbino	Marche	Centre	Medium	0	0.93	0.89	0.87	0.89
Venezia Cà Foscari	Veneto	North	Large	0	0.93	0.88	0.93	0.94
Venezia Iuav	Veneto	North	Small	0	0.89	0.84	0.91	0.92
Verona	Veneto	North	Large	1	0.92	0.90	0.93	0.96

(a) (c): unbiased DEA estimation, Model 1, Table 2

(b) (d): adjusted efficiency levels (eq 7 Tab 5, eq 6 Tab 6)

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