How (in)efficient are European Higher Education Institutions?
A Robust Nonparametric Analysis

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Introduction and research questions

On the basis of the first comparative study on European universities based on quantitative data, Bonaccorsi and Daraio (2007) discussed the notion of university strategy, as an emergent pattern of configuration of university outputs that (at least partially) depend on (relatively) autonomous decision making by universities, supported by appropriate inputs. The notion of strategy clearly implies recognizable differences across universities. These differences depend, on one hand, on institutional configurations at the level of countries (e.g. dual vs. unitary systems; role of the private sector; level of massification of higher education, and the like), but also on individual positioning that capitalize on their resources.

The proposition was that strategic subjectivity of universities, in a world where students' mobility is becoming a reality, and emergent countries create universities at a high pace, will become more and more important. The higher the turbulence of the environment the more stringent becomes the need for universities to leverage on their strategic profile. A vivid description of what it may mean for global universities is offered by Wildavsky (2010).

In this paper we make a further step in the articulation of the notion of university strategy. It is essential to this notion the idea that decisions about the offering profile, or in the space of outputs, depend on constraints on the inputs. Universities deal with how to make the best use of their existing resources, and procure future resources, in order to make their competitive position sustainable in the long run. Strategic management must build the best possible relation between resources and offering, or inputs and outputs. One relevant question, in this perspective, is whether the unit is making the best use of existing resources, or whether technical efficiency is in place. While allocative efficiency requires a price system to be in place (which is not the case for universities in the European system), the notion of technical efficiency relies on how resources (inputs) are used to produce the maximum possible level of outputs.

Clearly, efficiency is not the only relevant strategic question, but it is one of the most important. The lack of any link between inputs and outputs may be fatal for any strategy, whatever ambitious it may be. Therefore in this paper we address the question of *technical efficiency*, as an important topic in the broader research agenda of university strategy.

We will address the following main questions.

First, how efficient are European universities? Second, are there increasing returns to scale in university production, particularly in teaching? Finally, is there a trade-off, or a substitution effect, between teaching and research activity?
These questions are largely discussed in the literature, but typically on the basis of poor empirical evidence, or sometimes flawed models. We give a contribution by employing the last generation of robust non parametric techniques on data that come from a unique census of higher education institutions in all European countries.

Existing literature

The literature on efficiency of higher education institutions is very large, and has been typically based on Data Envelopment Analysis, or on regression techniques using flexible specifications (see Johnes, 1992; Worthington, 2001; Salerno, 2005 for a survey). There are several limitations with these approaches, as discussed in Marsh (2004) and Bonaccorsi and Daraio (2004). For example, there is a need for a large sample in order to test a rich model, and the presence of outliers and anomalies makes the estimation of efficiency not reliable. Furthermore, the point estimation of efficiency depends on the most efficient ones in the sample, which makes the positioning of individual universities vis-à-vis the others highly variable over time. We contribute to this literature not only by using, for the first time, a large census of European higher education institutions, but also by using robust techniques, which offer much more reliable results.
Also the problem of economies of scale is largely debated (Brinkman and Leslie, 1986; Charnes, Cooper and Rhodes, 1978; Cohn, Rhine and Santos, 1989). While the empirical results are mixed (Nelson and Hevert, 1992; Lloyd, Morgan and Williams, 1993; see Von Tunzelmann et al., 2003 and Bonaccorsi and Daraio, 2005 for surveys), there is a widespread wisdom that large universities are more efficient than small ones, and that consolidation and mergers are good policy. We add fresh evidence to this debate, by offering detailed results at an aggregate European level, as well as at country level and by category of institutions.
Finally, the existence and strength of complementarity and substitution effects between the two main missions of universities, research and teaching, are also the object of passionate debate (Glass, Mckillop and Hyndman, 1995a; 1995b). One important implication of this debate is the one pointing to the need for differentiation of university profiles (Bonaccorsi, Daraio and Simar, 2006; Bonaccorsi and Daraio, 2009), or, as sometimes stated, to the need for post-Humboldtian models in higher education (Schimank and Winnes, 2000).
By and large, the discussion on these effects is based on the examination of the sign and magnitude of regression coefficients (if a parametric approach is used) or on average efficiency scores (in a non parametric setting) in small samples of universities.

Data

We take the unique opportunity to exploit a large database, recently constructed by the EUMIDA Consortium under a European Commission tender, supported by DG EAC, DG RTD, and Eurostat (EUMIDA, 2010; Bonaccorsi et al., 2010). This database is based on official statistics produced by National Statistical Authorities (NSAs) in all 27 EU countries plus Norway and Switzerland. The EUMIDA project included two data collections: Data Collection 1 (DC 1) included all higher education institutions that are active in graduate and postgraduate education (i.e. universities), but also in vocational training. Thus all institutions delivering ISCED 5a and 6 degrees are included, and the subset of those delivering ISCED 5b degrees that have a stable organization (i.e. mission, budget, staff). There are 2,457 institutions identified in Data Collection 1: these constitute the perimeter of higher education institutions in Europe. On these institutions a large set of uniform variables have been collected.

Of these, 1,364 are defined research active institutions: of these only 850 are also doctorate awarding. They are the object of Data Collection 2 (DC 2), for which a larger set of variables were collected. This means that a significant portion of research active institutions is found outside the traditional perimeter of universities, i.e. in the domain of non-university research (particularly in countries with dual higher education systems). Bibliometric indicators suggest that the research carried out in the non-university sector is less visible than the one in the university sector. There are also 1,052 non-research active institutions, most of which are non-doctorate awarding. In terms of the highest degree delivered, 840 institutions (34.2%) deliver up to the bachelor, 675 (27.5%) up to the master, and 892 (36.3%) up to the doctoral degree, while 2% of data is missing; this means that the higher education landscape is formed by three groups of approximately similar size.

According to Schubert et al. (2010) if various descriptors are used to build up clusters and their number is optimized, it turns out that only two clusters emerge (in a slightly different specification, a small third cluster is visible, mostly formed by private institutions). These clusters correspond quite precisely to the University model (i.e. doctorate awarding, research active institutions: 52.2% of the total) and the College model (i.e. non doctorate awarding, partly active, partly non active in research: 47.8% of the total). In the clustering exercise national differences do not matter a great deal. This means that the European landscape, notwithstanding several national specificities, is structurally similar to the landscape of other large countries in which there is a differentiation of educational missions across institutions. However, while the number of non-doctorate institutions is quite large, almost 80% of students are enrolled in institutions with the right to award the doctorate, while 8.8% are enrolled in the 846 institutions that deliver only bachelor degrees and 12.6% are enrolled in institutions that deliver up to master degrees. This means that the College model is not yet mature in most European countries, in the sense that it does not capture a significant share of students' preferences. It seems that students prefer to study at universities even if they do not reach the highest degrees, rather than attending non-doctorate institutions. This issue is discussed in the EUMIDA Report (2010) in the light of the debate on convergence of European countries towards the dual model.

We will use the data for addressing another issue: is there a relation between the educational model (i.e. doctorate vs non-doctorate awarding) and the research model (i.e. research active vs non research active) in terms of technical efficiency?

Furthermore, we will address the increasing returns issue by separating these categories and by using descriptors of the subject mix (specialisation across disciplines). This will deliver much more precise results than done before in the literature.

Data on PhD education are very detailed in the EUMIDA dataset. At the ISCED 6 level, the core data set covers 531,370 students and 92,631 doctorate degrees awarded. The number of institutions offering a doctorate as the highest degree is 885 - equivalent to 36% of all HEIs. A further 5 HEIs report offering an intermediary ISCED 6 qualification and thus have students at the ISCED 6 level. In total, 890 HEIs have students at the ISCED 6 level. Thereof 850 report being research-active, equivalent to 96% of all HEIs with ISCED 6 students. The remainder comprises art colleges, theological academies, defence universities, or specialised HEIs in management or finance. In the dataset 870 HEIs provide data for students at the ISCED 6 level. Therein the maximum share of ISCED 6 students within all students is 100%, the minimum 0.1%, the median 3.3%. The distribution of this share is extremely skewed. The HEIs with very high shares of ISCED 6

students are generally quite small (in terms of student numbers) and specialised in fields such as theology, arts, or specific technologies. The HEIs with very low shares are primarily teaching/education-oriented. The intersection with HEIs without ISCED 6 students appears to be diffuse. The "standard" universities can be found in the range between 2% and 8%; this share can then be interpreted in terms of research orientation.
Using these data we will address the third research question, i.e. whether there is a trade off between research and teaching. We will approximate research activity by using the share of PhD students out of the total number of students. We will also use data on internationalization of PhD and of staff, available for all DC 1 institutions, as well as data on scientific publications and patents, available for a much smaller set of institutions in DC 2, in order to test the robustness of the model based only on PhD.

Methodology

In efficiency analysis the main purpose is the study of how firms combine their inputs to obtain their outputs. More generally, in an activity analysis framework (see e.g. Debreu, 1951; Shephard, 1970), the management of a Decision Making Unit (DMU) is characterized by a set of inputs $x \in R_+^p$ used to produce a set of outputs $y \in R_+^q$. The set of technically feasible combinations of (x, y) is defined as:

$$\Psi = \{(x, y) \in I\!R_+^{p+q} \mid x \text{ can produce } y\}.$$

In this setting, the Farrell measure of output-oriented efficiency[1] for a firm operating at the level (*x, y*) can be defined as:

$$\lambda(x, y) = \sup\{\lambda \mid (x, \lambda y) \in \Psi\},$$

where $\lambda(x, y) \geq 1$ is the proportionate increase of outputs a DMU working at the level (*x, y*) should perform to achieve efficiency, and $1/\lambda$ is the Shepard output distance function (Shephard, 1970). The efficient frontier corresponds to those firms where $\lambda(x, y) = 1$.
In efficiency analysis, the nonparametric approach is based on envelopment techniques, whose main estimators are Data Envelopment Analysis (DEA, see Farrell, 1957, and Charnes, Cooper and Rhodes, 1978) and Free Disposal Hull (FDH, see Deprins, Simar and Tulkens, 1984). These estimators rely on the idea that the attainable set is defined by the set ofminimum volume containing all the observations. The DEA estimator relies on the free disposability[2] and on the convexity of the set ψ, whereas the FDH relies only on the free disposability assumption. The FDH estimator of ψ, based on a sample of *n* observations (x_i, y_i), is the free disposal closure of the reference set $\{(x_i, y_i) | i = 1, ..., n\}$. It can be defined as:

$$\widehat{\Psi}_{FDH} = \Big\{(x, y) \in I\!R_+^{p+q} \mid y \leq y_i, x \geq x_i, i = 1, ..., n\Big\}.$$

The DEA estimator of ψ, is the convex closure of $\hat{\psi}_{FDH}$:

[1] To save space, we only present the output oriented case that we applied in the empirical analysis.
[2] A set Ψ is free disposal if $(x, y) \in \Psi$ implies $(x', y') \in \Psi$ for any $x' \geq x$ and $y' \leq y$.

$$\widehat{\Psi}_{DEA} = \Big\{(x,y) \in I\!R_+^{p+q} \mid y \leq \sum_{i=1}^{n} \gamma_i \, y_i \; ; \; x \geq \sum_{i=1}^{n} \gamma_i \, x_i, \quad \text{for } (\gamma_1, ..., \gamma_n) \quad \text{s.t.} \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \geq 0, i = 1, ..., n\Big\},$$

The estimated output oriented FDH efficiency score of a firm (*x , y*) is given by:

$$\widehat{\lambda}_{FDH} = \max\{\lambda \mid (x, \lambda y) \in \widehat{\Psi}_{FDH}\}.$$

Similarly, the estimated output oriented DEA efficiency score of a DMU (*x , y*) is given by:

$$\widehat{\lambda}_{DEA} = \max\{\lambda \mid (x, \lambda y) \in \widehat{\Psi}_{DEA}\}.$$

The nonparametric approach in efficiency analysis offers several advantages, among whose:
- absence of specification of the functional form for the input-output relationship;
- measurement of the efficiency with respect to the efficient frontier which measures the best performance that can be practically achieved;
- appropriate benchmark to be used for comparison: non requirement of any theoretical models as benchmarks;
- production of *multi-inputs multi-outputs* performance indicators.

One of the main drawbacks of DEA/FDH nonparametric estimators is their sensibility to extreme values and outliers in the data.

To overcome this methodological limitation, the so called *robust partial* frontiers of order-m and order-alpha have been introduced in the efficiency analysis literature (see Daraio and Simar, 2007).

The robust nonparametric methodology we apply in this paper, based on partial frontiers or order-m and order-alpha, adds some new advantages to the traditional nonparametric approach (DEA/FDH):

- As the robust indicators are based on estimators that do not envelop all units, they are more robust to outliers and noise in the data which may strongly influence the nonparametric estimation of efficiency. The level of robustness can be set by means of *m* and alpha (tuning parameters).

The robust nonparametric indicators avoid the *curse of dimensionality*, typically shared by non-parametric estimators. The partial frontier indicators are $\sqrt{n}$-consistent estimators whereas the DEA are only $n^{2/(p+q+1)}$-consistent estimators ($n^{1/(p+q)}$ for the FDH). This indicates for the DEA/FDH the necessity of increasing the number of observations when the dimension of the input-output space increases to achieve the same level of statistical precision;

- The possibility of explaining inefficiency, considering the *conditional influence* of *external factors* on the full frontier and on its robust counterpart, by using conditional efficiency measures (Daraio and Simar, 2005, 2006, 2007).

- Using this approach, we can evaluate the effect of external/environmental *Z* variables on the performance of firms in a more general and flexible way (Badin, Daraio and Simar, 2010; Daraio, Simar and Wilson, 2010).

Expected results

We will build up several input-output models, based on the available data, using the number of ISCED 5 students and degrees, plus the number of ISCED 6 students and degrees as the main output variables. This will be considered a “teaching efficiency model”, in the former case, and a “teaching and research model” in the latter case.
For units in DC 2, we will add variables representing research activities, such as publications, patents and spinoff companies, for separate subsets of institutions, depending on the availability of data.
Inputs will be represented by academic and non academic staff. Where available, for a subset of DC 2, data on financial resources will be used.
External variables will include the regional localization, the private/public configuration, and the size in terms of students and/or staff.
The expected results are the estimation of several efficiency models, the identification of characteristics of the most efficient (and least efficient) units, and the discussion on possible determinants of efficiency.
A broader discussion on the meaning of technical efficiency in the domain of reform of higher education will be presented as a conclusion of the paper.

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