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Advanced indicators of productivity of universities. An application of robust nonparametric methods to Italian data

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This paper explores scale, scope and trade-off effects in scientific research and education. External conditions may dramatically affect the measurement of performance. We apply the DARAIO & SIMAR's (2005) nonparametric methodology to *robustly* take into account these factors and decompose the indicators of productivity accordingly. From a preliminary investigation on the Italian system of universities, we find that economies of scale and scope are not significant factors in explaining research and education productivity. We do not find any evidence of the trade-off research vs teaching. About the trade-off academic publications vs industry oriented research, it seems that, initially, collaboration with industry may improve productivity, but beyond a certain level the compliance with industry expectations may be too demanding and deteriorate the publication profile. Robust nonparametric methods in efficiency analysis are shown as useful tools for measuring and explaining the performance of a public research system of universities.

Introduction

In recent years the pressure on public budgets in almost all industrialised countries has lead governments to pursue efficiency in the allocation and management of public sector resources. The increasing societal demand for accountability and transparency of science and research also makes it important to demonstrate that public funding follows clear rules. A manifestation of this trend is the effort to apply to public scientific research two concepts drawn from economic analysis, that are economies of scale and economies of scope. At the level of universities, size and scope may be reflected in appropriate measures of inputs or outputs (e.g. staff or enrollments or graduate students, number of schools, number of different curricula) in a range between specialist universities, covering a few fields, to generalist universities, covering almost the entire spectrum of disciplines. If these two forces were at play in scientific research and higher education, then a sound policy implication would be that in order to improve the public

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efficiency, resources should be concentrated into larger institutions and/or more generalist universities. On the other hand, there may be negative scope effects, implying that different activities are *rival* rather than being complementary. This paper explores scale, scope and trade-off effects in scientific research and higher education. We apply robust nonparametric techniques for estimating the technical efficiency of the Italian system of universities. *Robust* methods are really useful in this framework for their properties of not being influenced by extreme values and outliers in the data. Several methodological advancements have been done in nonparametric frontier estimation with robust methods based on the concept of order-m frontiers (CAZALS et al., 2002). These recent methods have been applied for the first time to scientific research by BONACCORSI & DARAIO (2003), who offer a comparison between two large institutions in biomedical research in two countries.

In science and education, external factors may be cause of heterogeneity and may considerably affect the performance of universities. Several studies tried to face this problem by developing and applying one-stage or two or multiple-stage approaches to take into account what they define as *socio-economic differences*.[1] The basic idea was to relate efficiency measures to some external or environmental factors which might influence the production process but which are not under the control of the managers. Unfortunately, both one stage and multiple stage approaches are flawed by restrictive prior assumptions and/or on the role of these external factors on the analysed process. On the one hand, as discussed and demonstrated by SIMAR & WILSON (2005), the multiple-stage approaches suffer of several methodological problems related to the complicated and unknown autocorrelations between first and second stages estimation procedures but also to the inherent bias of the first stage efficiency estimates. On the other hand, in the one stage approach one has to assume the effect of the external factors on the production process, i.e. the analyst should know in advance if the external factors affect positively or negatively the comprehensive performance. Of course, these problems and assumptions are very strong.

DARAIO & SIMAR (2005) generalizing the approach of CAZALS et al. (2002) propose a full nonparametric methodology to explain efficiency differentials by external-environmental factors that overcomes most limitations of previous approaches. In particular, the effect of external factors came as a result of the analysis and is not assumed.

The nonparametric approach in efficiency analysis is based on envelopment techniques, whose main estimators are Data Envelopment Analysis (DEA, see FARRELL, 1957 and CHARNESet al., 1978) and Free Disposal Hull (FDH, see DEPRINS et al., 1984). It offers several advantages, such as: 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

[1]See RUGGIERO (2004) and the references cited there.

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. The robust nonparametric methodology we apply in this paper, based on order-m efficiency scores (see CAZALS et al. (2002) and DARAIO & SIMAR (2005)) adds some new advantages to the traditional nonparametric approach (DEA/FDH): these indicators are more robust to outliers and noise in the data; they avoid the *curse* of dimensionality, typical of nonparametric estimators, meaning 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 order-m indicators allow to compare samples with different size, avoiding the *sample size bias*, of which nonparametric indicators (DEA/FDH) suffer.

DARAIO & SIMAR (2005) introduce *conditional* measures of efficiency (for the FDH and the order-m case), i.e., efficiency scores affected by external factors. They also propose a simple methodology to explain efficiency differentials by these *external factors Z*. The procedure is based on the comparison of the *conditional* FDH measure with the *unconditional* FDH measure. Accordingly, the same comparison is done for the robust order-m efficiency measures. In particular, the ratios of conditional/ unconditional FDH scores Q^z (and their robust version Q^z_m) are useful to investigate on the effects of Z on performance: if $Q^z=1$, then the conditional and unconditional efficiency measures are equal: this means that Z does not affect the performance of the analysed firm; if Q^z is much lower than 1, this means that the firm has been *highly* influenced by Z. When Z is univariate, the scatterplot of these ratios against Z and its smoothed nonparametric regression line is also very helpful. In the Appendix we report a series of these scatterplots. In each Figure the top panel illustrates the ratios of conditional/ /unconditional FDH efficiency scores on the value of the chosen Z; the bottom panel shows the robust version of the previous scatterplot (conditional/ nonconditional order-m efficiency scores on the value of the chosen Z). By looking at these pictures (Figures 1–8), the analyst has an immediate view on the global effect of external factors on the performance: an *increasing* line indicates a positive influence of the factor, a *decreasing* line points to a negative effect and a *straight* line reveals no influence of the factor on the performance. Using this approach, it is possible to decompose the performance of a Decision Making Unit (DMU), measured by the *Conditional Efficiency* score (FDH or more robust order-m) in three main indicators (for more details see DARAIO, 2003): an *unconditional* efficiency score, which represents the *internal or managerial efficiency*. It is the FDH (or order-m) efficiency score computed using only the selected inputs and outputs; an *externality index* which is the *expected value* of the ratios Q^z (Q^z_m) given the value of z owned by the DMU; an *individual index* which represents the firm's expected *intensity* in exploiting the external factor. This decomposition offers the possibility of measuring *individual* and *localized* effects of external factors.

Advanced robust methods in efficiency analysis, as applied to our data, help to shed lights on two main phenomena:

(a) the existence of scale and scope economies in the Italian system of universities;

(b) the analysis of the trade-off between teaching vs publication activities and between academic research (publication) vs industrial applied research.

Economies of scale and scope in universities

The literature in economics of education has long debated whether higher education institutions, such as universities, benefit from economies of scale and scope. Clearly, both aspects are relevant and the interplay between returns to scale and scope in the fields of education and research is the most intriguing aspect.

In manufacturing, economies of scale apply when an increase of k times in all factors of production determines an increase in output of more than k times. Therefore the higher the scale of production, the lower the unit or average cost in the long run. To claim that increasing returns to scale are at play one must increase simultaneously all factors of production. Economies of scope, on the other hand, refer to the reduction in average cost associated to the possibility to produce two or more qualitatively different outputs using the same structure of inputs. In the field of research and education, they refer to the joint production of undergraduate and postgraduate education, and to the use of common inputs for the production of different degrees (e.g., teaching calculus to students of physics and engineering). In the case of universities, economies of scope between teaching and research and between different types of research should also be considered.

In higher education and research it is not easy to identify the relevant unit of analysis.

The economics of research (e.g., RAMSDEN, 1994; JOHNSTON, 1994; ADAMS & GRILICHES, 2000) focuses mainly on departments as unit of observation, while economics of education considers schools or universities (e.g., COHN et al., 1989). The only level of observation that allows to explore the relation between the two fields is the university level. In general, the activity of researchers and teachers is reasonably well represented at the university level.

The arguments for assuming increasing returns of scale and scope are several.

- *Teaching process.* Up to a certain point, the cost to teach to more students grows less than proportionally with respect to the number of students. Large universities may allocate resources more efficiently if they can fill classrooms. It is likely that this effect has an upper bound given by congestion phenomena. On the other hand, if teaching involves significant interpersonal relation, the maximum number of students per teacher does not depend on the size of the university, so that costs may increase proportionally with the number of students.

- *Indivisibilities in human capital for research* We should be careful in defining the level of observation. First of all, indivisibility is more important at the level of team or laboratory than at the level of institute or department. Second, while the notion of indivisibility is clear in abstract terms, its empirical relevance may be highly variable. The minimum size of a team or laboratory may be extremely variable across specific areas within the same field. Economies of scale may be important up to a threshold level, then become irrelevant. If the threshold level is quite small, even small institutes may be highly efficient, provided that they meet the minimum requirement.
- *Educational and research infrastructure* Educational activities require fixed assets such as libraries and computer rooms, while research activities often require expensive equipment and instrumentation. To the extent that these resources are indivisible, efficient units must be large enough to ensure full utilization of assets.
- *Indivisibilities in administration.* This is a classical argument from minimum efficient scale in administrative staff. Small research institutes and universities may underutilize their fixed amount of personnel. With the increase of Information and Communication Technology (ICT) use in administration, it is no clear how this argument may be important. In addition, one should also consider the possibility of congestion of large bureaucratic institutions as a source of diseconomies.

There is lack of consensus on the existence of economies of scale in scientific production and higher education. See Table 1 which offers a sample of previous empirical evidence.

Table 1. Economies of scale: previous empirical evidence

Positive economies of scale	Ambiguous evidence
BRINKMAN (1981)	JOHNSTON (1994) – review
BRINKMAN & LESLIE (1986)	VON TUNZELMANN et al. (2003) – review
COHN et al. (1989)	
DE GROOT et al. (1991)	**Non significant economies of scale**
NELSON & HEVERT (1992)	NARIN & HAMILTON (1996) – review
LLOYD et al. (1993)	
Constant returns to scale	**Local effects**
VERRY & LAYARD (1975)	BONACCORSI & DARAIO (2004, 2005)
VERRY & DAVIES (1976)	
ADAMS & GRILICHES (2000)	

Despite ambiguity in empirical evidence, the notion of economies of scale and scope is often invoked to support policies of concentration of resources in larger universities or institutes, forcing small institutes to merge or disappear (see ABBOTT & DOUCOULIAGOS (2003) on the Australian case).

The policy implication of finding, for example, economies of scale will be consolidating universities or merging research units. But if size effects are local the policy may even worsen the situation. Suppose there are several regions of returns to scale, initially increasing then constant or decreasing. Merging units means that smaller institutes, which initially benefited from economies of scale, will become larger and will enter into a region where these effects are eliminated.

Trade-offs

We also address a classical topic in the economics of education and research. It is well known that university people are left (relatively) free to allocate their time budget across various activities. At the same time the teaching burden may be largely variable across universities. The relevant question is whether competing activities are substitute or complementary. This question applies to two different problems:

- the trade-off between research and teaching
- the trade-off between research for publication and research for industrial use or patenting.

These are critical issues for the overall organisation of universities and for policy-making.

Let us first discuss the trade-off between research and teaching.

At the individual researcher level, teaching activities not only refers to classroom teaching but also involves tutoring of students, revision of homework, supervision of theses. If these activities refer to undergraduate students, they do not contribute very much to research record. On the other hand, working with students gives the opportunity to identify at an early stage potentially promising researchers. Exposing ideas to students is usually a challenging activity, that contributes to research creativity. Also, in some countries (as Italy) the preparation of undergraduate dissertations involves heavy work that in some cases may be useful for research purposes. Therefore the net effect is rather indeterminate.

At the university level, the net effect is even more complex: the larger the number of students per professor, the smaller the time budget to be allocated to research. Thus large and overcrowded universities are expected to discourage professors from carrying out good research. At the same time, however, most institutional systems give funds to universities in proportion to the number of students. If this is true, having more students means having more resources, part of which may be allocated to research. For example, using an incentive-based model, GAUTIER & WAUTHY (2004) show that if multi-department university may redistribute resources, they may induce better teaching quality and research. GRAVES et al. (1982) found a negative impact of teaching on research in economics departments. On the contrary, COHN et al. (1989) found positive teaching/research complementarity, supporting the notion of economies of scope between the two activities.

A more recent trade-off has been explored in the literature on the so called third mission of universities. Put it briefly, the public research system has been pushed in many Western countries to engage in proactive exchanges with industry and to actively contribute to economic growth, at national and local level. In addition to teaching and research, universities have been invited to add in their objective function, the transfer of results from science to industry, and to implement it through the creation of intellectual property rights over the results of research, collaborative contractual relations with industry, joint consortia and research companies with industry, or creation of spin-off companies (MARTIN, 2001; THURSBY & KEMP, 2002).

Some recent results on the Italian case add evidence to this debate. BALCONI et al. (2004) have investigated the patenting behaviour of Italian academicians and identified a large pool of inventive activity that is not registered officially as university patenting. Comparing academic inventors to colleagues of the same discipline and seniority that did not patent, BRESCHI et al. (2004) find that academic inventors are much more productive. Along similar lines, CALDERINI & FRANZONI (2004) find that the event of patenting not only takes place after a period of high quality scientific publications but also is followed by a similar period, suggesting positive association.

While the debate cannot be solved without additional evidence across several countries, disciplines, and institutional settings, we put forward a conjecture. We suggest that the complementarity/rivalry relation is subject to local, non-linear effects along the distribution of relevant variables. In particular, we propose that the impact of industry involvement on pure scientific productivity may follow an inverted U-shaped relation with respect to the extent of involvement. Initially, collaboration with industry in various forms may improve productivity as measured by international publications, but beyond a certain level the compliance with industry expectations may be too demanding and deteriorate the publication profile.

Data description

We analyse data coming from two datasets collected by the Italian conference of university rectors (CRUI). The first one collects data for the academic years 1995/96 to 1997/98 and reports three sets of variables:

- Financial variables: financial resources and structure of expenses at the university level.

- Human resource variables (teaching staff, administrative and technical staff).
- Number of students enrolled and graduated.

The second database contains data on the Italian universities' research outputs; it has been constructed using the Information Science Institute (ISI) data and contains the cumulative number of publications and citations obtained in the period 1995–1999, by university. In particular, it contains detailed information for the following scientific areas: Mathematics and computer science; Physics; Chemistry; Geology; Biological sciences; Medical sciences; Agricultural sciences; Civil Engineering and Architecture; Industrial Engineering; Information Technology.

We have data on almost the universe of the Italian university system, composed by 69 units. For more than 80% of them we have data over the total period (1995–1999). We eliminated private universities in order to ensure comparability and leave out those universities with uncomplete data. We end up with a sample of 45 universities, whose names will be listed later in Table 4.

The Italian university system is characterized by universities that deeply differ by size and their teaching supply, but basically have the same legal status and offer degrees and diplomas with exactly the same legal value. With respect to balance sheet data, it emerges that the biggest university has a level of financial resources 88 times higher than the smallest; similar differences are at place for the teaching and student populations. The teaching supply is widely differentiated: the university of Bologna has the highest number of departments ("facoltá") with 18; around 28% of our sample have at least 10 departments, 35% have a number of departments between 5 and 9, and 37% of our sample have less than 5 departments, although in this group more than one third is composed by private universities.

In Table 2 we describe the variables used in the empirical analysis, while Table 3 reports a few summary statistics of inputs, outputs and external factors.

In the empirical application that follows, we apply an output oriented framework as, at least in the short run, the resources used by universities (human, financial and physical capital) are fixed.[2]

[2]For the robust estimation we set a level of robustness at 10% and obtain a value of m=75, which we use in the order-m efficiency computations. We adopt a triangular kernel, but we notice that the efficiency scores where stable using also other kernels with compact support (for more details see DARAIO & SIMAR (2003) and DARAIO (2003)).

Table 2. Definition of inputs outputs and environmental-external factors

INPUTS	Description
Human capital	
TOTDOC	Sum of full professors, associate professors assistant professors and researchers (average – academic years 1995/96–97/98)
TECHADM	Number of Technical and Administrative staff (average - academic years 1995/96–97/98)
Financial capital	
CUMEXP	Total cumulated expenses years 1995–1999 (in million of Italian lire)
CUMEXp100iscr	Cumulated expenses per 100 enrolled students
CUMEXp1doc	Cumulated expenses per 1 scholar
Physical capital	
SPACE	Number of places in the lecture-halls (average – academic years 1995/96–97/98)
OUTPUTS	
Research	
PUB	Cumulated sum of publications years 1995–1999
CIT	Cumulated sum of citations years 1995–1999
PUBp100doc	No. of publications per 100 scholars (average values)
Teaching	
LAUCUM	Cumulated sum of graduated (and with *diploma*) academic years 1995/96–97/98
LAUCUMp100iscr	No. of graduated per 100 enrolled students (average values)
EXTERNAL FACTORS	
ISCR	No. of enrolled students – average academic years 1995/96–97/98
FACULT	No. of schools within the university
LOAD	No. of curricula (or *courses of specialisation*) activated per 100 scholars
CITPUB	Ratio of CIT over PUB
TRASFPRIV	Percentage of private contracts over total university budget (average values – 1995/99)

Table 3. Summary statistics of inputs outputs and environmental-external factors

INPUTS	Mean	Max	Min	St. Dev.
Human capital				
TOTDOC	893.93	2643.53	85.47	707.84
TECHADM	972.08	4859.5	76.33	888.87
Financial capital				
CUMEX	1022933	3130092	136203	755922.1
CUMEXp100iscr	3841.88	6859.47	1328.30	1356.69
CUMEXp1doc	1246.42	2730.70	753.79	325.29
Physical capital				
SPACE	11803.19	31558	1739	7599.94
OUTPUTS				
Research				
PUB	2494.6	11360	10	2468.70
CIT	12807.18	65046	147	14449.08
PUBp100doc	253.47	498.89	3.48	112.42
Teaching				
LAUCUM	6329.76	24942	610	5965.49
LAUCUMp100iscr	20.55	32.98	10.30	5.74
EXTERNAL FACTORS				
ISCR	29529.44	102253	4898.33	25494.81
FACULT	7.18	15	2	3.26
LOAD	4.76	9.10	2.23	1.79
CITPUB	5.33	23.3	1.97	3.18
TRASFPRIV	2.18	6.99	0.02	1.70

Table 4. Partial ranks of Italian universities

University	Rank A	Rank B	Rank C	Rank D
Ancona	8	14	10	4
Bari	39	26	18	34
Basilicata	4	41	31	19
Bergamo	40	12	3	42
Bologna	36	7	33	14
Brescia	23	13	11	1
Cagliari	34	38	29	32
Calabria	9	30	8	26
Cassino	43	34	22	41
Catania	13	35	6	36
Chieti	32	17	19	24
Ferrara	16	27	43	3
Firenze	26	20	42	18
Genova	10	8	25	17
L'Aquila	17	36	44	9
Lecce	44	39	34	23
Messina	15	37	24	38
Milano	42	18	45	2
Milano Politecnico	37	2	12	20
Modena	7	3	39	7
Molise	33	45	4	27
Napoli Federico II	31	24	20	25
Napoli II	6	44	7	33
Napoli Navale	38	40	1	43
Napoli Orientale	14	6	14	45
Padova	21	10	17	6
Palermo	30	31	37	40
Parma	25	5	21	15
Pavia	11	4	32	5
Perugia	18	21	30	21
Pisa	22	23	38	10
Reggio Calabria	1	28	2	29
Roma III	20	43	36	37
Roma Tor Vergata	2	15	23	11
Salerno	45	32	40	30
Sassari	12	33	16	35
Siena	3	11	5	22
Teramo	41	29	9	44
Torino Politecnico	29	9	28	31
Trento	27	16	15	12
Trieste	19	22	41	16
Udine	5	25	13	13
Venezia	35	1	27	39
Verona	28	19	26	8
Viterbo Tuscia	24	42	35	28

Rank A: CUMEXp100iscr, 1=the worst, 45= the best
Rank B: LAUCUMp100iscr, 1= the best, 45= the worst
Rank C: CUMEXp1doc, 1= the worst, 45= the best
Rank D: PUBp100doc, 1= the best, 45= the worst

In Table 4 we report some partial ranks of the Italian universities in our sample. The second column shows the rank of universities by their Cumulated expenses per 100 enrolled students (CUMEXp100iscr). The university of Reggio Calabria is the first in this ranking meaning that its CUMEXp100iscr is the highest of the sample, while the university of Salerno is the last (it occupies the place 45), meaning that its CUMEXp100iscr is the lowest of our sample. The same interpretation has to be given to the third, fourth and fifth columns which report the partial ranks for, respectively, the number of graduated per 100 enrolled students (LAUCUMp100iscr), the Cumulated expenses per 1 scholar (CUMEXp1doc), and finally, the number of publications per 100 scholars (PUBp100doc).

Empirical results

We run a series of efficiency models of varying complexity. We explore the efficiency of universities using separately two indicators of output, namely the research output (total number of publications – in science and social science fields – in international refereed journals, cumulated 1994–1999, PUB or total number of citations – in science and social science fields – received, 1994–1999, CIT) and the educational output (total number of students enrolled, average 1994–1999, ISCR or cumulated total number of degrees and "diplomas" 1994–1999, LAUCUM). Even if the methodology we apply here allow for multiple input multiple output analysis, in these first explorative elaborations we analyse the two outputs separately, in order to investigate the trade-off between research and teaching. We present results separately for the input indicators only if results are different and deserve discussion. We study how the efficiency of each university is affected by external factors.

External factors are neither inputs nor outputs of the university production process, but may influence the performance of universities.

As explained in the introduction, the comparison between efficiency *conditional* to the external factors and *unconditional* efficiency informs about the sign and magnitude of the effect. This methodology is vastly superior to classical parametric regression analysis, because first it avoids the burden of functional specification of the efficient frontier and of the nature of the conditioning and second, it captures the shape of the cloud of points at its efficient boundary and not in its middle or at an average behavior (as is the case for the regression approach).

Scale and scope effects

Our initial result refers to the effect of size of universities on research efficiency. What we find is that the efficiency in the research activity model, that we call PUB MODEL (in which we use as inputs several proxies of human, financial and physical capital, and as output the total number of publication, PUB), is not affected by size effects, as measured by the number of enrolled students (ISCR). Therefore the net effect of working in a large or a small university on publication activity is not only almost zero on average, but more precisely almost zero along all the observed distribution of university size. See Appendix, Figure 1.

A similar result is observable with respect to economies of scope. Since these refer more to educational efficiency, we study how the efficiency in the teaching activity model that we call TEACH MODEL (in which we use as inputs several proxies of human, financial and physical capital, and as output the cumulated number of degrees and "diplomas", LAUCUM), is affected by the fact that the university has many schools or faculties (number of *facoltá*, FACULT), runs many undergraduate curricula (number of different *corsi di laurea* or *corsi di diploma*, COR) or asks its professors to teach in several programmes (number of curricula per 100 professors, LOAD).

Of course these measures refer to different aspects of *specialisation*. Perhaps the most important is the number of faculties. A small number of faculties is typical of small, young universities, or of large, specialised, mainly technical universities (such as Polytechniques). Large universities usually also have a large number of faculties, but the reverse is not always true. Given the number of faculties, the number of curricula is a decision variable for the university. Legislation in the early '90s (L.571/1993) gave Italian universities the so called autonomy, which implies the freedom to set up new curricula, within a set of ministerial guidelines and authorizations, in order to capture student demands. Further, the reform following the Bologna process encouraged universities to diversify their offering, leading to a rapid increase in the number of curricula. Given the number of professors, universities that have a strategy of diversification or extension of educational supply may ask professors to engage in more teaching activities, taking more courses per year.

All these measures are clearly *very crude approximations* for economies of scope. They try to capture first order effects, rather than going into the details of cost structures and possible synergies via resource sharing. We do not have data on doctoral programmes for testing economies of scope between undergraduate and postgraduate education.

Given these limitations, data show that the number of different faculties or curricula (FACULT, COR) or number of curricula per 100 professors (LOAD) does not have any impact on the efficiency in producing graduate students (TEACH MODEL). See Appendix, Figures 2 and 3. In some sense the same pool of students is offered a more segmented structure of offer. Proliferating the number of faculties of curricula does not improve the efficiency in production of graduate students, but perhaps makes their education more finely segmented with respect to labour market requirements. Recall that data are taken from a period where the 3+2 scheme of the Bologna process was not in place. After that reform, many students were encouraged to enrol, mainly because they considered the opportunity of a short curriculum as attractive. Under these conditions, the extension and differentiation of offer may be a sensible strategy, but we have no data to support this intuition.

The impact of differentiation of offer on research efficiency is more complex. When the number of curricula per 100 professors increases to levels of 2-3 the efficiency of universities as measured by PUB is negatively affected. Beyond this level a flat region is identified. Another negative effect region is apparent at 7-8 curricula although only a few observations are available here. It seems that universities, after an initial shock, may adjust internally to heavier burdens of teaching by redistributing tasks and maintain adequate effort for research. If the burden becomes excessive, research efficiency may suffer, but again more evidence is needed to confirm this effect. See Appendix, Figure 4.

Summing up, we find that "being big and diversified" is not necessarily good at the university level. Economies of scale and scope are not the most important drivers of efficiency in higher education institutions.

Trade-offs

We consider two types of trade-offs: between research and teaching, and between research for publication and applied research for industry. Again, we study the overall universities, aggregating scientific disciplines and educational programmes that are extremely heterogeneous in their pattern of use of inputs and production of outputs.

We study how research efficiency (PUB MODEL) is affected by the education activities (as measured by LAUCUM), see Figure 5 in the Appendix. It comes out that a good educational efficiency (in terms of high number of LAUCUM) does not deteriorate research efficiency. Moreover, we find that increasing scientific quality (as measured by the ratio CIT/PUB) improves educational efficiency (in terms of LAUCUM), see Figure 6 in the Appendix.

Furthermore, we study how research efficiency (PUB) is affected by an external variable that describes the overall importance of research collaborations with industry (percentage of university budget funded by industry, average 1994–1999, TRASFPRIV). Here some interesting results emerge.

Figure 7 in the Appendix shows that increasing the share of university budget represented by industrial sources has a beneficial effect on research productivity. The direction of causation may be left open: on the one hand, good universities, with a recognized international standard of publication, signal their quality and attract industry interest and money; on the other hand, universities with a higher share of industry funds benefit from more resources and improve their research productivity. As a matter of fact, the overall effect is largely positive. In the right tail of the distribution of industry funding, the impact on research productivity is negative although this particular shape is mainly due to a few of observations. If this effect was confirmed by further evidence, it would imply that the trade-off actually applies, so that being exposed to industry requests to a significant extent may reduce pure publication productivity. Of course, more definite conclusions should require more data to confirm this inverse U-shaped pattern. Even more interesting, the overwhelming majority of Italian universities are located in the region of *positive effects*, meaning that collaboration with industry and international publication are not substitute but complements.

On the other hand, the share of university budget represented by industrial sources (TRASFPRIV) does not deteriorate the educational offering of universities, as it emerges from Figure 8, in the Appendix.

This is a clear example of the potentiality of robust techniques. While most discussion based on regression techniques ends up in weighting contrasting average results, we believe that understanding the impact of external variables along the entire distribution is much more informative.

An example of detailed results available

In this section we report some detailed robust results available for a model in which we use as outputs PUBp100doc and LAUCUMp100iscr, as input CUMEXP, and as external factor TRASFPRIV.

Here the name of universities have been coded. The second column of Table 5 reports the values of the unconditional efficiency score of order-m ($\hat{\lambda}_m(x, y)$), the third column reports the efficiency score of order-m conditioned to the value of TRASFPRIV of each university ($\hat{\lambda}_m(x, y \mid z)$),the forth one shows the value of TRASFPRIV, the fifth column shows Q_m^z that is the ratio of conditional on unconditional order-m efficiency score, the sixth one shows the Externality Index of order-m (EI_m); the seventh one the Individual Index of order-m (II_m^z), followed by the R_m value, that is given by the ratio of Q_m^z on the geometric mean of all Q_m^z. The last two columns report the number of universities which dominates each university (*Np*) in the input-output space, and the number of dominating universities conditioned to the value of *Z* (Np_z).

To illustrate the meaning of the variables listed in Table 5, we reveal that A is the University of Basilicata, B is the University of Lecce, C is the University of Messina and D is the University of Calabria.

From this model, it appears that the University of Basilicata and the University of Lecce are efficient in the production of their two main outputs (teaching and research), i.e. their output efficiency score is equal to one. In fact the number of their dominating universities (universities which do better) is zero both unconditionally and conditionally to their level of *Z* (TRASFPRIV) (see *Np* and Np_z).

Table 5. Conditional order-m efficiency measures and various indicators. Model with outputs: PUBp100doc and LAU-CUMp100iscr, input CUMEXP, and *Z* is TRANSPRIV

University	$\hat{\lambda}_m(x, y)$	$\hat{\lambda}_m(x, y \mid z)$	Z	Q_m^z	$E(Q_m^z)$	II_m^z	R_m^z	Np	Np_z
A	1	0.99999	1.73	0.99999	0.96078	1.0408	1.0956	0	0
B	0.99998	1	0.84	1	0.88719	1.1272	1.0956	0	0
C	2.1181	1.4664	0.12	0.69233	0.81396	0.85058	0.75853	21	3
D	1.3012	1	1.10	0.76852	0.93174	0.82482	0.84201	6	0
E	1.0372	1.0376	3.59	1.0004	0.96771	1.0338	1.0961	1	1
F	1.4899	1.3574	2.37	0.91104	0.91803	0.99238	0.99815	15	4
G	1	0.99999	0.35	0.99999	0.82245	1.2159	1.0956	0	0
J	1.1695	1.1822	1.13	1.0109	0.93583	1.0802	1.1075	2	1
K	0.99982	0.99999	3.87	1.0002	0.96798	1.0333	1.0958	0	0
L	1.8689	1.8765	1.21	1.0041	0.9453	1.0622	1.1001	15	4
M	1	1	1.27	1	0.95099	1.0515	1.0956	0	0
N	1.8453	1.8645	1.69	1.0104	0.96181	1.0505	1.107	25	6
O	1.0567	1.0569	3.34	1.0002	0.96562	1.0358	1.0958	2	1
P	1.1867	1	1.88	0.84269	0.95465	0.88272	0.92327	1	0
Q	1.4004	1.4152	1.76	1.0106	0.95984	1.0529	1.1072	10	2
R	1.1852	1.1421	6.27	0.9636	0.95755	1.0063	1.0557	3	2
S	1.366	1.3665	3.54	1.0004	0.96757	1.0339	1.0961	1	1
T	1.0556	1.0677	3.04	1.0115	0.95274	1.0616	1.1082	1	1
U	0.99355	1	3.74	1.0065	0.96782	1.04	1.1027	0	0
V	0.99429	1	1.47	1.0057	0.96178	1.0457	1.1019	0	0
W	1	0.99999	1.37	0.99999	0.95788	1.044	1.0956	0	0
X	1.4446	1.0073	0.44	0.69727	0.8288	0.84131	0.76395	19	1
Y	2.3148	1.4164	0.67	0.61191	0.85699	0.71403	0.67042	17	5
Z	1.0904	1.0904	0.94	1	0.90571	1.1041	1.0956	2	1
AA	0.99999	1	0.17	1	0.81518	1.2267	1.0956	0	0
BB	1.0041	1.0056	3.69	1.0015	0.96781	1.0348	1.0972	1	1
CC	1.7419	1.1302	0.26	0.64881	0.81811	0.79306	0.71085	19	2
DD	1.0976	1	3.24	0.91105	0.9632	0.94587	0.99817	1	0
EE	0.99721	1	4.22	1.0028	0.97284	1.0308	1.0987	0	0
FF	1.4136	1.4348	1.95	1.015	0.95066	1.0677	1.112	6	2
GG	1.1842	1.1248	1.83	0.9498	0.95708	0.9924	1.0406	5	2
JJ	1.2832	1	0.02	0.77932	0.81205	0.9597	0.85384	4	0
KK	2.238	1.9598	2.16	0.87571	0.93511	0.93648	0.95945	13	3
LL	1.2059	1.21	5.69	1.0034	0.99302	1.0104	1.0993	4	3
MM	1.4111	1.0064	0.32	0.71319	0.82081	0.86889	0.78139	8	1
NN	1.728	1.4163	3.86	0.81959	0.96795	0.84672	0.89796	10	4
OO	1.2031	1.0947	3.42	0.90994	0.96675	0.94124	0.99695	4	2
PP	1	0.99999	0.34	0.99999	0.82188	1.2167	1.0956	0	0
QQ	1.1878	1	6.99	0.8419	0.86137	0.9774	0.9224	1	0
RR	1.0469	1.0469	4.55	1	0.98504	1.0152	1.0957	1	1
SS	1.3511	0.99999	0.77	0.74013	0.87422	0.84661	0.8109	5	0
TT	1.3065	1.0561	2.56	0.80837	0.91142	0.88693	0.88566	5	1
UU	0.99855	1	1.50	1.0015	0.96242	1.0406	1.0972	0	0
VV	1.1427	0.99999	1.63	0.87511	0.9628	0.90892	0.95879	1	0
WW	1	1	1.12	1	0.9345	1.0701	1.0956	0	0
Mean	1.27690	1.15180	2.17820	0.92100	0.92344	0.99650	1.0091	5.0889	1.2222

The University of Messina, on the contrary, could increase its outputs of more than two times (with its level of input could produce 2.12 times its level of outputs), but if we take into account TRASFPRIV its output efficiency score falls down to 1.47 and becomes more close to unity (which indicates efficiency). This information is important because could signal that one of the cause of its inefficiency is its low level of TRASFPRIV, and a policy measure to take into account could be an increase in its private funding. The case of the University of Calabria again shows that if we take a more precise comparison, taking into account the percentage of TRASFPRIV owned by the university, it becomes efficient. On the contrary there are some other universities in the sample, such as L, the performance of whose is not affected by the percentage of TRASFPRIV. The remaining indicators in Table 5 offer the possibility of finely characterize the profile of each university as compared with the other universities of the sample, isolating the effects of the external factor on their overall performance.

Conclusions

This paper has explored two large debated issues in the economics and policy of science and education. Concerning economies of scale and scope we show that they are not significant factors in explaining research and education productivity. With respect to the issue of trade-offs we find that beyond a threshold quality of publication increasing scientific quality improves educational efficiency. On the other hand, a good educational efficiency does not deteriorate research efficiency. About academic publications vs applied industrial research, we come to the preliminary conclusion that trade offs effects (complementarity/rivalry relations) have a *local* characterization. More evidence is needed to confirm the inverted U-shaped conjecture that appears from our first exploration of data.

Our results show the advantage of robust nonparametric techniques over standard regression techniques and regression-based frontier estimation techniques both from the methodological rigor of the analysis and for the richness of information for interpretation and policy consideration.

In this paper we presented a first preliminary investigation on the Italian system of universities at aggregate level. We are going to carry out an analysis at more disaggregated level, investigating more finely on the effects of scale, scope and trade-offs at the level of schools/faculties. We also plan to enrich the analysis by using information on the patenting activity of Italian professors and data on territorial agglomeration.

*

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Appendix
Scale and scope effects

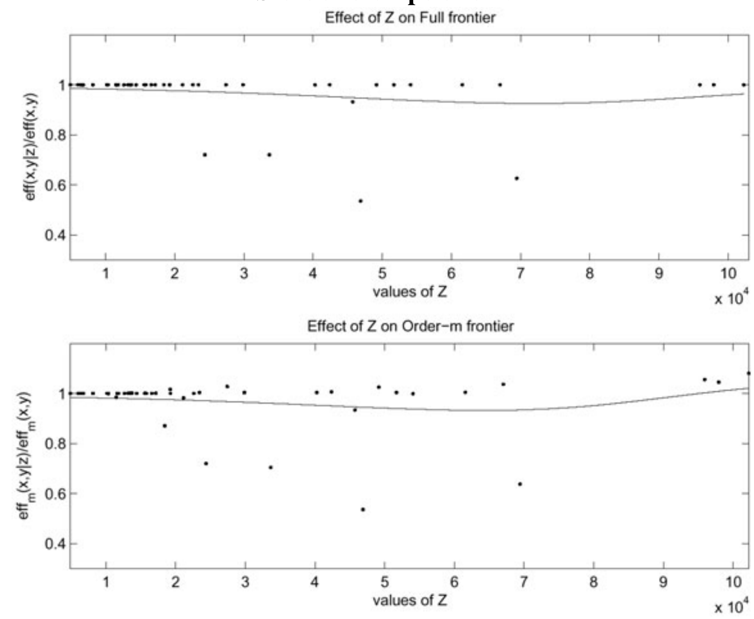

Figure 1. *PUB MODEL Z ISCR.*

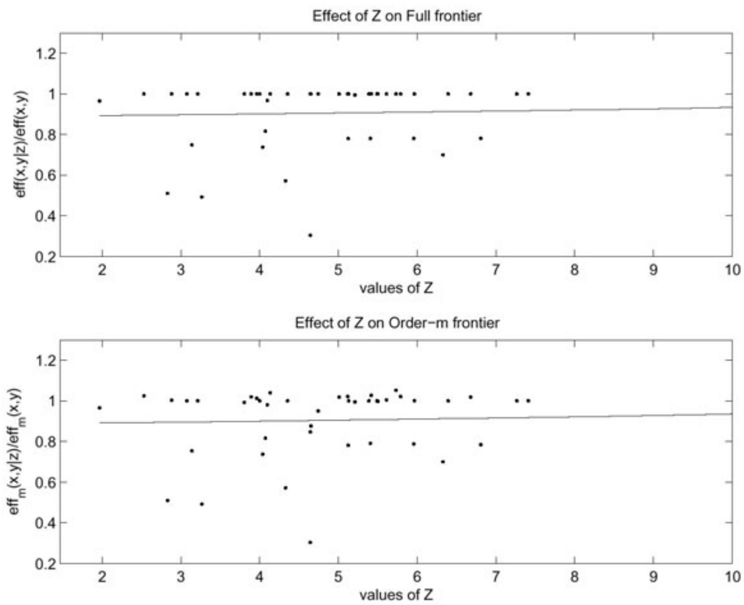

Figure 2. *TEACH MODEL Z FACULT.*

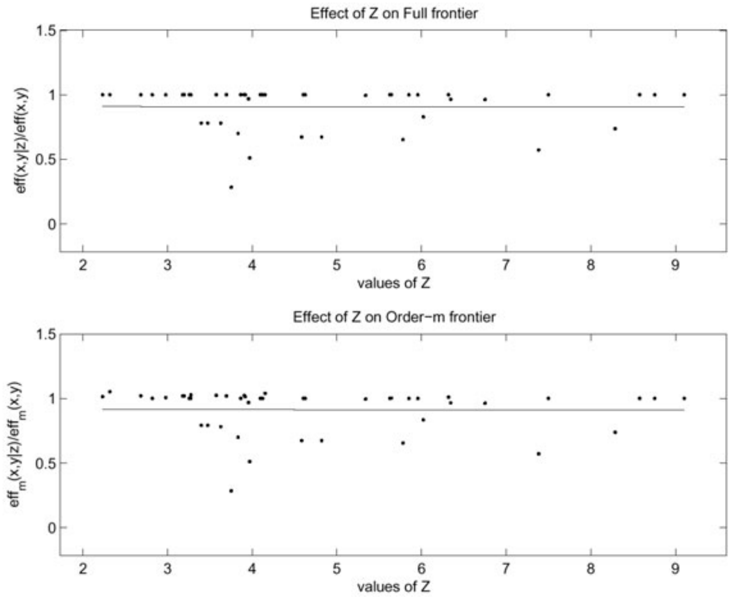

Figure 3. *TEACH MODEL Z LOAD.*

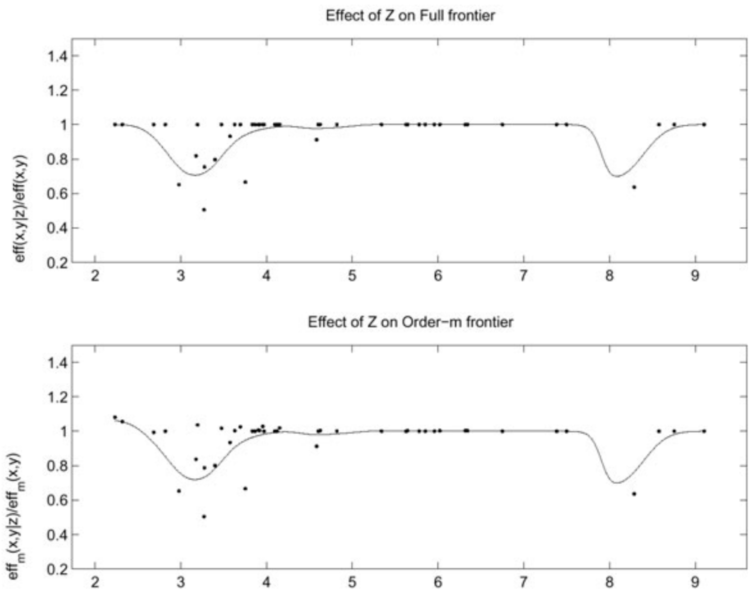

Figure 4. *PUB MODEL Z LOAD.*

Trade-off research vs teaching

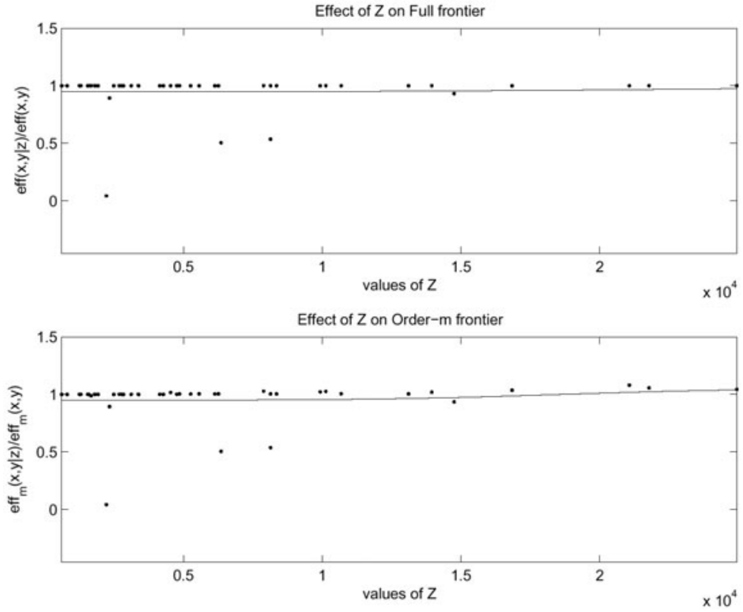

Figure 5. *PUB MODEL Z LAUCUM.*

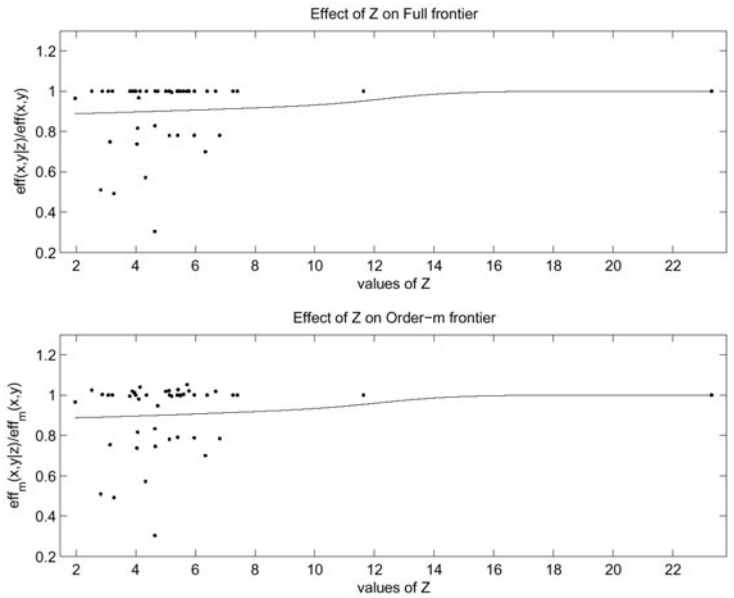

Figure 6. *TEACH MODEL Z CIT/PUB.*

Trade off scientific research vs applied/industry research

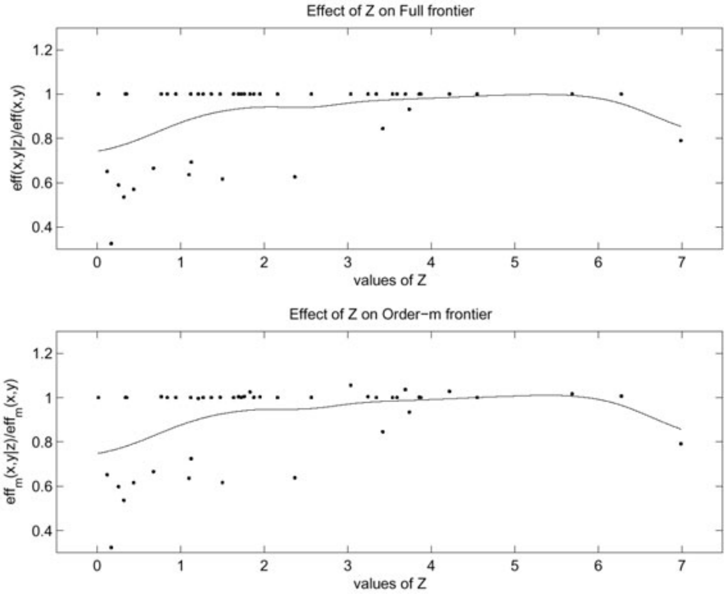

Figure 7. *PUB MODEL Z TRASFPRIV.*

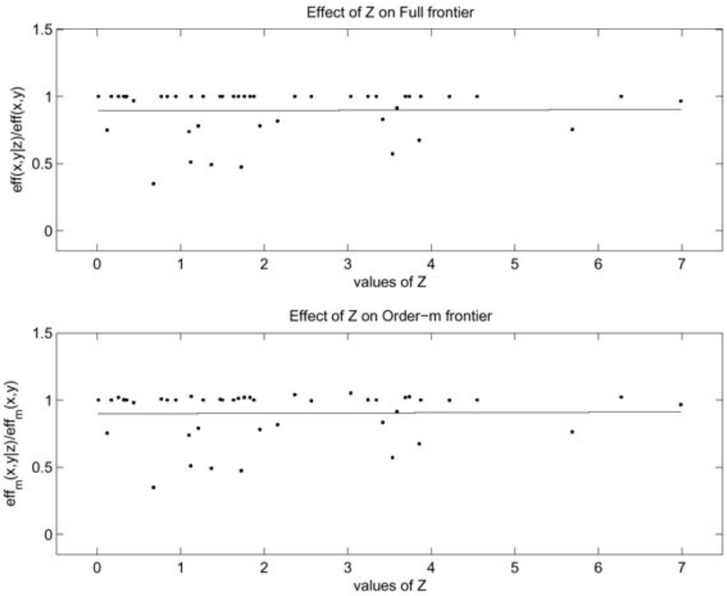

Figure 8. *TEACH MODEL Z TRASFPRIV.*