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The ratio of top scientists to the academic staff as an indicator of the competitive strength of universities

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ABSTRACT

The ability to attract and retain talented professors is a distinctive competence of world-class universities and a source of competitive advantage. The ratio of top scientists to academic staff could therefore be an indicator of the competitive strength of the universities. This work identifies the Italian top scientists in over 200 fields, by their research productivity. It then ranks the relative universities by the ratio of top scientists to overall faculty. Finally, it contrasts this list with the ranking list by average productivity of the overall faculty. The analysis is carried out at the field, discipline, and overall university levels. The paper also explores the secondary question of whether the ratio of top scientists to faculty is related to the size of the university.

1. Introduction

The single most important distinctive competence of world-class universities is probably their ability to attract and retain highly qualified faculty (Salmi, 2009; Mohrman, Ma, & Baker, 2008). Talented professors attract talented students. They produce groundbreaking research results, which in turn attract donations, public and private research funds, venture capital and establishment of high-tech companies in the territory. The outstanding reputation, abundance of financial resources, and highly attractive research environment feed a virtuous circle, leading to a sustained competitive advantage over other universities. Competitive higher education systems, such as those observed in English speaking nations, are therefore likely to present a number of universities with distinctive achievement in quality of education and research. This supposition is supported by a glance at the most popular world university "league tables", such as the Academic Ranking of World Universities (ARWU), the Times Higher Education (THE) World Academic Rankings, the CWTS Leiden Rankings, and the SCImago Institutions Rankings (SIR). Several studies call into question the methodology and the relevance of the indicators used in these rankings (Abramo, D'Angelo, & Viel, 2011; Butler, 2010; Dehon, McCathie, & Verardi, 2010; Turner, 2005; Van Raan, 2005). However, Saisana, D'Hombres, and Saltelli (2011), while accepting that the ARWU and the THE should not be used to compare the performance of individual universities, demonstrate that their rankings are reliable for the top 10

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universities. Indeed the top 10 institutions in both the 2015 ARWU[1] and THE 2015–2016 ranking[2] consist entirely of ones situated in the U.S. or U.K., and the same also occurs in the 2015 SIR and Leiden size-independent rankings.

The U.S. and U.K. have experienced an evolution of national policies that favor the birth and development of true markets in higher education. In contrast, many European nations witness an excess of public control, inhibiting the initiation of competitive mechanisms and leading to the development of generally undifferentiated higher education systems that are unable to compete at a global level for access to economic and human resources (public and private funds, talented students, excellent faculty) (Veugelers & van der Ploeg, 2008). Auranen and Nieminen (2010) report that in countries such as Germany, Sweden and Denmark, there is still no expectation of distinguishing different levels of excellence among universities, due to the almost total lack of competition among the actors in the systems. (The present authors observe the same situation in Italy.)

Recently, scientometricians have inquired into the distribution of talented scientists among universities. Because top-level scientists contribute more than unproductive ones to the overall research performance of universities (Abramo, Cicero, & D'Angelo, 2013), logic would have it that in competitive systems, top research universities would achieve this status from a concentration of top scientists (TSs). However, what is the case in education systems with little differentiation? Are the TSs quite uniformly distributed among universities? Common sense would lead us to expect this, otherwise the universities with a high concentration of TSs would have to experience an even higher concentration of unproductive scientists in order to remain undifferentiated, a fact which seems difficult to accept. The intention of the current work is to answer this question of the distribution of top scientists in undifferentiated higher education systems, taking the Italian case as specific reference. Italy offers a classic example of an undifferentiated higher education system, as shown by Bonaccorsi and Cicero (2015) and Abramo, Cicero, and D'Angelo (2012a), and confirmed through a further sophisticated assessment methodology, accounting for uncertainty in the measure of research performance (Abramo, D'Angelo, & Grilli, 2015).

The literature on the distribution of TSs among universities is quite scarce. To the best of our knowledge, the only work to specifically focus on this subject is by Yang, Rousseau, Huang and Yan (2015). These authors identify the world's top scientists and institutions in twenty broad research fields, by total counts of citations for publications indexed in the Web of Science (WoS) in the period 2008–2011. Their findings are that in the larger fields, more than 80% of TSs work at top institutions, although the concentration is less for smaller fields such as mathematics and computer science. Other research, tangentially related to the topic, has been by Bornmann and Bauer (2015), who rank institutions by the total number of highly cited researchers, and by Abramo and D'Angelo (2015), who rank universities by the number of highly-cited articles per scientist.

The current study overcomes what in our view are two major limits of Yang et al. (2015). The first concerns the performance indicator used to identify the top research institutions. In fact Yang et al. adopt the measure of the total count of citations, but this is a size-dependent indicator, which inevitably favors large institutions. In this study we employ a size-independent indicator, specifically fractional scientific strength (FSS), which is a productivity indicator embedding both the fractional counting of publications and their field-normalized citations (Abramo & D'Angelo, 2014). The second limit concerns the results under examination. What interests Yang et al. is the whole numbers of TSs employed in the top institutions (or the percentages of top scientists out of the overall population). Once again, all others equal, the larger the size of the institution, the greater the chance of employing the higher number of TSs. We will instead calculate, for each university, the ratio of TSs to the overall faculty. This change provides an indicator of the competitive strength of the universities, and responds to our first research question.

Further, we will then investigate the specific aspect of the relation between the institution's average research performance and its ratio of TSs to overall academic staff. We will also verify the side question of whether there are varying returns to size. The analytical approach involves a fine-grained analysis in over 200 research fields, meaning that the analysis is ten times finer than that of Yang et al. (2015). Given that the intensity of publication varies across fields (Abramo & D'Angelo, 2007; Butler 2007; Garfield, 1979; Moed, Burger, Frankfort, & Van Raan, 1985), this approach has the particular advantage of avoiding distortions due to the coarse aggregation of research fields (Abramo, D'Angelo, & Di Costa, 2008).

In the next sections of the paper we describe the distinctive features of the Italian higher education system and then present the data and methods used. The final sections provide the results of the analysis, leading to the conclusions.

2. The Italian higher education system

The Italian Ministry of Education, Universities, and Research (MIUR) recognizes a total of 96 universities as having the authority to issue legally recognized degrees. Of these, 29 are small, private, special-focus universities, of which 13 offer only e-learning, 67 are public and generally multi-disciplinary universities, scattered throughout Italy. Six of them are *Scuole Superiori* (Schools for Advanced Studies), specifically devoted to highly talented students, with very small faculties and tightly limited enrolment per degree program. In the overall system, 94.9% of faculty are employed in public universities (0.5% in *Scuole Superiori*). Public universities are largely financed by the government through non-competitive allocation of funds. Until 2009 the core government funding (56% of universities' total income) was input oriented (i.e., independent of merit,

[1] http://www.shanghairanking.com/ARWU2015.html, last accessed on April 19, 2016.

[2] https://www.timeshighereducation.com/world-university-rankings/2016/world-ranking#!/page/0/length/25, last accessed on April 19, 2016.

and distributed to universities in a manner intended to satisfy the needs of each and all equally, with respect to their size and research disciplines). It was only following the first national research evaluation exercise concluded in 2006, that a minimal share, equivalent to 3.9% of total income, was assigned by the MIUR as a function of the assessment of research and teaching.

Despite interventions intended to grant increased autonomy and responsibilities to the universities (Law 168 of 1989),[3] the Italian higher education system is a long-standing, classic example of a public and highly centralized governance structure, with low levels of autonomy at the university level and a very strong role played by the central state.

In keeping with the Humboldtian model, there are no 'teaching-only' universities in Italy, as all professors are required to carry out both research and teaching. National legislation includes a provision that each faculty member must provide a minimum of 350 h per year of teaching. At the close of 2015, there were 54,800 faculty members in Italy (full, associate and assistant professors) and a roughly equal number of technical–administrative staff. All new personnel enter the university system through public competitions, and career advancement depends on further public competitions.

Salaries are regulated at the central level and are calculated according to role (administrative, technical or professorial), rank within role (e.g., assistant, associate or full professor) and seniority. None of a professor's salary depends on merit. Moreover, as in all Italian public administration, dismissal of unproductive professors is unheard of.

The entire legislative–administrative context has created a culture that is hardly competitive, yet flourishing with favoritism and other opportunistic behaviors that are dysfunctional to the social and economic roles of the academia (Perotti, 2008; Zagaria, 2007). Abramo, D'Angelo, and Rosati (2014) and Abramo, D'Angelo, and Di Costa (2014) investigated 287 associate professor competitions. The analysis showed several critical issues, particularly concerning unsuccessful candidates who outperformed the competition winners in terms of research productivity, as well as a number of competition winners who resulted as totally unproductive. Almost half of individual competitions selected candidates who would go on to achieve below-median productivity in their field of research over the subsequent triennium. A more recent work (Abramo, D'Angelo, & Rosati, 2015) showed that the fundamental determinant of an academic candidate's success is not scientific merit, but rather the number of years that the candidate has belonged to the same university as the president of the selection committee. Thus, universities are unable to attract significant numbers of talented foreign faculty: only 1.8% of research staff are foreign nationals. Over the period 2009–2013, 3178 (9.1%) of the 34,862 professors in the Sciences did not publish any scientific articles in WoS indexed journals. Another 868 professors (2.5%) achieved publication, but their work was never cited. This means that 4046 individuals (11.6%) had no impact on scientific progress measurable by bibliometric databases.[2] This share of unproductive faculty has been declining but is still too high, particularly given that the legislative structure obligates all professors to conduct research. Indeed, highly competitive academic systems typically present instances of distinct "research" and "teaching" universities, but in Italy all universities are intended to serve both purposes, with all of them staffed by professors who are responsible for both research and teaching.

3. Data and methods

The intention of our analysis is to provide and examine the ranking all Italian universities according to their ratio to total faculty of those professors that rank in the top 10% for productivity, out of all Italian professors in the same field.

We restrict the analysis to those fields where the prevalent form of codification for research output is publication in scientific journals, and therefore bibliometrics can be applied to measure research performance. For brevity, we call those fields the Sciences, and distinguish them from the Social Sciences and Arts & Humanities. In the Italian university system all professors are classified in one and only one field, named the scientific disciplinary sector (SDS), 370 in all. SDSs are grouped into disciplines, named university disciplinary areas (UDAs), 14 in all.[4] 192 such fields, grouped into nine UDAs,[5] fall in the Sciences.

Data on the faculty at each university and their SDS classification were extracted from the database on Italian university personnel, maintained by the MIUR. The bibliometric dataset used to measure performance is extracted from the Italian Observatory of Public Research, a database developed and maintained by the present authors and derived under license from the Thomson Reuters WoS. Beginning from the raw data of the WoS, and applying a complex algorithm to reconcile the author's affiliation and disambiguate the true identity of the authors, each publication (article, article review and conference proceeding) is attributed to the university scientist or scientists that produced it (D'Angelo, Giuffrida, & Abramo, 2011). Thanks to this algorithm, we can produce rankings of research performance at the individual level, on a national scale.

In this work we measure the research performance in the publication period 2009–2013. As said above, the indicator of performance that we use for professors and universities is FSS. At the professor level, we calculate FSS_P, as follows:

$$FSS_P = \frac{1}{t}\sum_{i=1}^{N}\frac{c_i}{\bar{c}}f_i \qquad (1)$$

[3] http://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:Legge:1989-05-09;168, last accessed on April 19, 2016.

[4] The complete list is accessible on http://attiministeriali.miur.it/UserFiles/115.htm, last accessed on April 19, 2016.

[5] Mathematics and computer sciences, Physics, Chemistry, Earth sciences, Biology, Medicine, Agricultural and veterinary sciences, Civil engineering, Industrial and information engineering.

where

t = number of years of work in the period under observation.

N = number of publications in the period under observation.

c_i = citations received by publication i (counted at 31/05/2015).

$\bar{c}$ = average of distribution of citations received for all cited publications[6] in same year and subject category of publication i.

f_i = fractional contribution of professor to publication i.

The fractional contribution equals the inverse of the number of authors in those fields where the practice is to place the authors in simple alphabetical order but assumes different weights in other cases. For the life sciences, widespread practice in Italy is for the authors to indicate the various contributions to the published research by the order of the names in the listing of the authors. So for the life science, we give different weights to each co-author according to their position in the list of authors and the character of the co-authorship (intra-mural or extra-mural) (Abramo, D'Angelo, & Rosati, 2013). If the first and last authors belong to the same university, 40% of the citation is attributed to each of them, the remaining 20% is divided among all other authors. If the first two and last two authors belong to different universities, 30% of the citation is attributed to the first and last authors, 15% of the citation is attributed to the second and last authors but one, the remaining 10% is divided among all others.[7]

A thorough description of the economic theory underlying the operationalization of FSS, together with the assumptions and limits of the measurement, can be found in Abramo and D'Angelo (2014).[8]

Based on the value of FSS we obtain, for each SDS, a ranking list of all professors. We define TSs as those that place from the 90 percentile up.

To analyze the relation between the ratio of TSs to the faculty and the performance of the university, we need to assess the research performance of universities. To do that, we first normalize the FSS of each professor to the mean of all Italian productive professors in the same SDS, and then average the normalized FSS to overall faculty. In formulae, the productivity FSS_U over a certain period for university U is:

$$FSS_U = \frac{1}{RS}\sum_{j=1}^{RS}\frac{FSS_{R_j}}{\overline{FSS_R}} \quad (2)$$

where

RS = number of professors of university U, in the observed period;

FSS_{R_j} = productivity of professor j;

$\overline{FSS_R}$ = national average productivity of all productive professors in the same SDS of professor j.

4. Results and analysis

In this section we prepare and analyze the rankings of universities. After displaying our dataset, we calculate the ratio of TSs to faculty for each university, at the SDS and UDA levels. We then rank the Italian universities by TS ratio and analyze the distribution of the ratio, in response to our first research question, concerning the distribution of top scientists in undifferentiated higher education systems. We follow on to investigate whether the size of universities affects the value of the TS ratio (varying returns to size). Finally, we contrast the universities rankings by TS ratio and average research performance (FSS_U).

Table 1 shows the dataset at the UDA level. For each UDA we report the number of universities with at least 10 faculty members, the total number of professors and the amount of TSs. We recall that TSs are defined here as those scientists above the 90th percentile in the ranking list of all Italian academic staff in the same SDS. The overall dataset concerns 64 universities and 34,862 professors, of which 3571 fall in the category of TS.

After identifying the TSs in each SDS, through their affiliation we are able to measure for every particular university the ratio of TSs to the overall faculty. As an example, in Table 2 we report the case of UNIV_45 in the SDSs of UDA 1 (mathematics and computer science). About a quarter of the faculty are TSs, however the TS ratios in each SDS are uneven: there are no TSs in two out of six SDSs.

Table 3 instead presents the TS ratios in each UDA and the corresponding national rank. In four UDAs, UNIV_45 employs less than 10 professors and the related statistics are not shown. The total number of TSs is 47, representing a TS ratio of 19.7% of overall faculty in the five UDAs analyzed. Univ_45 ranks in the national top 5% in UDA 1 (Mathematics and computer

[6] Abramo, Cicero, and D'Angelo (2012b) demonstrated that the average of the distribution of citations received for all cited publications of the same year and subject category is the most effective scaling factor.

[7] The weightings were assigned following advice from senior Italian professors in the life sciences. The values could be changed to suit different practices in other national contexts.

[8] The reader may notice that, differently from the formula found in the referenced article, in this work we do not normalize the total impact by capital (salary of the professor). The reason is that we want to identify the top producers, regardless their cost.

Table 1
Dataset for the analysis—number of universities, faculty and top scientists in each UDA.

UDA	Universities	Faculty	Top scientists[a]
1—Mathematics and computer science	50	3268	332
2—Physics	43	2333	237
3—Chemistry	42	2996	303
4—Earth sciences	31	1114	115
5—Biology	53	4971	507
6—Medicine	42	10,370	1062
7—Agricultural and veterinary sciences	29	3076	319
8—Civil engineering	36	1535	158
9—Industrial and information engineering	49	5199	538
Total	64	34,862	3571

[a] The number of top scientists does not equal exactly 10% of the research staff in each UDA because of ties in the ranking lists.

Table 2
Ratio of top scientists to overall faculty in each SDS of UDA 1 for the case of UNIV_45.

SDS[a]	Research staff	TS ratio
MAT/02—Algebra	3	33.3%
MAT/03—Geometry	9	44.4%
MAT/05—Mathematical analysis	16	0%
MAT/07—Mathematical physics	3	0%
MAT/08—Numerical analysis	6	50.0%
INF/01—Computer science	11	36.4%
Total	52	23.1%

[a] The SDSs with less than 3 professors were excluded.

Table 3
Ratio of top scientists to overall faculty in each UDA for the case of UNIV_45.

UDA[a]	Research staff	TS ratio	National rank	Percentile
1	52	23.1%	3 out of 50	95.9%
2	38	18.4%	6 out of 43	88.1%
5	14	7.1%	36 out of 53	32.7%
8	39	10.3%	16 out of 36	57.1%
9	75	25.3%	3 out of 49	95.8%
All	239	19.7%	5 out of 64	93.7%

[a] The UDAs with less than 10 professors were excluded. 1 = Mathematics and computer science; 2 = Physics; 5 = Biology; 8 = Civil engineering; 9 = Industrial and information engineering.

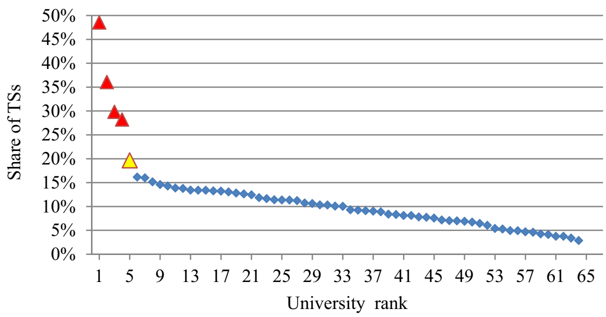

Fig. 1. Scatter plot of universities by ratio of top scientists to faculty and position in the ranking list; triangles indicate outliers.

science), and UDA 9 (Industrial and information engineering), but below the median in UDA 5 (Biology). In the overall ranking by TS ratio, UNIV_45 ranks fifth out of 64 universities.

Fig. 1 plots each university by its TS ratio and the corresponding position in the ranking list. With the help of the gaps in the density of the graph we can observe the differences in the TS ratios between neighboring universities in the rank. The first four universities in the ranking list stand out clearly. Then, starting from the 6th position, the TS ratio decreases quite evenly (average difference between neighboring positions is 0.2% TS ratio). The highest intervals appear between the first and the second, and the fourth and the fifth universities in the ranking list, with gaps in TS ratio of 12.5% and 8.5% respectively.

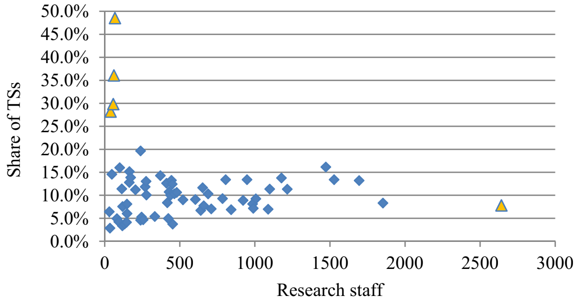

Fig. 2. Scatter plot of universities positioned by top scientists ratio and faculty size; triangles indicate outliers.

Table 4
Comparison of university ranking lists by TS ratio and FSS_U in UDA 7 (Agricultural and veterinary sciences).

University	Research staff	TS ratio	Rank	FSS	Rank	Rank Shift	Percentile shift	Quartile Shift
UNIV_26	64	25.0%	1	1.175	3	2	7.1	0
UNIV_8	12	25.0%	1	1.113	4	3	10.7	0
UNIV_18	93	17.2%	3	1.306	2	1	3.6	0
UNIV_2	12	16.7%	4	1.016	6	2	7.1	0
UNIV_12	72	16.7%	4	0.942	13	9	32.1	1
UNIV_34	184	16.3%	6	1.321	1	5	17.9	0
UNIV_44	189	13.8%	7	0.981	10	3	10.7	1
UNIV_49	22	13.6%	8	0.956	11	3	10.7	1
UNIV_39	15	13.3%	9	0.843	15	3	21.4	0
UNIV_56	255	13.3%	9	0.956	12	6	10.7	0
UNIV_29	273	13.2%	11	0.991	8	3	10.7	1
UNIV_28	64	12.5%	12	1.024	5	7	25.0	1
UNIV_32	209	12.4%	13	0.988	9	4	14.3	0
UNIV_62	45	11.1%	14	0.734	17	3	10.7	1
UNIV_20	195	10.8%	15	1.004	7	8	28.6	1
UNIV_60	139	8.6%	16	0.817	16	0	0.0	0
UNIV_35	108	8.3%	17	0.687	20	3	10.7	0
UNIV_58	105	7.6%	18	0.695	19	1	3.6	0
UNIV_47	103	6.8%	19	0.731	18	1	3.6	0
UNIV_17	74	6.8%	20	0.593	24	4	14.3	1
UNIV_36	75	6.7%	21	0.561	25	4	14.3	1
UNIV_25	146	5.5%	22	0.530	27	5	17.9	1
UNIV_38	153	4.6%	23	0.658	22	1	3.6	1
UNIV_43	73	4.1%	24	0.891	14	10	35.7	2
UNIV_41	135	3.7%	25	0.600	23	2	7.1	0
UNIV_13	55	3.6%	26	0.487	28	2	7.1	0
UNIV_52	64	3.1%	27	0.441	29	2	7.1	0
UNIV_57	38	2.6%	28	0.659	21	7	25.0	1
UNIV_31	18	0.0%	29	0.532	26	3	10.7	0

As a side question, we investigate also whether the TS ratios vary more than proportionally with the size of the university. In a previous paper we showed no evidence of returns of productivity to size (Abramo, Cicero, & D'Angelo, 2012c). We take the opportunity here to verify whether the same holds true for the TS ratio. Fig. 2 shows a scatter plot of universities, positioned by TS ratio and the size of faculty. The Pearson correlation coefficient is equal to −0.129, demonstrating negligible linear relationship between the two variables. The four outliers by TS ratio are small-sized universities, each with less than 70 professors in the UDAs analyzed, while the median of the distribution is 420 and the maximum is 2642. Calculating the correlation coefficient without the top four universities by TS ratio and the largest one by size, the correlation remains weak ($\rho = 0.226$). We now contrast the universities ranking list by TS ratio with that by productivity (FSS_U). We first show the analysis at UDA level, and then at overall university level. Table 4 presents the comparison for Agricultural and veterinary sciences (UDA 7). Here, 55% of universities occupy the same positions in both rankings. Although the correlation between the two rankings is very strong (Spearman $\rho = 0.861$), there still occur noticeable shifts in rank for several universities (on average 13.2%). The maximum percentile shift equals 35.7%, corresponding to a two-quartile shift (UNIV_43).

Table 5 shows the ranking lists of Italian universities in all UDAs by TS ratio and by FSS_U. Four universities outperform the others by both TS ratio and FSS_U: they are a private university focused in medicine and three Schools for Advanced Studies. The correlation between them is very strong (Spearman $\rho = 0.924$), however there are numerous universities that shift rank (only 9 out of 64 universities occupy the same position in both rankings). The maximum shift is two quartiles, occurring in two cases, with the largest leaps equaling 42.8 (UNIV_43) and 38.1 (UNIV_2) percentiles, while the average is 7.8%. UNIV_43 presents a very low TS ratio ranking, 59 out of 64. This low ratio does not jeopardize its rank (32) by the average productivity

Table 5
Ranking lists of Italian universities by TS ratio and by FSS_U.

University	Research staff	TS ratio	Rank	FSS	Rank	Rank shift	Percentile shift	Quartile shift
UNIV_64	68	48.5%	1	3.081	1	0	0.0	0
UNIV_6	61	36.1%	2	1.763	2	0	0.0	0
UNIV_8	57	29.8%	3	1.659	4	1	1.6	0
UNIV_7	39	28.2%	4	1.735	3	1	1.6	0
UNIV_45	239	19.7%	5	1.257	6	1	1.7	0
UNIV_34	1473	16.2%	6	1.233	7	1	1.7	0
UNIV_10	100	16.0%	7	1.409	5	2	3.1	0
UNIV_18	165	15.2%	8	1.135	10	2	3.2	0
UNIV_2	48	14.6%	9	0.883	33	24	38.1	2
UNIV_49	371	14.3%	10	1.166	8	2	3.1	0
UNIV_26	173	13.9%	11	1.001	19	8	12.7	1
UNIV_44	1177	13.8%	12	1.084	12	0	0.0	0
UNIV_29	1528	13.4%	13	1.136	9	4	6.3	0
UNIV_12	806	13.4%	14	1.023	16	2	3.3	0
UNIV_4	948	13.4%	15	1.095	11	4	6.3	0
UNIV_30	445	13.3%	16	1.016	17	1	1.6	1
UNIV_56	1695	13.2%	17	1.032	14	3	4.7	1
UNIV_55	276	13.0%	18	0.919	26	8	12.7	0
UNIV_51	164	12.8%	19	0.967	20	1	1.6	0
UNIV_22	412	12.6%	20	0.909	28	8	12.7	0
UNIV_59	450	12.4%	21	0.942	23	2	3.3	0
UNIV_15	270	11.9%	22	1.035	13	9	14.2	1
UNIV_5	652	11.7%	23	0.893	31	8	12.8	0
UNIV_16	114	11.4%	24	0.935	24	0	0.1	0
UNIV_60	1099	11.4%	25	0.898	29	4	6.4	0
UNIV_25	1216	11.3%	26	0.950	21	5	7.9	0
UNIV_14	205	11.2%	27	0.942	22	5	7.9	0
UNIV_62	429	10.7%	28	0.934	25	3	4.8	0
UNIV_54	480	10.6%	29	1.006	18	11	17.4	0
UNIV_61	464	10.3%	30	1.029	15	15	23.7	1
UNIV_37	689	10.3%	31	0.909	27	4	6.3	0
UNIV_53	278	10.1%	32	0.835	35	3	4.8	1
UNIV_46	439	10.0%	33	0.725	48	15	23.9	0
UNIV_38	785	9.3%	34	0.897	30	4	6.3	1
UNIV_40	1007	9.2%	35	0.802	37	2	3.2	0
UNIV_31	604	9.1%	36	0.823	36	0	0.0	0
UNIV_42	521	9.0%	37	0.796	38	1	1.7	0
UNIV_27	922	8.9%	38	0.761	43	5	8.0	0
UNIV_47	417	8.4%	39	0.847	34	5	7.9	0
UNIV_32	1853	8.3%	40	0.784	41	1	1.6	0
UNIV_58	985	8.1%	41	0.720	51	10	15.9	1
UNIV_52	148	8.1%	42	0.785	40	2	3.1	0
UNIV_39	2642	7.8%	43	0.740	47	4	6.4	0
UNIV_9	660	7.7%	44	0.752	44	0	0.0	0
UNIV_24	119	7.6%	45	0.789	39	6	9.4	0
UNIV_20	990	7.2%	46	0.748	46	0	0.1	0
UNIV_36	710	7.0%	47	0.723	50	3	4.8	1
UNIV_35	1089	7.0%	48	0.696	52	4	6.4	1
UNIV_28	842	6.9%	49	0.621	59	10	15.9	0
UNIV_23	640	6.7%	50	0.618	60	10	15.9	0
UNIV_1	31	6.5%	51	0.639	57	6	9.5	0
UNIV_48	149	6.0%	52	0.748	45	7	11.1	1
UNIV_50	334	5.4%	53	0.771	42	11	17.4	1
UNIV_17	246	5.3%	54	0.624	58	4	6.4	0
UNIV_41	424	5.0%	55	0.573	61	6	9.6	0
UNIV_21	81	4.9%	56	0.725	49	7	11.1	0
UNIV_3	256	4.7%	57	0.678	54	3	4.7	0
UNIV_57	239	4.6%	58	0.650	56	2	3.1	0
UNIV_43	94	4.3%	59	0.885	32	27	42.8	2
UNIV_13	145	4.1%	60	0.539	63	3	4.8	0
UNIV_33	133	3.8%	61	0.653	55	6	9.4	0
UNIV_19	453	3.8%	62	0.546	62	0	0.1	0
UNIV_11	118	3.4%	63	0.695	53	10	15.8	0
UNIV_63	35	2.9%	64	0.340	64	0	0.0	0

Table 6
Descriptive statistics of quantile shifts and correlation between university rankings by TS ratio and by FSS_U.

UDA[a]	No. of universities	Shifting in rank	Average percentile shift	Max percentile shift	Shifting quartile	Max quartile shift	Spearman correlation
1	50	94%	13.1	49.0	38%	2	0.847
2	43	88%	13.8	61.9	42%	2	0.779
3	42	93%	15.4	51.2	50%	2	0.766
4	31	97%	14.7	46.7	35%	2	0.816
5	53	89%	11.0	48.1	34%	2	0.870
6	42	93%	8.7	29.3	29%	1	0.922
7	29	97%	13.2	35.7	45%	2	0.861
8	36	92%	11.9	34.3	25%	2	0.878
9	49	73%	8.8	47.9	31%	2	0.892
All	64	86%	7.8	42.8	22%	2	0.924

[a] 1 = Mathematics and computer science; 2 = Physics; 3 = Chemistry; 4 = Earth sciences; 5 = Biology; 6 = Medicine; 7 = Agricultural and veterinary sciences; 8 = Civil engineering; 9 = Industrial and information engineering.

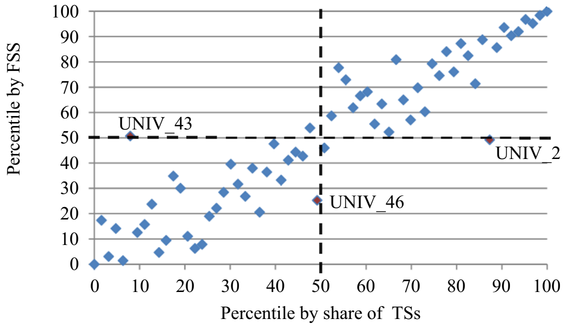

Fig. 3. Scatter plot of universities by their percentile ranks by FSS_U and TS ratio.

of all its professors (FSS_U), revealing a low dispersion of performance among the faculty. The opposite is true for UNIV_2, whereby the high share of TSs (rank = 9) cannot make up for the comparably lower productivity of the rest of the faculty (overall rank by $FSS_U = 33$), revealing a high dispersion of performance. For 50 universities there were no shifts in quartile.

Table 6 presents the descriptive statistics of the quantile shifts and the correlation between rankings by TS ratio and by FSS_U in each UDA. The last row shows values referring to all Italian universities without distinction per UDA. As expected, correlation between rankings is very strong in each UDA: the minimum Spearman coefficient of correlation (0.766) occurs in Chemistry (UDA 3) and the maximum (0.922) in Medicine (UDA 6). The largest percentage of universities shifting rank (97%) occurs in Earth Sciences (UDA 4) and Agricultural and veterinary sciences (UDA 7). Chemistry (UDA 3) registers the highest average percentile shift (15.4), while the maximum (61.9) occurs in Physics (UDA 2). In Chemistry, 50% of universities experience a quartile shift. The maximum quartile shift equals 2 for all UDAs with only one exception recorded for Medicine (UDA 6) where 12 out of 42 universities (or 29%) shift to a nearby quartile.

The scatter plot of Fig. 3 positions each university in terms of percentiles by TS ratio and FSS_U. Because top scientists have a very high effect on the overall rank by FSS_U of a university (Abramo, Cicero et al., 2013), one expects that all universities fall either in the bottom-left quadrant or in the top-right one. The scatter plot helps to visualize anomalous occurrences. Three outliers (triangles) can be observed near the lines of the median values. Starting from the left side of the graph their position could be explained as follows. The position of UNIV_43 (7.9; 50.7) ranking just above the median by FSS_U and among the bottom 10% by TS ratio, reveals that the productivity of its faculty is rather homogeneous. The opposite must be true for the UNIV_2 (87.3; 49.2), in the mirror position along the FSS_U median: a high number of low and unproductive performers must offset the high contribution to the overall performance of a very high number of TSs. UNIV_46 (49.2; 25.3) positioned around the TS ratios median, must employ a very high number of professors whose productivity is far below the median.

5. Conclusions

In all productive sectors, competition is the lifeblood of continuous improvement and an unequalled stimulus in the search for excellence. Long-standing successful organizations are those that have developed the ability to attract and retain top players. The ratio of TSs to the overall faculty of a university can therefore be an indicator of the competitive strength of the university in the market for education. Up to 80% of world TSs in large research fields work in the top research institutions (Yang et al., 2015), which are concentrated in nations where competition among universities is strong. In non-competitive higher education systems, the research performance of universities is generally little differentiated. Because TSs contribute more than low performers in determining the position of universities in performance ranking lists (Abramo, Cicero et al., 2013), one expects that in non-competitive higher education systems the TSs will be rather evenly distributed among universities. In this study we confirm this expectation for the case of Italy. The differences in the ratios of TSs out of the overall faculty are negligible for all Italian universities, except for the three Schools for Advanced Studies and a private university focused in medicine, which outperform all others. Needless to say, these four universities are the ones that enjoy the highest reputation in the country in their respective educational programs, and are much sought out by prospective students.

As expected, the correlation between the ranking lists by ratio of TSs and average productivity is found to be very strong in all disciplines of the Sciences: universities which rank high by productivity are those which show also the higher TS ratios. Very few outliers escape this rule. One university in particular presents a very high ratio of TSs, but where their contribution to the average performance of the university is offset by a high ratio of low and unproductive performers. This instance is a paradox from a managerial standpoint and would prompt a case study to further investigate the issue. We have also found that the variability of TS ratios across SDSs and UDAs within single universities is very much higher than between the universities. These findings align with those referring to the variability of average productivity of overall academic staff within and between universities (Abramo, D'Angelo, & Rosati, 2014; Abramo, D'Angelo, & Di Costa, 2014).

The investigation also showed that there are no returns of TS ratio to size, which means that the size of universities does not favor or disfavor the emergence of TSs.

Future research on the topic might concern a comparison of the results for the Italian case with those for a country with a competitive higher education system.

Author contributions

Conceived and designed the analysis: Giovanni Abramo, Ciriaco Andrea D'Angelo and Anastasiia Soldatenkova.
Collected the data: Giovanni Abramo, Ciriaco Andrea D'Angelo, and Anastasiia Soldatenkova.
Contributed data or analysis tools: Giovanni Abramo, Ciriaco Andrea D'Angelo, and Anastasiia Soldatenkova.
Performed the analysis: Giovanni Abramo, Ciriaco Andrea D'Angelo, and Anastasiia Soldatenkova.
Wrote the paper: Giovanni Abramo, Ciriaco Andrea D'Angelo, and Anastasiia Soldatenkova.

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