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Looking at the skeleton of university research performance A pilot study on an Italian university

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Abstract

Though university research performance is very much depending on the specific structure of its collaboration patterns between internal and external colleagues, extant studies did not focus on this aspect. Aimed at filling in this gap, this pilot study investigates into the inner structure of an Italian medium-large sized university, and shows a number of features concerning university knowledge production and transfer, like the high heterogeneity of productivity and collaboration propensity among colleagues, departments and disciplinary areas, topological properties common to other kinds of socio-economic networks, and high positive collaboration between direct and indirect collaboration and impact factor.

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1. Introduction

Whatever its specific "weight" in determining university performance and competitiveness is, research performance plays surely a fundamental role for students' and scholars' attractiveness and for establishing its international ranking. In fact, universities that exhibit higher research performance usually are likely also more competitive on the whole range of evaluation parameters, and receive more than proportional funding, so that academic systems resembles 'the-winner-takes-it-all' game [1]. Scientific communities as EUROCRIS are working into the field of evaluation methods and data collection and comparison among the many and diverse academic and research systems. As witnessed in this last conference, part of the studies are attempting to extend attention also to the determinants of performance, and not just limiting to the ways to rank it or to harmonize the various databases. In this effort, they look at inputs conditions, like financial assets, size in terms of students or scholars, and try to draw conclusions by contrasting inputs and outputs of these complex systems, as universities or, more generally, higher education or research centers are. However, in so doing they seem to overlook that, especially for complex systems, it is impossible to infer or understand the relationships between inputs and outputs without "opening the black box", that is without investigating the concrete ways in which inputs are transformed into outputs. In other words, studies on university rankings [2], while giving interesting results concerning performance evaluation and database accessibility and optimization, lack to link them to academic structures, either in terms of organizational design and coordination mechanisms or in terms of researchers'

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personnel management. A specular mistake is done by the ones who, mostly into the field of research policy, look exclusively at the supposed relationships connecting inputs and outputs skipping the analysis of its concrete transformation.

This is a serious lack, because individually- or collectively-performed research is supposed to be influenced by an organization's structural variables, like span of control, coordination mechanisms, etc., and personnel management variables, like performance evaluation mechanisms, etc. In fact, not differently from other kind of organizations, research productivity is supposed to depend *also* on either organizational design or human resource management. In other words, a university research performance is the final outcome of organizational design and personnel management choices concerning the selection of scientists – and to a certain extent also of people working into administrative functions – and the ways with which they produce knowledge as single individuals and collectively. Though the lack of specific data, it is reasonable to believe that a significant share of university research performance is obtained through collaboration and not just individually. Moreover, one could further speculate that, for scientific research is a growing complex and inter- or trans-disciplinary task, the more collective it is, the more performing it is at either inter- and intra-university level. Further, instead of being constituted by a set of small separated groups, it is reasonable to expect that within a single university research groups are (more or less densely) connected one another. In this view, a university should be seen as a knowledge production and transfer network whose nodes are single researchers, and at the inter-university level of national and international academic systems single universities are nodes of national and international knowledge production and transfer networks.

In this perspective, this work intends to contribute to the development of this kind of studies by analyzing a pilot case of a medium-large sized Italian university, characterized by a very broad scope of disciplinary areas. This analysis evidenced the following findings: i) university knowledge network shares many traits common to most socio-economic networks, ii) scholars' productivity and collaboration propensity are very heterogeneous within departments and disciplinary areas, and between disciplinary areas, iii) intra- university collaboration is much higher than inter-university collaboration, iv) who collaborates more gets higher scores in terms of impact factor.

2. Dataset and methodology

Data refers to the University of L'Aquila (Italy), which is a generalist university, lacking only few disciplinary areas, mainly within social sciences. Its early initial core at the beginning of the fifties was in agricultural studies, soon followed by medicine and engineering, and over time adding new disciplinary areas and courses, the most recent ones being vocational science and sport sciences. At the time of data gathering (2014) the university was constituted by 546 scholars, plus 137 laboratory technicians, whose actual tasks goes much beyond the simple job description of supporting practical research and maintaining laboratories in an efficient state, because they often "substitute" failures of the Italian recruitment system for research or teaching positions, hence covering de facto that role. To this set it should be added also 91 research grants beneficiaries, who are supposed also to produce scientific knowledge through publications and various forms of collaborations, plus few (4) "anomalous" professional roles, like professor emeritus. At that time there were about 500 administrative employees, and it should be noted that, as most Italian universities, during last six years all these roles downsized of about 2-5% yearly.

The questionnaire was completed by 60% of all scholars, which decreases to 58% if one includes even research fellows and to 47% if laboratory technicians were included too. The sample of respondents is fairly well balanced across roles and departments. Data refer to the five years 2009-2013.

Most analyses have been distinguished in terms of the sub-groups of our scientific community:

- 6 Roles: PPF (full professor), PSF (associate professor), RIC (research fellow), TL (laboratory technicians), ASS (research grant beneficiary), AL (other categories, not-renewed type of roles, emeritus professors, etc.);
- 7 Departments: DICEAA (Civil Engineering, Architecture, and Environment), DISIM (Information, Mathematics), DIIIE (Industrial Engineering, Information, and Economics), MESVA (Medicine, Public Health, Life Sciences, and Environment), DISCAB (Applied Clinical Sciences, and Biotechnology), SFC (Physical and Chemical Sciences), DSU (Humanities);
- 13 Disciplinary areas (see the list in Appendix).

As concerning collaborations, we have considered those occurred for:

- All kinds of publications (PUB-ATE);
- National research projects (PRO-IT-ATE);
- International research projects (PRO-INT-ATE);
- Patents (BRE-ATE);
- Conferences organizations (CON-ATE).

Each type of collaboration represents a type of link, and thus, it generates a specific topology of collaboration networks, because potentially we can build a network for each type of collaboration. Therefore, the university knowledge network is a

multiplex, whose dimensions are defined by the five types of collaborations. However, in order to simplify the analysis of this pilot study, they have been grouped in just two sets: collaborations for publications (COLL-PUB), and all the other types (COLL-ELSE). Therefore, only the two corresponding types of collaboration network have been analyzed.

Besides them, we have distinguished collaborations only with colleagues within this university - addressed to as "intra-university" collaboration network - and collaborations with any kind of partner, internal or external to this university, either belonging to another university or research center or even belonging to companies or other organizations – addressed to as “inter-university” collaboration network. According to the double categories of collaboration type and intra- vs. (intra+inter)-university collaborations, four networks have been built.

To analyze them we employed some of the most elementary indicators of social network analysis: absolute and relative density, degree centrality, direct and indirect centralization, average path length, diameter, global clustering, and small-world. Due to space limits, we cannot introduce them here, but they can be found easily in any popular handbook [3, 4, 5, 6]. The two only indexes that we briefly comment by suggesting its meaning for our subject are those of direct (degree) centrality and betweenness centrality. The former refers to the number of links that a node has with its neighbors, that is with other adjacent nodes. For our nodes are scholars and links are collaborations for publications or other research activities, a node’s direct centrality addresses to a scholar’s capacity to create new knowledge through direct interactions with collaborators. Conversely, betweenness centrality refers to the number of knowledge that flows through a given node channeled by the (shortest) paths between pairs of nodes that pass across that node. Thus, in our context of knowledge networks, betweenness centrality measures a scholar’s capacity to access knowledge created by others and possibly to transfer it to others. In short, scholars with high degree centrality play the role of hubs and have high knowledge creation capacity, while the ones with high betweenness centrality have high capacity to access - and possibly also transfer – knowledge created by others, and thus play the role of knowledge brokers.

In principle, one could be good in one and not in the other role, but most often the two roles tend to coincide. Moreover, both capacities are expected to be in a recursive process with knowledge productivity, because the more you collaborate and the more you have occasions (and new knowledge) to publish. On the other way round, the more you publish, the more attractive you become for potential collaborators. Similarly, the possibility to access much knowledge indirectly – by intermediating others’ collaborations - enhances your capacity to publish, and in turn this makes you more attractive for potential collaborators. Hence, we should expect that direct and indirect centrality are highly correlated with a scholar’s productivity or with indicators of research impact, like the h-index or other impact indexes.

3. Main results

During the five years considered (2009-2013), scholar’s mean productivity for publications and scholar’s mean number of (general purpose) collaboration were, respectively, about 17 publications and 54 collaborations at the whole university level. These outcomes vary substantially either at the whole university level or at department level or according to the professional role, as measured by the high coefficient of variations (co. var.). Therefore, respondents are very heterogeneous in terms of productivity and propensity to collaborate. This is even more alarming when considering that, rather reasonably supposed, who did not respond were the less productive and collaborative, and thus, if all had responded, such heterogeneity would be much stronger. Moreover, disparities are accentuated regarding collaborations.

Tab. 1 Productivity and collaborations

	Productivity			**Propensity to collaborate**		
	abs. val.	mean	co. var. %	abs. val.	mean*	co. var. %
Whole university	6210	16.74	83.51	19193	53.61	129.73
Professional roles						
PPF	2031	22.82	87.88	5851	66.49	128.84
PSF	1871	16.86	70.45	5531	52.67	110.64
RIC	1867	14.36	72.36	6276	49.42	143.33
Departments						
DICEAA	433	16.65	55.89	857	37.26	112.98
DISIM	1040	16.77	99.65	3251	57.04	85.86
DIIIE	1398	16.45	102.95	3563	43.99	107.03
MESVA	1224	17.49	68.87	3745	55.07	92.53
DISCAB	856	16.15	82.07	2600	50.98	88.63
SFC	859	16.84	64.15	4323	90.06	154.35
DSU	400	16.67	78.70	585	27.86	239.85

*the mean of collaboration in this tab. is a slightly higher than that of the following tab. because it is standardized with the number of respondents, while the other with the number of scholars involved into networks, who are remarkably higher by including also colleagues that did not respond but have been cited and counted into the topology.

Looking at the different disciplinary areas (tab. 2), we see that in terms of collaboration propensity they are very heterogeneous too. Further, though internal propensity is always higher than the sum of internal plus external, it varies a lot depending on the purpose and the scientific field of collaboration. Strangely enough, the peak difference is in physics and philosophy: in both disciplines the reduction of collaboration with any kind of collaborators for other purposes is much higher than the reduction of collaboration with any kind of collaborators for publications. In general, scholars in social sciences and humanities – especially juridical and literature studies – collaborate much less than their colleagues in natural and artificial sciences. Colleagues in the areas of medicine, computer science and agriculture-biology are the most collaborative ones.

Tab. 2 Collaboration behaviors in terms of disciplinary areas average

Disciplinary areas	COLL-PUB A	COLL-ELSE A	COLL-PUB B	COLL-ELSE B
AGR-BIO	38.63	49.57	25.38	32.67
CHIM	34.18	39.36	14.45	18.73
FIS	76.9	100.41	18.49	28.51
GEO	39	71.5	8.75	13.25
ICAR	23.24	34.52	13.2	21.9
INF	49.58	73.68	24.42	40.05
ING	41	56.92	18.21	27.46
IUS	2.78	19.56	2.33	14.56
LANT	2.71	13.86	0.67	4.17
M-FIL	28.07	46.07	7.73	11
MAT	16.74	23.47	5.13	10.13
MED	42.96	51.22	23.22	27.07
SECS	10.25	13.19	3.17	6.08
university	38.28	52.1	17.61	25.22
std. dev	31.74	46.10	13.05	20.06
co. var.	0.54	0.50	0.50	0.43

A = calculated on the intra-university network

B = calculated on the intra- plus inter-university network

Noteworthy, tab. 3 shows that, when aggregated per disciplinary areas, collaboration is extremely positively and significantly correlated with both impact factors indexes, and that this holds for all the types of collaboration.

Tab. 3 Correlations (per disciplinary areas) between collaboration types and impact factors

	h-index	g-index	COLL-PUB A	COLL-ELSE A	COLL-PUB B	COLL-ELSE B
h-index	1	.991**	.891**	.804**	.718**	.644*
sig.		.000	.000	.001	.006	.017
g-index	.991**	1	.908**	.843**	.703**	.622*
sig.	.000		.000	.000	.007	.023
COLL-PUB A*	.891**	.908**	1	.957**	.777**	.737**
sig.	.000	.000		.000	.002	.004
COLL-ELSE A**	.804**	.843**	.957**	1	.673*	.684*
sig.	.001	.000	.000		.012	.010
COLL-PUB B*	.718**	.703**	.777**	.673*	1	.943**
sig.	.006	.007	.002	.012		.000
COLL-ELSE B**	.644*	.622*	.737**	.684*	.943**	1
sig.	.017	.023	.004	.010	.000	

Once given this outlook at the high heterogeneity of scholars' commitment for the main aspects of research activities, in tab. 4 we show the main traits of the four collaboration networks:

- According to the data provided by the 369 respondents, the corresponding intra-university network is made of 435 scholars, who are connected by 662 links of collaborations for publications and 821 links concerning the other four kinds of collaborations;
- When considering intra- plus inter-university collaborations, network size enlarges to 2547 nodes, connected by 2886 relationships to publish and 3289 links to collaborate in the other four types of activities.

Tab. 4 The four networks under examination

Network scope	Type of link	size	links
Intra-university collaborations	Collab. for publications	435	662
	Other types of coll.		821
Intra- plus inter-university collaborations	Collab. for publications	2547	2886
	Other types of coll.		3289

The intra-university network

Relative density of both networks is very low: 0.7 for the former and 0.87 for the latter. Such a low density degree depends also on the fact that the network is very fragmented: 47 scholars are "islands", because they did not collaborate at all with anybody for any purpose within the university. Moreover, about 20% of scholars are grouped into 76 small components (disconnected sub-networks) in the COLL-PUB network, and 23 in the other network. Anyway, scholars collaborate more for other purposes than for publications, either in terms of the number of colleagues with whom they collaborate or in terms of the number of activities that are the objects of such collaborations.

Despite the high fragmentation due to isolated scholars and many small components, there is a "giant component" (i.e. a sub-network fully connected), which includes the 67% and 84% of colleagues, respectively for COLL-PUB and COLL-ELSE. This is a property shared with most knowledge or cognitive networks.

Although the average number of collaborations is rather low in both networks, some colleague is supposed to collaborate very much, because the degree of direct centralization (Dc-CE) is quite high (tab. 5), meaning that there is a group of colleagues highly connected, playing the role of "hubs" of the entire network. For betweenness centralization (Bc-CE) is also rather high, especially in such a sparse network, most scholars are "peripheral" respect to any kind of collaboration activities. In particular, for collaborations else than publications, most colleagues are not involved at all or they are involved in just few collaboration activities. There are then few colleagues who collaborate more in both the direct and indirect forms, that is, who contribute more either to knowledge creation or knowledge transfer. Consistently with this relatively high centralization of direct and indirect collaboration and with its sparseness, only a fraction of scholars are close to all others: that is, closeness centralization (Cc-CE) is high. It means that most colleagues could be reached only through long chains of collaborations.

Both networks show a similar (and moderate) level of global clustering (Cl) of about 10%, but nevertheless both networks appear highly shaped into a small-world structure (SW_Q = 26 and 27%), meaning that, either within or outside the giant component, who collaborates does it through many cohesive sub-groups. However, in both networks the average distance (Apl) between any two couples of colleagues is rather long, if compared with the relative small size of networks.

Tab. 5 Main topological indicators of the intra-university network

	Publications	Other forms of collaboration
Dc-CE	7.40%	7.23%
Bc-CE	12.26%	17.38%
Cc-CE	20.20%	18.52%
Cl	9.97%	9.81%
Apl	5.38	5.35
SW Q	25.74	26.7

The intra- plus inter-university network.

This network is much larger than the previous one, because it adds 2076 external nodes, i.e. colleagues from other universities - or other institutions, such as the research department of the Bank of Italy, etc. - with whom they collaborate. Besides the larger size and a much higher fragmentation in small groups - more than 4 times – this network presents very similar characteristics to the internal network under all other respects (tab. 6). It has the same (high) level of structuring in a small-world topology. Further, here too the average distance (Apl) between any pair of colleagues is the same and still rather high respect to network size, even though size increases of about 6 times respect to the other network. This is consistent with the fact that, even though this is a rather regular network, there are many connections linking distant (groups of) scholars. Instead, due to a presumable presence of a central core of colleagues highly connected, its degree of direct centralization (Dc-CE) is less than half.

Tab. 6 Main topological indicators of the (intra+inter)-university network

	Publications	Other forms of collaboration
Dc-CE	6.40%	6.29%
Bc-CE	11.59%	16.73%
Cc-CE	18.44%	17.56%
Cl	10.24%	10.10%
Apl	5.68	5.51
SW Q	38	38.66

4. Discussion and conclusions

As we have seen, a university is a knowledge creation and transfer network in which colleagues collaborate with internal and external researchers to produce publications, research projects, patents and conferences. Therefore, they share existent knowledge, jointly create new knowledge, and transfer it within and between universities and other kinds of research (or various types of) organizations. The analysis of the specific topology of the corresponding networks sheds precious lights on the conditions in which such knowledge is created and transferred. A first result that we can draw from the analysis of the four networks is that scholars collaborate much more with colleagues within the same university than with external others. At the whole university level, both types of collaboration are a little bit more than double when limited to the same university respect to the mean collaboration when considering all partners, wherever placed. Therefore, merely external collaborations are really marginal. This result is all but trivial, because one could think that in the era of computer-mediated communication geographical distance would not matter anymore. A further result indicates that each network shows many of the typical properties of social networks [7, 8] and knowledge networks [9], like the presence of a giant component, the presence of hubs, a high degree of small-wordliness [10], and others that for space limits we did not have discussed here. A remarkable exception is the absence, among these common properties, of a short average distance (Apl).

A third result is that, when measuring in terms of disciplinary areas, who collaborates more records also a higher score of impact factor, because the two variables are strongly and significantly correlated. Even more noteworthy, such a high correlations do hold also when collaboration concerns activities not directly connected with publications, like participating to research projects, patenting, and conference organizing.

A further finding is that knowledge productivity – measured in terms of the sum of any kind of publication – and propensity to collaborate do vary a lot within departments and disciplinary areas, and between disciplinary areas. Moreover, collaboration propensity differs considerably also in relation to its purpose, whether for publications or not. Moreover, even in all the giant components, collaboration commitment is all but uniform, because there is a core of about 10% of colleagues extremely collaborative and productive, among whom knowledge circulates with few steps only, allowing to find synergies within disciplinary areas, and potentially even across areas and departments.

It should be underlined that most of these findings could be not known without viewing and analyzing university research activities as a network of knowledge creation and transfer, on its own and in connection with other external research organizations, like universities or other research institutions or research units inside profit or public/governmental organizations. Further, we argue that the same conclusion could be extended even at the higher (inter-university) level of aggregation, that is, when considering a whole academic system. At that level, in fact, one could discover a number of interesting and fundamental things, i.e. if there is any correlation between topological properties of single departments (or even single universities) and research performance.

Finally, it is evident that, without accessing and analyzing these kinds of findings, any university research policy would risk being inappropriate or ineffective, because lacking the understanding of the deep structure that determines its knowledge production and transfer.

Appendix : List of disciplinary areas

Acronym	Content
AGR-BIO	Agriculture-Biology
CHEM	Chemistry
FIS	Physics
GEO	Geology
ICAR	Civil Engineering and Architecture
INF	Mathematical and computer sciences
ING	Engineering
IUS	Juridical sciences
LANT	Antiquity sciences and philology-literature
M-FIL	History sciences, philosophy, pedagogy, and other humanities
MAT	Mathematics
MED	Medicine
SECS	Economics and statistics

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