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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 likely 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-sized university, and shows a number of interesting features concerning university knowledge production, like the high heterogeneity of collaboration propensity among colleagues, departments and disciplinary areas, the similarity with other kinds of social networks, and the structuration in a sort of "three sub-universities".

**Keywords**: collaboration networks, disciplinary areas, knowledge production, knowledge transfer, knowledge network, small-world, research performance, research policy, social network analysis, university research structure.

## 1. Introduction

Whatever its specific "weight" in determining university performance and competitiveness, research performance plays a fundamental role for attractiveness and ranking. In fact, universities that exhibit higher knowledge production usually are likely also more competitive on the whole range of parameters and receive more than proportional funding, so that academic systems resembles a 'the-winner-takes-it-all' game (Hazelkorn, 2015). Studies on university rankings (Huang, 2011), while giving interesting results with performance indicators, lack to link them to academic structures, either in terms of organizational design and coordination mechanisms or in terms of researchers' personnel management.

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 meta-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-sized Italian university, characterized by a quite 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) collaboration propensity is very heterogeneous among departments, disciplinary areas and single colleagues, iii) intra- university collaboration is much higher than inter-university collaboration, iv) who collaborates more gets

higher scores in terms of impact factor, v) the combination of these (and other) types of heterogeneity suggest that this university is divided into three "sub-universities" corresponding to very different capacities of knowledge production and transfer.

## 2. Dataset and methodology

Data refers to the University of L'Aquila (Italy), which is a quite broad spectrum (or generalist) university, lacking only a 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 training 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 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 is reduced to 58% if one includes even fellows and to 47% if it also extends to laboratory technicians, and it is fairly well balanced across roles and departments.

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[1].

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. However, in order to simplify the analysis of this pilot study, these five types of collaborations have been grouped in just two sets: collaborations for publications (COLL-PUB), and all the other types (COLL-ELSE). Therefore, only two 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.

[1] See in Appendix the list.

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, like Borgatti *et al.* (2013), Knoke & Yang (2008), Prell (2011), Scott (1992).

## 3. Main results

Propensity to collaborate (tab. 1) either for publications (COLL-PUB) or for the other four forms (COLL-ELSE) varies a lot, because the coefficient of variation is 83.5% in the former type and 129.7% in the latter at the university level. Moreover, it varies quite significantly between the various departments, but not between roles.

Tab. 1 Propensity to collaborate

| | **COLL-PUB** | | | **COLL-ELSE** | | |
|---|---|---|---|---|---|---|
| | abs. val. | mean | co.var. % | abs. val. | mean | co.var. % |
| whole | 6210 | 16.74 | 83.51 | 19193 | 53.61 | 129.73 |
| Hierarchical 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 |

Looking at the different disciplinary areas (tab. 2), we see that they are very heterogeneous and, though internal collaborations are always higher than the sum of internal plus external, they vary a lot depending on the purpose 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. Very 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. 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 |

* Intra-university
* Intra- plus inter-university

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 | |

The main traits of the four collaboration networks are shown in tab. 4:

- An intra-university network of 435 scholars connected by 662 links of collaborations for publications and 821 links of the other four kinds of collaborations;
- A network of intra- plus inter-university collaborations involving 2547 people connected by 2886 relationships to publish and 3289 to collaborate in the other four types of activities.

Tab. 4 The four networks under examination

| **Network scope** | **Type of link** | **size** | **(binary) absolute density** |
|---|---|---|---|
| **Intra-university collaborations** | Collab. for publications | 435 | 662 |
| | Other types of collab. | | 821 |
| **Intra- plus inter-inter- university collaborations** | Collab. for publications | 2547 | 2886 |
| | Other types of collab. | | 3289 |

*The intra-university network*

During the five years under examination, in average each scholar collaborated for publications with 3 colleagues 12 times, and she collaborated for other purposes - national or international research projects, patents, or conferences organizations - with 4 colleagues 19 times. Relative density of both networks is very low: 0.7 for the former and 0.87 for the latter. Indeed, 47 scholars did not collaborate at all with anybody within the university. Moreover, there are 76 small disconnected components in the COLL-PUB network, and 23 in the other, so that such a fragmentation further reduces density. Anyway, scholars collaborate more for other purposes than for publications, either in dichotomous (binary) terms or in value (number of publications or other collaboration activities). Despite the high fragmentation due to isolated scholars and to 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.
Although the average number of collaborations is rather low in both networks, some colleague should 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 collaboration activities. In particular, for collaborations else than publications, most colleagues are not involved at all or they are 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, 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 | 26.70 |

*The intra- plus inter-university network***.**
This network is much larger than the previous one, because it adds 2,076 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. Here, mean collaboration is with 2 colleagues with whom one collaborates 8 times for publications and 10 times for other types of collaboration. Besides the larger size and 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). And also, it has the same (high) level of structuring in a small-world topology, and here too the average distance (Apl) between any pair of colleagues is rather high respect to network size, even though, nevertheless size increases of about 6 times respect to the other network, Apl remains almost equal. 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[2].

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

| | Publications | Other forms of collaboration |
|---|---|---|
| Dc-CE | 6.4% | 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 | 38.00 | 38.66 |

**Discussion and conclusions**

As we have seen, a university is a knowledge production 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 kind of research (and even non-research) 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 our contribution of the four networks on which we have directed our analysis 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[3].

A further results indicates that each network shows many of the typical properties of social networks (Gallo, 2012; Jackson & Rogers, 2007) and knowledge networks (Biggiero, 2016), like the presence of a giant component, the presence of hubs, a high degree of small-wordliness, and others that for space limits we did not have discussed here. A remarkable exception is the long average distance In fact, contacting a colleague through the "chain of collaborations" takes an average of a little more than five-six intermediaries, that is definitely a lot, if compared with that corresponding to communications within all humanity - the famous six degrees of separation (Watts, 2003) – whose network size is nearly 7 billion nodes.

The third important result is that propensity to collaborate does vary a lot between departments and disciplinary areas, which means that a university is not homogeneous in this respect, and concerning the relative consequences of few collaboration.

The fourth finding is that, when measuring in terms of disciplinary areas, who collaborates more obtains also the 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.

The fourth finding is that 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.

[2] One of the analysis that here we cannot include concerns just the core-periphery analysis, which would show the presence of a core of highly connected colleagues.

[3] Indeed, this should depend considerably also on the fact that external collaborators are only “cited” by the internals, and thus, being not respondents, we ignore their reciprocal collaborations. In other words, the squared matrix on internal+external scholars is incomplete, because it lack connections between externals.

However, the “dark side” of this structure of a core within the giant component is that the research network is divided into an “A-university”, which works fairly densely within a single "large group" comprising about 70% of colleagues, while the rest of colleagues into the giant component constitutes a “B-university”. Finally, the ones grouped in small components or - even more – the ones who are completely isolated constitute a sort of “C-university”, where collaboration is sporadic, and thus, knowledge is at best encapsulated and not shared.
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 kind of findings any university research policy would risk to be inappropriate or ineffective, because lacking the understanding of the deep structure that determines its knowledge production and transfer.

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## Appendix

Tab. 7 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 |