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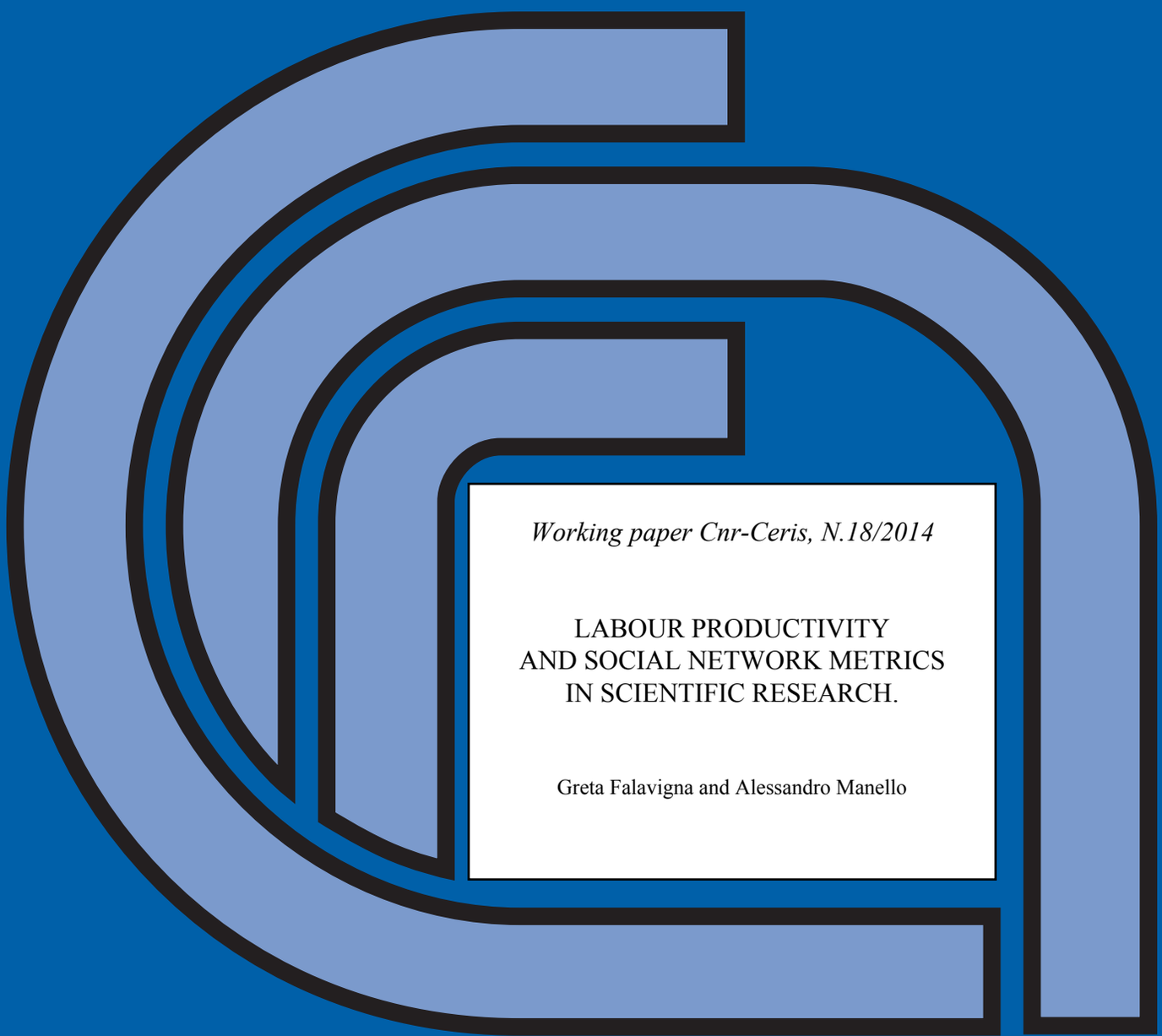

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LABOUR PRODUCTIVITY AND SOCIAL NETWORK METRICS IN SCIENTIFIC RESEARCH.

Greta Falavigna and Alessandro Manello

Working Paper

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Labour productivity and social network metrics in scientific research

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ABSTRACT: This paper presents an analysis of relationships between collaborations and scientific outputs of the Italian National Research Council (CNR). In order to evaluate collaborations among CNR institutes and between CNR institutes and universities, social network metrics have been applied with the aim to measure relationships and to understand if to cooperate allows researchers to publish higher quality outputs, improving their labour productivity. Research institutes are considered as nodes of the internal collaboration network, following the main aim of recent reform. Collaborations are stimulated not only by governments with the aim to have knowledge spillovers but they can improve citations and also their reputation. This last is extremely relevant for winning competitions, calls or grants. In this paper authors used data of scientific publications related to all institutes of CNR for the 2007 year and they ask to the question if researchers that publish more and better are those that collaborate more.

KEYWORDS: labour productivity, social network metrics, research institutes.

JEL CODES: I23, J24

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CONTENTS

1. INTRODUCTION

Since the first restructuring of the CNR in 1999, one of the main goals of all interventions has been to recover efficiency and reduce costs. Indeed, Cesaroni and Piccaluga (2002) underline that, since the 1980s, as a consequence of financial crises the Governments have progressively reduced research funds inducing research institutes and universities to adopt a managerial vision (Etzkowitz *et al.*, 2000). Considering this, the last 2003 restructuring was focused on increasing collaborations among institutes, between institutes and industry, local institutions (Coccia and Rolfo, 2008) and firms (Tuzi, 2005). The first aim of increasing knowledge and innovation through technological spillovers is at least as strong as the need to cut costs. With the last reform, researchers have to partially rethink their position in order to be able to attract funds on the market by offering their skills to external institutions. This process is common to all industrialised countries, even though to different extents (Geuna and Nesta, 2006), but it is particularly important in some scientific fields where fund cuts create strong financial problems.

Taking the CNR's reform into consideration, the evaluation criteria have not been updated and researchers' careers are still evaluated on the basis of their scientific production, interpreted in terms of papers published in ISI or refereed journals or books or patents. From this point of view the situation is slightly different in other EU countries, e.g. in France, where researchers are incentivised on the basis of the relationships they establish within research activities and technology transfer[1] (Llerena *et al.*, 2003).

The aim of our work is twofold: on the one hand we apply a methodology commonly-used in the environmental field to assess the efficiency of Institutes of the Italian National Council of Research, as suggested by Falavigna and Manello (2014) and by Coccia et al. (2014); on the other hand, we analyse the role of collaborations in scientific production through a network analysis in order to find a relation between scientific efficiency and the centrality role of institute.

With the last call of the SIR[2] and the Crisis-Lab Project[3], the CNR has focused the attention on the exchange of competences, favoring collaborations through cooperative projects. In this manner, the scientific research activity gains in eterogeneity and gives to researchers the possibility to publish in top journals of different fields. Indeed, as suggest by Tuzi (2005), good quality scientific production and technology (i.e., patents) are linked and Calderini et al. (2007) shows a positive correlation between patenting activity and the production of articles in top journals. In addition, Li et al. (2013) finds a positive influence of the scientific reputation within the scientific network.

[1]Technology transfer is the diffusion of the complex bundle of knowledge which surrounds a level and type of technology. For a thorough explanation of this concept, see Bernard and Jones (1996).

[2] Scientific Indepence of young Reserachers (SIR), is a program designed by the Italian Ministry of Education, University and Research (MIUR). Information available at http://sir.miur.it/

[3] Crisis Lab is a research program funded by the CNR and collaborations among institutes are recommended. More information at http://www.cnr.it/commesse/Scheda_Modulo.html?id_mod=8905.

Considering previous remarks, the reminder of the paper is organized as follows: section 2 surveys the literature on efficiency models applied to the science field and the role of collaboration in improvements of scientific research; section 3 presents the methodological framework; data and results are shown in section 4 and results are discussed in section 5. Finally, some concluding remarks summarize the main issues raised by the paper (section 6).

2. THEORETICAL BACKGROUND AND RELATED WORKS

While reducing costs and improving productivity are the goals of the last reform, researchers are always evaluated on the basis of their scientific production. Efficiency and productivity in this paper have been computed weighting research outputs on the basis of their scientific reputation. In this manner, efficiency scores represent the ability of researchers to publish in top journals and they perfectly interpret CNR's competition rules. From this point of view, many authors have analysed the problem of evaluating the research activities because, in general, grey literature is not considered in all international competitions. Moreover, this problem has been studied considering also the relation of national funding with the research quality. For example, Groot and García-Valderrama (2006) find that the amount of national funding is positively related to academic quality, whereas the gains from external research commitments are negatively related to academic quality.

It is then clear that researchers must maximize their scientific production in order to win competitions and to improve their career. This paper aims at studying if there is a correlation between the number of collaborations and labour productivity performances. Since a goal of CNR reform is to incentivize spillovers among institutes and between institutes and universities, a network analysis on scientific production of CNR research bodies has been made.

Indeed, authors want to analyze if having collaborations and relationships improves from the one hand the knowledge and the heterogeneity of researchers, from the other hand, the reputation of research units.

Gazni and Didegah (2011) and Sooryamoorthy (2009) show that publishing cooperation increases the expected impact of articles from a scientific point of view. Katz and Martin (1997) and Lee and Bozeman (2005) argue that the productivity of researchers increases with the number of their collaborations.

For this reason, Moody (2004) shows that authors strengthen their position in the network in order to be cited most often.

Ding (2011) shows that productive authors tend to directly co-author with and closely cite colleagues sharing the same research interests.

At the same time, improving reputation increases the probability to win international/national calls, projects and grants. Li et al. (2013) find that cooperation affects reputation and allows scholars to increase opportunities for sponsored programs (grants). In addition, collaborations inspire scholars to continue and improve research efforts.

At Italian level, Abramo *et al.* (2011) find that the top authors in Italy are those who collaborate, mainly with international partners, but it is not always true the reverse. Finally, De Stefano et al. (2013) analyse co-

authorship in Statistics publications using metrics from Social Network Analysis (SNA) and they find results supporting a positive relationship between the centrality of researchers in the network and their scientific performances in term of publication.

Therefore, considering previous literature, with this paper authors want to ask to the following question "are performances of institutes linked to their position in the network of scientific publications?"

3. METHODOLOGY

3.1 Measuring labour productivity of researchers

The measurement of labour productivity of research units is a common procedure in order to evaluate their performances.

There is substantial agreement on how to proceed: the output is divided by the labour inputs to obtain a sort of per capita level of publication, the main outputs in the case of research units.

The labour is normally considered as specialised labour, in the sense that only the research people are considered in the computation (Lee and Bozeman, 2005).

However, that way of measuring performances can be acceptable only under stringent conditions; first of all we have to accept that all outputs produced by research units can be resumed in just one indicator of output level.

All the different kind of outputs produced such as reports, national article, international ISI articles, books and patents have to be considered equivalent and then aggregated in some way; or some of them have to be ignored to obtain a unique proxy of the output.

We consider three types of variables:

- Labour Inputs (e.g. researchers,)
- Scientific Outputs (called SOs) such as ISI articles, refereed articles, books and conferences.

3.2 Measuring the intensity of relationship among institutes within the CNR

After the measurement of global productivity of institutes by mean of the DDF model, we are interested in computing the intensity of relationships within the Italian CNR. In this sense, we adapt the definition of scientific collaboration among two or more scientists to the case of institutes: we define the collaboration as the interaction within a social context of two or more institutes in order to pursue a shared goal, ending with a scientific publication on peer review journals. The idea of extending social network tools not to individual scientist, but to group of researchers is drawn by Kim et al. (2012) who do similar social network analysis (SNA) on a sample of Korean scientists. We decide to adopt a SNA in order to compute social network metrics to analyse the structure of collaborations among institutes, taking metrics definitions by Newman (2001a and 2001b) and Cimenler et al. (2014).

Normalized Degree Centrality (NDC) of an institute I_i, represented by NCD(I_i), is the total number of other institutes which are directly connected to the institute I_i (adjacent institutes in network terms), divided by the total number of network node (n), excluding the institute I_i. NDC(I_i) range from 0 to 1 and is given by:

$$\mathrm{NDC}(I_i) = \frac{\sum_j e_{ij}}{n-1}. \qquad (3)$$

Where e_{ij} represent the number of unique edges e_{ij} that are connected to the institute I_i (Wasserman and Faust, 1994).

Normalised Closeness Centrality (NCC) of an institutes I_i is the sum of all geodesic distances to all other nodes in the network of institutes, multiplied by (n-1), as suggested by Wasserman and Faust (1994). The geodesic distance, denoted by d(I_i, I_j), is the shortest path, or the lower number of edges, that links institute I_i to a generic institute I_j (Cimenler et al, 2014). The sum of geodesic distances is given by $\sum_j^n d(I_i, I_j)$. Normalised closeness centrality has a range from 0 to 1, and a higher NCC represents a more central position for the specific institute in the CNR network.

$$NCC(I_i) = \frac{n-1}{\sum_j^n d(I_i, I_j)} . \quad (4)$$

Normalised Betweenness Centrality (NBC) measure the capacity of an institute I_i of being in a position useful for brokering ideas, projects and then publications (McCarty et al. 2013). The non-normalized version counts the number of geodesic paths that pass through the institute I_i, and then it represents the capacity of the institutes to be a bridge among different research units. The NBC is given by:

$$NBC(I_i) = \sum_j^n \sum_k^n \frac{g_{jk}(n_i)}{g_{jk}} . \quad (5)$$

It range from 0 to 1 and $g_{jk}(n_i)$ represent the sum of geodesic distances containing the institutes I_i, divided by the total number of geodesic distances connecting the two generic k and j institutes.

4. DATA

Our application is based on data coming from the Italian National Research Council (CNR), which represents the larger Italian research institution. During recent years, an intense restructuring process involved the CNR, with the aim of reducing public funds, increasing its efficiency, but also increasing the level of internal and external collaborations. Moreover, its structure is similar to other European research institutions (such as CNRS in France, CSIC in Spain, Max Planck in Germany, etc.) and the results we get can be partially extended to other parent cases.

Firstly, we collect data on institutes operating in the natural sciences and engineering, relative to the year 2007, the last for which information on labour inputs are available on the CNR balance sheet. In particular, research institutes involved in the present study are 108, gathered in nine departments[4].

We collect information on the labour inputs of research institutes from the official CNR balance sheet, number of researchers and the information on outputs are derived from the so called "Research output database" and they are mainly Scientific Outputs: ISI articles, refereed non ISI articles, books and conference proceedings. In table 1 we report the partial labour productivity indicators per researcher (PR) employed in each CNR institutes. These indicators have been computed by dividing the total number of research outputs with the total number of researchers and/or technicians for each institute.

[4] See the CNR's web sites for additional information on that point.

Table 1. Labour productivity indicators

Partial Labour Productivity Indicators	Mean	SD	max
Isi Article PR	1.394	1.053	5.875
Referred articles PR	0.537	0.648	3.167
Conferences PR	0.943	0.904	4.000
Books PR	0.577	0.940	5.154

Secondly, we collect information on the relationship among institutes by analysing the Scopus Database, where all the information on ISI articles published are reported. We download Scopus data of all articles published in 2007, which the generic "CNR" affiliation has been reported for at least one author.

Therefore, by using the additional detail in the database, we identify all the relationship among institutes on the basis of co-authorship. In particular, only for the 2007 year, we reconstruct all the co-authorship records referring to each article published on journals recorded by Scopus, published at least by one author coming from the Italian CNR.

Moreover, if two or more authors come from two different CNR institutes, we assume that these institutes collaborate, while in all the case of external collaborations, we do not identify specifically the university or the research units of affiliation. Our focus has been mainly on internal collaboration among CNR's researchers; then, we treat all other collaborators as a generic "External entities", for which no additional information have been collected. Finally, we have analysed all possible combinations of authors' affiliations as cooperation between institutes.

Collected information has been summarized in a two way table describing all possible pairs of institutes and their effective scientific cooperation. We treat this table as a weight matrix (symmetric) for the network analysis.

5. RESULTS

Labour productivity results have been reported in table 2, where each column correspond to a different indicators, obtained considering a specific scientific outputs as reference, dividing it by the labour input, number of researchers.

The higher labour productivity in term of ISI article is a characteristic of hard sciences, such as Material and Devices or Molecular Design. Social sciences show the worst productivity in term of ISI articles, but the higher in term of referred articles (not ISI), books and participations to conferences.

The computations of SNA metrics for each node (institutes) of the internal CNR network, lead to the results reported in table 3.

Indeed, the low level normalised centrality, reflecting the number of connection, and betweenness (range 1 to 100) highlight how the network of internal collaboration is not dense.

A high number of nodes is not directly connected each other's, because the biggest number of collaboration is with external research entities, such as universities or external research institutes.

Table 2: Labour productivity results by departments

Department	Isi Article PR	Referred articles PR	Conferences PR	Books PR
Agribusiness and Food	0.97	0.53	1.18	0.63
Energy and Transport	1.68	0.04	1.46	0.09
ICT	1.40	0.34	1.62	0.31
Cultural identity	0.24	1.35	0.71	2.18
Materials and Devices	2.47	0.34	0.86	0.13
Medicine	1.64	0.17	0.30	0.08
Cultural heritage	0.33	1.03	1.75	0.88
Molecular Design	2.44	0.21	0.96	0.11
Life Sciences	1.39	0.09	0.04	0.08
Engineering and Production Systems	0.98	0.75	1.46	0.27
Earth and Environment	1.17	0.72	1.04	0.59

Table 3: Social network analysis metrics, average by department (in %)

Department	NDC	NCC	NBC
Agribusiness and Food	0.063	34.12	0.166
Energy and Transport	0.156	34.86	0.603
ICT	0.054	33.27	0.008
Cultural identity	0.005	26.94	0.002
Materials and Devices	0.184	34.94	0.271
Medicine	0.281	34.98	1.446
Cultural heritage	0.007	33.53	0.002
Molecular Design	0.141	34.57	0.287
Life Sciences	0.067	34.00	0.045
Engineering and Production Systems	0.046	33.80	0.018
Earth and Environment	0.091	34.15	0.069

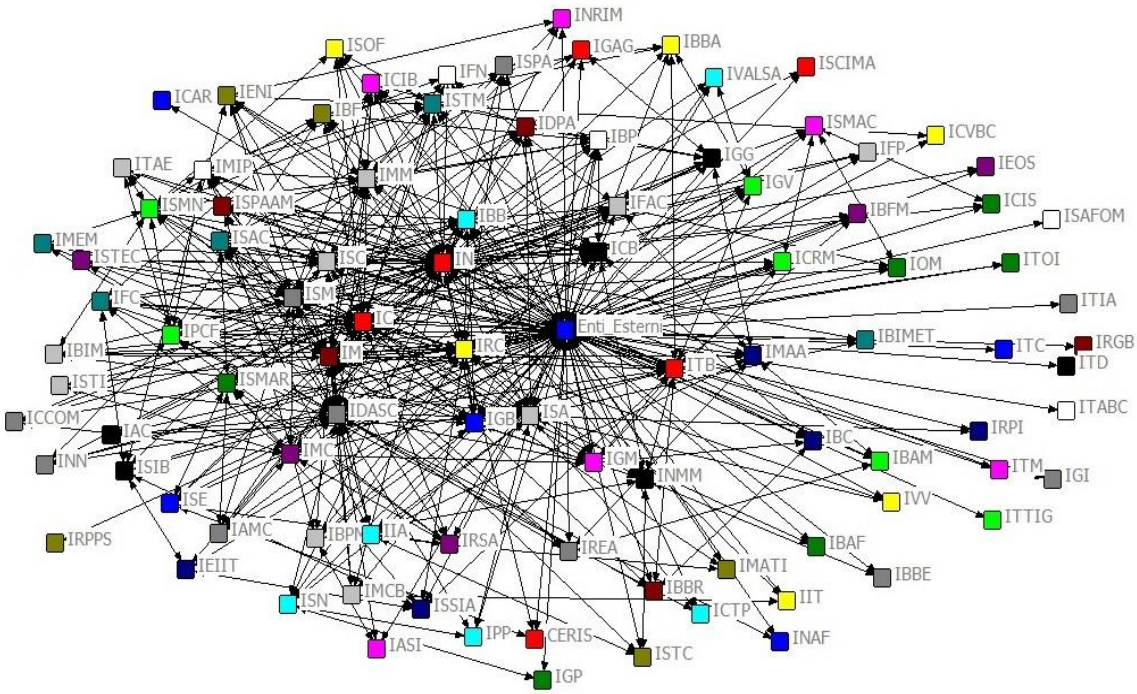

Figure 1: Graphical representation of internal and external collaborations

Figure 1 shed light on this latter point, highlighting the fundamental role of external collaborations: the totality of CNR institutes publishes articles with co-authors coming from universities or external research entities. Of course, the graphical representation of the co-authorship network in figure 1 overestimates the centrality of the node external entities that collects a large number of national and international universities or research centres because we are not able, given the available database, to distinguish precisely among them.

Just a minority of institutes is able to publish with colleagues working in many different institutes, while the majority of scholars publish without internal colleagues or with colleagues coming from a very limited number of institutes (1 or 2).

Table 4 reports individual results for the top institutes in term of ability to collaborate with other CNR components in terms of scientific publications on Scopus journals. Moreover, the table shows how the institutes on Neuroscience is the most able to collaborate, with a Normalised Degree Centrality (NDC) near 2%. In the other case, the level of NDC is lower and confirms the scarce propensity to collaborate among different institutes.

Of course, this result is partially due to recent CNR reform aimed at increasing the size of institutes and facilitating mergers among similar research units.

The consequence is a progressive concentration of practice in specialised research units that, till in 2007, have some difficulties to share with scientists coming from different fields.

Table 4: Most important institutes in the internal CNR publication network (NDC in %)

Ranking		NDC
0	External bodies	7.994
1	IN	1.764
2	IC	0.76
3	IFC	0.671
4	IRC	0.542
5	IMM	0.412
6	IGG	0.352
7	IDASC	0.298
8	ISM	0.266
9	ISC	0.231
10	IM	0.201
11	IPCF	0.184
12	ICB	0.175
13	ISTM	0.166
14	ISMN	0.164
15	IFAC	0.158

Finally, table 5 reports the correlation matrix among labour or global productivity indicators and SNA metrics computed internally on co-authorship within the Italian CNR. In general, we can conclude that partial productivity indicators and SNA metrics show a significant correlation, while the evidence is weaker in term of global productivity.

There are four labour productivity indicators, one for each output considered in the DDF efficiency model, but they do not show accordance in their correlation outcome, reinforcing the evidence on the partial trade-off between publications on ISI journals and other outputs.

What we were expected is a positive correlation between partial labour productivity indicators, but we find that ISI articles per-researcher (PR) are negatively correlated with referred articles PR or books, while the correlation is positive with conferences PR.

The last three rows of table 6 report SNA metrics to show their correlation with productivity indicators.

The impact of collaboration intensity, measured by SNA metrics, on labour productivity is positive and significant if we consider only ISI articles per researcher, confirming findings by Lee and Bozeman (2005), while the correlation becomes negative with different definitions of outputs. In details, labour productivity in term of ISI articles is positively correlated with Normalised Degree Centrality(NDC) and Normalised Closeness Centrality (NCC), while no relationship appears with Normalised Betweeness Centrality (NBC) measure.

Table 5: Correlation matrix among labour productivity, efficiency and SNA metrics.

	Isi Articles PR	Referred articles PR	Books PR	Confs PR	NDC	NCC	NBC
Isi Article PR	1						
Referred articles PR	-0.3795*	1					
Books PR	-0.4248*	0.5644*	1				
Conferences PR	0.1743*	0.2022*	-0.0408	1			
NDC	0.2614*	-0.1838*	-0.2223*	-0.1159	1		
NCC	0.2443*	-0.1622	-0.4780*	-0.0226	0.4584*	1	
NBC	0.1625	-0.1314	-0.1151	-0.0584	0.9893*	0.4536*	1

*indicates significance at 90% level

6. CONCLUSIONS

Recent reform of the Italian National Council of Research (CNR), as well recent grants and international tenders, tries to stimulate cooperation among research units specialised in different fields. In this paper, we focus on the internal collaborations of the CNR, using data on scientific publications of instates and their cooperation via co-authorships. We try to answer to the question if researchers that publish more and better are those that collaborate more with scientists from different fields, or, at least, if institutes which publish more are those which cooperate more.

Nevertheless, even if the present paper shows a clear correlation between the capability to collaborate and the labour productivity of institutes, it is also necessary to notice that this study has some limits.

An interesting future extension of this work will be to analyse publication and cooperation trends by increasing the number of years considered in order to verify if recent CNR reform has been able to increase the exchange of practices and instruments among institutes.

Moreover, the results of the present study can be reinforced by the information on citations and on joint participation to international and national tenders in order to have more precise idea on the real collaboration trends.

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