ISSN : 2321-9602

Indo-American Journal of Agricultural and Veterinary Sciences




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ISSN 2321–9602 www.iajavs.com
Vol. 1, Issue 1 Mar 2013

Indo-American Journal of Agricultural and Veterinary Sciences

Do the best scientists tend to be those that work together more on a global scale? The Italian University System: A Research Study1

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Abstract

cooperation, especially international cooperation, is becoming more common in scientific research and is therefore attracting more attention and encouragement from policymakers. However, there are still open concerns about how internationalization at the level of individual researchers affects research output. The current effort aims to provide some answers to these issues by a bibliometric analysis of the complete Italian university population engaged in the hard sciences between 2001 and 2005. The findings reveal that academics who do better than their national peers tend to work with their peers overseas, but the converse is not always true. There are also notable variations among industries. Last but not least, one must discount the significance of the country's impact on the international alliance.

Keywords
International research collaboration; top scientist; research performance; bibliometrics; Italy

1. Introduction

Working together is a crucial part of any scientific endeavor. There are a variety of reasons why people work together, but "pragmatic attitude to collaboration" (Melin, 2000) seems to be at the root of most of them. In fact, cooperation is an essential part of scientific inquiry, to the point that it is more of a must than a luxury (Beaver & Rosen, 1978). Research cooperation has grown steadily over time, and this isn't by chance (Hicks & Katz, 1996; Wuchty et al., 2007; Schmoch & Schubert, 2008). There has also been a steady growth in international collaborations (Archibugi & Coco, 2004; Zitt & Bassecoulard, 2004). Given the potentials associated with disparities in researchers' scientific and cultural backgrounds, international cooperation takes on an especially important role. In multinational partnerships, it is acceptable to predict that projected outcomes would be higher due to the disparities between partners. According to research on group innovation, groups with a wide range of perspectives produce better outcomes (De Dreu & West, 2001). Researchers from various countries may benefit from working together since they are more likely to pick up novel ideas, methods, and approaches from one another (Burt, 1992).

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ISSN 2321–9602 www.iajavs.com
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However, partnerships often include transaction costs, such as the time and energy spent negotiating and mediating goals, selecting methodology, dealing with outcomes, managing logistics for communications, organizing meetings, and coordinating other activities (Landry & Amara, 1998). Olson and Olson (2000) found that the likelihood of failure and underperformance increased with the distance between research partners. While greater outcomes are possible in international collaborations due to the diversity of resources (both intellectual and otherwise), greater transaction costs, such as those stemming from cultural and linguistic barriers or travel to greater distances, are also to be expected. "the successful organization of an international cooperation is more demanding than that of a purely national one," Schmoch & Schubert (2008) write.

As a result, cooperation are frequently promoted at all governmental levels since their advantages are seen as outweighing their drawbacks. Scientific production resulting from cooperation has a substantially bigger influence than that created by intra-mural collaboration, as shown by studies analyzing the impacts of collaboration on research output (Wuchty et al., 2007). When it comes to international collaborations, it was Narin & Whitlow (1990) that first showed a substantial positive difference in impact for publications with co-authors from various countries. Abramo et al. (2010) show that the amount of international cooperation a scientist achieves is positively connected with both productivity and the average effect of output. This study aims to delve deeper into this question by contrasting the internationalization of highly productive researchers with that of their peers and by analyzing the correlation between participation in international collaborations and research output at the individual level. The study is aimed at answering the following particular questions:

Asking, "Do the most productive researchers also engage in the most international collaboration?"

• Does it turn out that researchers that work together more on a global scale also end up with the greatest results?

Is there a connection between "partner nation" and enhanced productivity and globalization?

In an effort to provide some answers, this research will examine the prevalence of international co-authorship among the Web of Science (WoS)-indexed articles generated by Italian university researchers in the hard sciences between 2001 and 2005.

The study's methodology and the measures used to define each researcher's performance and level of internationalization are outlined in the next section. The answers to the first two questions are presented in Section 3. In Section 4, we provide the specifics in answer to the third question. The last portion provides analysis of the findings and suggestions for where the field may go from here.

2. Strategies, data, and benchmarks

Italian academics were separated into smaller groups based on a number of characteristics before they could begin responding to the study questions provided to them. The existence of i) outstanding scientific performance, ii) high globalization, and iii) partnership with a certain foreign country. In order to try to answer the first two concerns, the study analyzes the correlation between scientists' research performance and internationalization to see whether those with strong research performance also have strong internationalization. To address the third question, we compare the research output and internationalization levels of Italian researchers who have

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collaborated with foreign colleagues from the same country with those who have not collaborated with the same country.

The next section discusses the dataset used for the study and the decisions taken in categorizing academics along the two variables examined (research performance and degree of internationalization of their research activity).

1.1 Methodological approach

This paper takes a distinctly bibliometric approach, since it is based on the joint authorship of articles in scholarly journals from across the world. If we restrict our bibliometric analysis to the "hard sciences," we may be certain that our output is accurately reflected. Co-authorship on a publication is no guarantee of actual cooperation (Melin & Persson, 1996; Katz & Martin, 1997; Laudel, 2002; Vuckovic-Dekic, 2003), and scientific partnerships do not always result in published findings. Despite these caveats, analyzing co-authored publications remains one of the most concrete and well-documented methods for quantifying scientific cooperation (Price & Beaver, 1966; Cockburn & Henderson, 1998; McFadyen & Cannella, 2004; Glänzel & Schubert, 2004). Analysis that is objective, measurable, non-invasive, and very low-cost may be carried out using data like that based on co-authorship (Katz & Martin, 1997). In addition, a large number of observations may be used, which isn't achievable with methods like survey samples.achieve results that are statistically more robust (Smith & Katz, 2000).

1.2 Information Collected and Study Area

All WoS articles produced by Italian universities2 between 2001 and 2005 were mined for their raw data, which was then refined for use in this study. In order to determine who wrote what at which Italian institution, a complicated algorithm was used to decipher the writers' e-mail addresses and determine their genuine identities3. Scientists in Italy now all belong to what is termed a "scientific disciplinary sector" (SDS) inside the country's educational system. In turn, each SDS is embedded inside a larger "university disciplinary area" (UDA). The subject matter of this work, the hard sciences, consists of 9 UDAs4 and 205 SDSs. The study is restricted to the 165 hard science SDSs where at least 50% of the member scientists published at least one publication in the time under consideration5 in order to provide a more representative sample of the phenomena studied. In addition, the dataset is made more reliable by excluding any researchers who joined or left the academic system, or switched SDSs or universities, within the time period of study. The CINECA database of the Italian Ministry of University and Research6 provides a census showing that 26,273 scientists had a permanent faculty post in the 165 SDSs throughout the time of observation. The identification and disambiguation technique enables the identification of 128,487 WoS-indexed papers written by these scientists between 2001 and 2005.

It is important to note, returning to the discussion of caveats and assumptions, that the observations made do not concern a sample, but rather the entire population under analysis: the entire scientific output (censused in the WoS) of Italian university researchers in the 165 SDSs considered.

1.2 Indicators

For this study, we have chosen six indicators that seek to collect numerous features, as specified below, to characterize each university researcher along the two dimensions analyzed (research performance and degree of internationalization).

Research performance indicators

When evaluating a scientist's research performance, both their output and the average effect of their work are taken into

ISSN 2321–9602 www.iajavs.com
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account. These first two examples

The second set of metrics focuses on output, while the third looks at output quality and effect.

Productivity (P) is the number of papers a scientist has written throughout the time frame of study.

Fractional productivity (FP) is the sum of a scientist's contributions to publications in which they were listed as authors, with each author's share of the work being calculated as the reciprocal of the number of other authors listed on the paper.

• Average Quality (AQ): the average value of the quality of a scientist's publications, where the quality of each publication is approximated by the number of times it has been cited relative to the number of times all other publications of the same type (article or review) published in the same year and in the same subject category have been cited.

The selection of these indicators is predicated on the idea that an Italian scientist's ability to recruit a foreign partner and that partner's desire to engage with him or her rises in tandem with the quantity and quality of the publications he or she produces. It is timely to incorporate a measure of productivity (FP) that accounts for the scientist's co-authorship contributions, given the importance of gauging the depth of cooperation.

Indicators of internationalization

There are three aspects that may be used to assess a scientist's level of internationalization in their work: i) the volume, as shown by the number of foreign publications; ii) the frequency, as indicated by the frequency with which the scientist publishes with foreign colleagues; and iii) the breadth, as indicated by the number of countries represented in the scientist's own writings. Each dimension is probed with its own unique metric (Table 1).

One's "international collaboration intensity" (ICI) is the number of articles he or she has written in collaboration with a researcher from a foreign organization ("cross-national publications"). Another's "international collaboration rate" (ICR) is the percentage of ICI to a scientist's total number of articles published (9).

Different scientific domains (often distinguished by varying publication coverage) have varying degrees of measurement distortion, which must be reduced.

Although "impact" is generally accepted as the more accurate word in the bibliometric field for discussing what citations measure, we use "quality" here as a synonym. Quality of a product is defined as meeting specifications in the "quality management" literature. To us, it is essential that the results of a study really contribute to the furtherance of science and technology. That's why both terms are often used synonymously.

8 If a researcher wrote two publications, one with two co-authors and the other with three, their FP would be 1/3 + 1/4 = 7/12. Each co-author's contribution was weighted differently in the life sciences depending on where they fell on the author list and whether or not they were an internal or external contributor.

9 Of the 26,273 scientists who maintained a faculty post over the observed time at the 165 SDSs, 21,504 ended up as authors of a publication in the dataset, indicating that ICR only has value for academics who produced at least one publication in the WoS during the five-year period under observation.

10 The ICA value of an Italian researcher would be four if he or she collaborated with colleagues from four different countries (the USA, France, Spain, and Germany) on four papers, seven papers, with authors from France and Germany, and 23 papers from the USA. Therefore, 12,511 researchers in the sample have ICA values greater than zero because they have authored at least one publication with a

foreign co-author.

ISSN 2321–9602 www.iajavs.com
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the dataset, different "fertility", intensity of citation, degrees of internationalization, etc.)[11], the analysis is always conducted by individual SDS. This means that absolute values of the indicators are calculated for every scientist of the dataset, and through comparison to the same measurements for the other university researchers of the same national SDS, we then obtain percentile rankings for each individual scientist with respect to his/her national colleagues.

Dimension	Sub-dimension	Indicators
Research performance	Productivity	Product (P) Fractional Product (FP)
	Average Quality	Average Quality (AQ)
Degree of internationalization	Intensity	International Collaboration Intensity (ICI)
	Propensity	International Collaboration Rate (ICR)
	Amplitude	International Collaboration Amplitude (ICA)

Table 1: Classification of indicators used.

Individual top scientists' performance and internationalization are evaluated using a variety of indicators

This section offers studies on whether or whether scientists who succeed in one of the two dimensions investigated (research performance or internationalization) are also characterized, in comparison to the rest of the population, by values that are higher along the other axis. In reality, it is not safe to assume that academics who interact internationally are also the greatest researchers in terms of output, either quantitatively or qualitatively. This is especially true if the "sub-dimensions" indicated by the indicators within each dimension are taken into account.

For each of the six metrics, we can break down the total pool of researchers into two supplementary subsets: the "top scientists" and everyone else. Scientists who rank highest on a certain indicator relative to their peers are regarded to be among the best in the field. For each of the 165 SDSs evaluated, the top scientists were those that were in the top 10 percent of the rankings (by percentile) for the indicator used. Depending on the criterion used, the exact top 10% of scientists is likely to vary. The remaining 90% of scientists whose performance is below the top 10% make up the second subset.The next two subsections present a comparison of the top scientists with the rest of the population and measurement of the average differences:

- of internationalization, when the top scientists are identified on the basis of a performance index;
- of research performance, when the top scientists are identified on the basis of an un internationalization index.

1.3 Top scientists identified on the basis of a research performance index

The best researchers, as determined by each of the research performance indices, had consistently higher average values across the board for each internationalization indicator compared to

ISSN 2321–9602 www.iajavs.com
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their less successful peers (Table 2). In Table 2, the first number (27.12) indicates that, on average, a top scientist who has been identified using P has an ICI value that is higher (by 27.12 percentile rankings) than the one of his peers who are part of the general population. It turns out that top-performing researchers, whether measured quantitatively (P, FP) or qualitatively (AQ), engage in more international collaboration (ICI) and have wider networks (ICA) than their peers.

		Internationalization index		
		ICI*	ICR*	ICA**
Performance index for top scientists selection	P	27.12	8.07	15.54
	FP	23.50	5.71	13.38
	AQ	8.56	9.22	5.27

Table 2: Average difference in percentile ranks, for each indicator of internationalization, between top scientists identified on the basis of performance indicators and the rest of the population of scientists.
** The analysis for indicators ICI and ICR were carried out for the 21,504 researchers resulting as authors of a publication in the dataset.*
*** Analysis for the indicator ICA was carried out for the 12,511 researchers that realized at least one publication with co-authorship abroad.*

However, there are variations beyond the overall pattern depending on the metric of performance under scrutiny. As may be predicted, the top scientists in terms of productivity (P) show the largest average disparities in terms of the number of cross-national publications (ICI: 27.12) and the number of partner countries (ICA: 15.54). Those determined by FP had the smallest standard deviation in terms of internationalization bias (ICI: 5.71).
However, those leading scientists who have the greatest ICR (9.22) and lowest values for ICI (8.56) and ICA (5.27) are the ones whose work has been judged to be of the best quality on average (AQ). The researchers defined by a higher quality of output are thus less productive and include fewer countries, but in relative terms, they cooperate more with foreign authors than the top scientists selected based on P or FP.

The previous study was detailed for each of the nine UDAs studied in order to uncover any discrepancies at the disciplinary level. A UDA's top scientists are those who scored highest in each of the SDSs that made up that UDA. Table 3 shows that there are significant variations in performance across indicators, per discipline.
The Civil Engineering and Architecture UDA has the smallest differences in P across all three internationalization indices (18.85 for ICI, 4.03 for ICR, and 4.52 for ICA). The average ICR difference in Chemistry is 14.2, which is more than 75.96% of the total value. For both ICI (+41.7% compared to the overall data) and ICA (+62.03%), the Physics UDA has the greatest values of average difference. When FP is used instead of P, the Physics and Chemistry UDAs show comparable features (Table 4).

	Internationalization index*		
UDA	ICI	ICR	ICA
Civil engineering and architecture	18.85 (-30.49%)	4.03 (-50.06%)	4.52 (-70.95%)
Industrial and information engineering	19.21 (-29.17%)	6.18 (-23.42%)	9.89 (-36.37%)
Agricultural and veterinary sciences	20.34 (-25%)	4.98 (-38.29%)	8.81 (-43.28%)
Biology	30.93 (14.05%)	8.89 (10.16%)	15.84 (1.9%)
Chemistry	31.7 (16.89%)	14.2 (75.96%)	19.5 (25.48%)
Earth sciences	26.21 (-3.36%)	6.38 (-20.94%)	15.69 (0.94%)
Physics	38.43 (41.7%)	8.1 (0.37%)	25.18 (62.03%)
Mathematics and information sciences	26.59 (-1.95%)	5.66 (-29.86%)	11.33 (-27.1%)

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Medical sciences	25.99 (-4.17%)	7.79 (-3.47%)	13.2 (-15.08%)
Total	27.12	8.07	15.54

Table 3: Average difference for degree of internationalization (in percentile ranks) between top scientists identified for P and the rest of the population: analysis by disciplinary area.

* *Brackets show percentage variations of values for average differences in the UDA when compared to the general aggregate values, indicated in the bottom row.*

	Internationalization index*		
UDA	ICI	ICR	ICA
Civil engineering and architecture	16.29 (-30.68%)	2.23 (-60.95%)	3.43 (-74.4%)
Industrial and information engineering	16.56 (-29.53%)	3.9 (-31.7%)	8.25 (-38.37%)
Agricultural and veterinary sciences	15.87 (-32.47%)	2.75 (-51.84%)	6.66 (-50.26%)
Biology	26.41 (12.38%)	5.8 (1.58%)	14.06 (5.09%)
Chemistry	28 (19.15%)	11.57 (102.63%)	16.88 (26.15%)
Earth sciences	22.54 (-4.09%)	4.08 (-28.55%)	14.4 (7.58%)
Physics	29.92 (27.32%)	2.08 (-63.57%)	17.54 (31.04%)
Mathematics and information sciences	21.51 (-8.47%)	1.91 (-66.55%)	8.9 (-33.54%)
Medical sciences	24.38 (3.74%)	7.36 (28.9%)	12.72 (-4.96%)
Total	23.5	5.71	13.38

Table 4: Average difference in degree of internationalization (in percentile ranks) between top scientists identified for FP and the rest of the population: analysis by disciplinary area.

* *Brackets show percentage variations of values for average differences in the UDA when compared to the general aggregate values, indicated in the bottom row.*

The results for AQ (Table 5) are different: the Biology UDA shows the highest values of differences for all the internationalization indices. Chemistry shows the lowest values of average differences for ICI (5.64) and ICR (2.72), while the lowest average difference for ICA (0.45), is seen, as occurred for P and FP, for Civil engineering and architecture.

	Internationalization index*		
UDA	ICI	ICR	ICA
Civil engineering and architecture	8.22 (-3.97%)	5.9 (-36.01%)	0.45 (-91.38%)
Industrial and information engineering	9.3 (8.64%)	8.2 (-11.06%)	2.69 (-48.9%)
Agricultural and veterinary sciences	7.91 (-7.59%)	7.37 (-20.07%)	5.56 (5.53%)
Biology	12.31 (43.81%)	14.22 (54.23%)	7.46 (41.53%)
Chemistry	5.64 (-34.11%)	2.72 (-70.5%)	3.09 (-41.36%)
Earth sciences	10.25 (19.74%)	10.5 (13.88%)	5.76 (9.31%)
Physics	10.59 (23.71%)	13.14 (42.52%)	6.97 (32.31%)
Mathematics and information sciences	6.65 (-22.31%)	6.4 (-30.59%)	2.84 (-46.1%)
Medical sciences	7.13 (-16.71%)	9.64 (4.56%)	4.53 (-14.11%)
Total	8.56	9.22	5.27

Table 5: Average difference in degree of internationalization (in percentile ranks) between top scientists identified for AQ and the rest of the population: analysis by disciplinary area.

* *Brackets show percentage variations of values for average differences in the UDA when compared to the general aggregate values, indicated in the bottom row.*

3.2 Top scientists identified on the basis of an internationalization index

Now we conduct the counter-analysis of that just completed, meaning the top scientists, in each SDS, are identified on the basis of an internationalization index, and their research performance (P, FP, and AQ) is compared to that of their colleagues (Table 6). Unlike the preceding analysis, this test no longer verifies the top scientists as showing greater values than their colleagues for every index considered. The top scientists identified on the basis of ICR show negative average differences for P (-3.48) and FP (-6.92). However, considering average quality of product (AQ), the top scientists for ICR show higher values than their colleagues (average difference is +9.23) Thus, in practice, those who have a greater propensity for international collaboration produce less on average than do their colleagues, but their total product (cross-national and domestic) results as being of higher average quality. Again referring to ICR, it can also be seen that this indicator registers the lowest values of average difference, for all 3 performance indices. The top scientists identified on the basis of ICI and ICA do, however, show positive average differences with respect to their colleagues for every performance index. Those who collaborate more at the international level (in absolute terms), or who have more extended networks, thus show research performance that is better than the remainder of the population. The maximum values of average difference (+37.4 for P, +36.0 for FP, +21.0 for AQ) are all verified for ICI: top scientists identified on the basis of ICI show on average, with respect to their colleagues, values for all 3 indices of performance that are notably higher than those for the rest of the population.

		Performance index		
		P	FP	AQ
Internationalization index for top scientists selection	ICI	37.42	35.97	21.02
	ICR	-3.48	-6.92	9.23
	ICA	22.74	21.03	14.26

Table 6: Average difference in percentile ranks, for each indicator of performance, between top scientists identified on the basis of an internationalization index and the rest of the population.

Once again the analysis was detailed at the level of the single UDA. Concerning ICI (Table 7) the variations seen at the level of disciplinary area are quite contained. In terms of P, the difference in performance between top scientists (for collaboration intensity) and the remainder of the population varies between +31.46 in Civil engineering and architecture and +43.22 in Physics. Very similar situations are also seen when examining the differences for FP and AQ. In all cases, whatever the extent, the top scientists of all the UDAs show values of performance that are higher than those of their colleagues.

Disciplinary variations are more evident when considering ICR (Table 8) and ICA (Table 9). In all the UDAs, with the sole exception of Chemistry, the performance of top scientists for collaboration propensity (ICR) is seen as lower than that for the rest of the population (Table 8), with very marked differences in Physics, for P (-14.7%) and FP (-21.31%). The situation is the opposite for average quality (AQ): here the difference in performance between top scientists for ICR and the rest of the population is one of advantage for the former, in every UDA, with particularly substantial jumps in Civil engineering and architecture (+40.76% higher than the general aggregate), Agricultural and veterinary sciences (+37.37%) and Medicine (+37.59%).

	Performance index*		
UDA	P	FP	AQ
Civil engineering and architecture	31.46 (-15.93%)	31.18 (-13.32%)	20.72 (-1.44%)
Industrial and information engineering	34.49 (-7.83%)	31.15 (-13.4%)	19.69 (-6.32%)
Agricultural and veterinary sciences	32.33 (-13.6%)	30.2 (-16.04%)	21.04 (0.08%)
Biology	39.53 (5.64%)	38.51 (7.06%)	22.79 (8.43%)
Chemistry	39.89 (6.6%)	37.3 (3.7%)	19.32 (-8.1%)

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Earth sciences	35.55 (-5%)	34.14 (-5.09%)	21.43 (1.94%)
Physics	43.22 (15.5%)	37.26 (3.59%)	19.99 (-4.92%)
Mathematics and information sciences	37.69 (0.72%)	36.23 (0.72%)	17.77 (-15.47%)
Medical sciences	37.06 (-0.96%)	38.2 (6.2%)	22.51 (7.09%)
Total	37.42	35.97	21.02

Table 7: Average difference in performance, by percentile ranks, between top scientists identified on the basis of ICI and the rest of the population: analysis by disciplinary area.

** Brackets show percentage variations of values for average differences in the UDA when compared to the general aggregate values, indicated in the bottom row.*

	Performance index*		
UDA	P	FP	AQ
Civil engineering and architecture	-0.47 (86.49%)	-6.05 (12.57%)	12.99 (40.76%)
Industrial and information engineering	-0.05 (98.56%)	-4.3 (37.86%)	11.03 (19.49%)
Agricultural and veterinary sciences	-2.5 (28.16%)	-6.91 (0.14%)	12.7 (37.59%)
Biology	-2.41 (30.75%)	-5.41 (21.82%)	11.96 (29.61%)
Chemistry	3.06 (187.93%)	0.41 (105.92%)	4.36 (-52.76%)
Earth sciences	-11.71 (-236.49%)	-16.93 (-144.65%)	0.93 (-89.87%)
Physics	-14.7 (-322.41%)	-21.31 (-207.95%)	3.75 (-59.33%)
Mathematics and information sciences	-7.2 (-106.9%)	-13.24 (-91.33%)	1.55 (-83.24%)
Medical sciences	-3.27 (6.03%)	-4.46 (35.55%)	12.68 (37.37%)
Total	-3.48	-6.92	9.23

Table 8: Average difference in performance, by percentile ranks, between top scientists identified on the basis of ICR and the rest of the population: analysis by disciplinary area.

** Brackets show percentage variations of values for average differences in the UDA when compared to the general aggregate values, indicated in the bottom row.*

Considering the top scientists identified on the basis of ICA (Table 9), the Physics area is notable for negative differences in performance relative to the rest of the population, for both P and FP (-13.36% and -12.16% respectively). In all the otherareas, scientists characterized by particularly extensive collaborative network show a higher average performance relative to the rest of their colleagues. In every case, in terms of AQ, top scientists for collaboration amplitude have performance that is significantly greater than that for the rest of the population

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	Performance index*		
UDA	P	FP	AQ
Civil engineering and architecture	51.29 (125.54%)	41.88 (99.14%)	7.12 (-50.08%)
Industrial and information engineering	72.93 (220.7%)	65.18 (209.93%)	11.47 (-19.54%)
Agricultural and veterinary sciences	67.8 (198.16%)	60.95 (189.82%)	12.71 (-10.89%)
Biology	56.91 (150.25%)	52.03 (147.4%)	16.24 (13.87%)
Chemistry	64.83 (185.08%)	63.62 (202.54%)	14.13 (-0.93%)
Earth sciences	18.12 (-20.3%)	14.16 (-32.68%)	13.25 (-7.11%)
Physics	-13.36 (-158.77%)	-12.16 (-157.82%)	15.22 (6.75%)
Mathematics and information sciences	75.41 (231.64%)	65.37 (210.83%)	10.41 (-26.99%)
Medical sciences	11.92 (-47.6%)	9.69 (-53.9%)	14.93 (4.72%)
Total	22.74	21.03	14.26

Table 9: Average difference of performance, by percentile ranks, between top scientists identified on the basis of ICA and the rest of the population: analysis by disciplinary area.

** Brackets show percentage variations of values for average differences in the UDA when compared to the general aggregate values, indicated in the bottom row.*

2. Performance, internationalization and nationality of foreign partner

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In this section, the characterization of the researchers of the dataset refers to the nationality of the foreign institutions to whom their co-authors belong. This is aimed at finding out if and how research performance and degree of internationalization vary with the nation involved in collaboration.

The selection of nations/continents for analysis was based on the numbers of cross- national publications by Italian university researchers. In an attempt to detect the most possible aspects of the phenomenon under observation, the selection includes the top four nations for frequency of publication by the population of Italian university researchers over the period under consideration (USA, France, Germany, UK), with an additional selection of four nations and regions considered of emerging importance (China, India, Latin America[12] and Africa) (Table 10).

Over the period considered, Italian researchers realized more publications with the USA than with any other nation. Of the 41,445 publications produced in international co-authorship by the researchers under observation, a full 12,560 of these products (30.3%) were realized with American researchers. The Italian researchers involved in these publications numbered 6,167, or 28.68% of the total considered, and represented all of the 165 SDSs considered.

To attempt to isolate and evidence potential specificities of the nations under observation, we concentrate on the set of Italian researchers that collaborated exclusively with the foreign nation considered. For example, of the 6,167 Italian researchers that collaborated with the USA, there are 2,500 that collaborated only with the USA and not with any of the other 7 nations/regions analyzed.[13]. These 2500 are thus compared to the rest of the population, composed of all remaining Italian scientists who collaborated with foreign nations.

Country	Publications		Italian university researchers		
	Total publications	Incidence (%) in total Italian cross-national publications	Collaborating with a partner in the country	Incidence (%) in total of university researchers	Number of SDSs
USA	12,560	30.3	6,167	28.68	165
France	6,646	16.0	3,725	17.32	160
Germany	5,831	14.1	3,376	15.70	150
UK	5,772	13.9	3,229	15.02	157
Latin America	1,542	3.7	998	4.64	134
Africa	711	1.7	531	2.47	114
China	555	1.3	413	1.92	93
India	349	0.8	255	1.19	64

Table 10: Publications co-authored by Italian university researchers and colleagues of foreign nations considered: 2001-2005.

In general, the researchers who collaborated with each of the foreign nations considered show average values that are higher than their colleagues for two indicators of productivity (P and FP, Table 11). Both the maximum values for differences (7.60 for P and 13.57 for FP) occur for the set of researchers who collaborated with Indian colleagues. The situation is more heterogeneous when examining

ISSN 2321–9602 www.iajavs.com
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average quality of research (AQ): scientists who collaborated with the USA show the greatest performance difference (+6.64), while those who collaborated with Africa, China or India show lower performance compared to their colleagues, with respective negative differences of -3.02, -0.73 and -0.32.

Country	Number of Italian researchers considered	Performance index			Internationalization index		
		P	FP	AQ	ICI	ICR	ICA
USA	2,500	7.49	6.45	6.64	-2.52	-0.67	-5.65
France	931	4.17	3.52	2.51	-6.28	-3.84	-6.43
Germany	654	1.14	1.10	1.34	-7.95	-3.83	-7.21
UK	765	2.93	2.11	2.95	-6.18	-3.12	-6.39
Latin America	197	3.87	3.95	1.91	-2.92	1.63	-3.39
Africa	120	2.08	0.54	-3.02	-1.90	1.47	-2.25
China	68	5.51	0.90	-0.73	-3.62	-1.44	-4.79
India	39	7.60	13.57	-0.32	-9.11	-10.69	-8.58

Table 11: Average difference in percentile ranks for each indicator of performance and of internationalization between scientists who exclusively collaborated with a specific nation and the rest of the population.

However, considering the indicators of internationalization, the average differences for ICI are all negative (ranging from -9.11 for Indian to -1.90 to Africa), as we would have expected: in effect, the rest of the population, from which the differences are calculated, is composed of researchers who collaborated with more than one of the nations considered or with other foreign nations, and therefore their scientific production in foreign co-authorship is likely greater. The average differences for ICR are also negative values, with the exception of values relative to Latin America (+1.63%) and Africa (+1.47%). For ICA, the values are all negative and range from a low for India (-8.58%) to a high for Africa (-2.25%).

3. Discussion and conclusions

This work, taking a bibliometric approach, examines the relationship between research performance and the degree of internationalization of scientific activity, conducting the examination at the level of the individual researcher. The intent was to verify if scientists with the best research performance are also those who collaborate more internationally, and vice versa. To obtain robust results, the dataset selected was unique for its size and completeness, including 124,000 WoS-listed publications over the period 2001-2005, authored by all the Italian university community, made up of more than 26,000 scientists of the hard science disciplines.

The results seem to confirm the initial hypothesis that researchers characterized by the best research performance also have a greater intensity of and propensity towards international collaboration. This applies to both sub-dimensions identified to study the research performance: productivity and average quality of the research products.

In fact, both more productive scientists and the ones with top impact results collaborate more abroad than do their colleagues, both in absolute (number of cross- national publications) and in relative terms (ratio of cross-national

ISSN 2321–9602 www.iajavs.com
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publications to total authored publications), and present more extensive collaboration networks (number of different nations represented in cross-national publications).

Although there are notable differences at the disciplinary level, for each indicator of performance, this is especially evident for the top-performer scientists in three basic sciences: chemistry, physics and biology. In these disciplines in fact the scientists characterized by better research performance tend to collaborate internationally more. This is particularly true in chemistry and physics when we consider research productivity, and in biology and physics as far as research quality is concerned. On the other hand, the top scientists in Civil engineering and architecture, regardless of the performance index used to select them, show lower values in terms of international collaboration networks than their colleagues. In this specific discipline the researchers with better research performance collaborate with fewer foreign countries.

Considering the top scientists for international collaboration intensity, the results are a mirror image: these scientists have research performance that is clearly superior to the rest of the population along all aspects considered (quantitative, contributive, qualitative). The same occurs for the top scientists for amplitude of international collaboration. In other words the researchers who author more cross-national papers in absolute terms or with a greater number of foreign countries tend to outperform their colleagues in terms of research outcome (along all the three performance dimensions).

However, when identified for propensity to collaborate abroad, there is no indication that the top scientists achieve superior productivity than their colleagues, except in average impact. These researchers produce less than their colleagues, but on average their research products are of higher quality. As these researchers tend to produce more in relative terms with foreign colleagues, their lower productivity be caused by the higher transaction costs typically involved in international collaborations. The registered greater impact appears completely in line with what has already been noted in the literature: works in international co-authorship on average receive greater citations. This means that those researchers with a higher incidence of cross-national publications among their total publications then register an average impact that is generally superior to that of their colleagues.

Also here there are disciplinary variations: while they are enough contained when the selection criteria for top scientists is based on international collaboration intensity, they are larger for the other two international indices. Again the largest differences are registered in physics and chemistry.

Elaborating the data by nationality of the foreign partner with which the Italian researchers collaborated, tests demonstrate that the greatest difference in productivity with respect to the rest of the population occurs for scientists who collaborate with the USA and India, while those who collaborate with the USA also achieve the highest difference in average impact.

In a context of increasing interest on the part of the policy-maker for “internationalization of research”, and so mirrored by interest among management in universities and public research institutions, it seems evident that incentive schemes in

ISSN 2321–9602 www.iajavs.com
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favor of foreign collaboration should not substitute, but at most integrate those directed towards stimulating increased performance. This is because, while performance appears directly correlated to intensity/propensity for international collaboration, the reverse correlation is not equally evident.

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