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The relationship between research performance and international collaboration in chemistry

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Abstract The number of internationally co-authored articles have significantly increased in recent years and now receive more citations than domestic works. Abramo et al. (Scientometrics 86:629–643, 2011b) investigated scholars in Italian universities and found a positive correlation between their research performance and degree of internationalization. This study uses a data set in chemistry to examine the robustness of the results presented by Abramo et al. (Scientometrics 86:629–643, 2011b) and the relationship between international collaboration and mobility among researchers. The results confirmed the robustness of the previous study and raised the possibility that the higher citation rate of international papers is not solely explained by the higher performance of researchers. Therefore, international research collaboration seems to exert some kind of "bonus" effect because of internationalization. The results also indicate that researchers who collaborate internationally accumulate science and technology human capital through collaboration. A positive relationship between the international mobility of researchers and their performance is also shown although the direction of the cause and effect is not yet clear.

Keywords International co-authorship · Research performance · Bibliometrics · Chemistry · Research collaboration

JEL Classification D83 · O31

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Introduction

Teamwork in research involves a common pursuit in knowledge production (Wuchty et al. 2007). Researchers have stated that their reasons for collaboration include access to expertise or equipment and for education/mentoring purposes (Beaver 2001). In summary, the advantages of collaboration include an increase in scientific productivity, research quality, innovative capacity, and the accumulation of science and technology human capital (S&T HC). It must be noted though that collaboration does have some disadvantages have also been pointed out (Ordóñez-Matamoros 2008). Research collaboration and co-authorship are not always consistent because some authorship is not based on collaborative contributions and research collaboration does not always result in publication (Laudel 2002). However, using co-authorship as an indicator of research collaboration has four advantages: verifiability, stability, ease of measurement, and data availability. These advantages have been cited as the most appropriate documented indicators for research collaboration (Katz and Martin 1997).

Among co-authored papers, internationally co-authored papers (hereafter, international papers) are on average, with a few exceptions, more highly cited than domestic papers (Glänzel 2001; Glänzel and Schubert 2001). Over time, international papers have increased in number, and in 2010, they accounted for 21.6 % of the world's published scientific papers. This growth indicates transcendence in the knowledge production of institutes and countries. However, it is apparent that the international co-authorship rate varies among countries and disciplines (NISTEP 2011). This phenomenon may correlate with scientific policy implementation favoring international research collaboration, such as the EU Research Framework Network.

International co-authorship may reflect an individual researcher's interests and motivations as stated above, or it may be influenced by macro reasons such as international knowledge diffusion, for example researchers in China (Bell et al. 2007), or the influence of large and special equipment such as CERN in Switzerland. Links among countries are influenced by the proximity of economic, geographical, historical, linguistic factors and by people's mobility among countries (Zitt et al. 2000; Nagpaul 2003; Choi 2012).

The higher citation rate of international papers on the macro level may also be due to an increase in diversity within research teams (Adams et al. 2005), stringent bilateral selection processes to compensate for the expense of international liaison, or an increase in readers who would like to reduce search costs and prefer papers written by familiar authors (Schmoch and Schubert 2008); these explanations are yet to be confirmed. However, Abramo et al. (2011b) recently presented the results of an empirical analysis that showed, based on an analysis of Italian faculties, a positive relationship between researcher performance and the international co-authorship rate. In that study, the authors used the individual researcher as the unit of analysis. Previous literature lacked this individual perspective.

Researcher performance and international networks can be linked through research grants. Many studies around the world have investigated this relationship: Bozeman and Corley (2004) in the United States, Defazio et al. (2009) in the EU, and Ubfal and Maffioli (2011) in Argentina. Bozeman and Corley (ibid) confirmed that researchers who receive more Grants have bigger networks than those who do not. In addition, they found that professors have bigger networks than do post-doctoral fellows. Other studies have indicated a positive relationship between the size of an author's research network and its quality (Ding 2011; Kretschmer 1994). Regarding international collaborations, researchers with higher performance and more Grants increase the number of international students because research grants generally make it possible to attend or hold international conferences. There is a positive relationship between international students and international collaboration (Choi 2012; Regets 2007). Therefore, the number of international collaborations can easily be assumed to have a positive relationship with the number of research grants and publication performance.

Considering its importance for scientific policy as well as for a theoretical framework, the robustness of the Abramo et al. (2011b) results should be confirmed (Research Question 1). Although the results could be interpreted to state that the higher performance level of researchers who engage in international collaboration might explain why international papers are more highly cited than domestic papers, other factors such as the greater diversity of the teams involved may also play a role (Research Question 2). If the higher citation rate of international papers is only a result of the higher performance level of particular researchers, then there is little motivation to encourage international collaboration to enhance the quality of research output.

S&T HC encompasses the productive social capital network that enables researchers to create and transform knowledge and ideas, and contributes to individual human capital endowments and tacit knowledge. This is because knowledge creation is neither a solitary nor singular event (Bozeman et al. 2001). How exactly factors in S&T HC are related to each other and lead to scientific output is not yet clear. However, because the experience through international collaboration (social capital network) is embedded in researchers' mindsets, it enhances the knowledge or skills (S&T HC) of researchers and results in a higher level of performance. Higher performance then leads to grant acquisition and international collaboration, with international collaboration resulting in better outputs with greater S&T HC. Thus, the relationship between international collaboration and researcher performance is mutually reinforcing. In this sense, engagement in international collaboration may increase the performance of researchers (Research Question 3).

International papers enjoy higher citation rates.[1] If this is because of researchers' better performances, then it is performance that will matter and not international collaboration. Many studies have investigated the factors underlying researcher performance. These factors include grants, age (Levin and Stephan 1991) (science is a young person's game?), position (Abramo et al. 2011a), gender (Sandström 2009), education (selectivity), individual talent (taste for "puzzle solving"), size of the laboratory to which researchers belong (Carayol and Matt 2006), type of employment (Stephan 2008), and collaboration (Lee and Bozeman 2005). David (1994) identified cumulative advantage as an underlying reason for the grossly unequal distribution of scientific performance. That is to say, renowned researchers receive more Grants and success because of the Matthew effect. Although the factors that initiate favorable cycles have not yet been examined, they might include having new trans-disciplinary ideas (Burt 2004). Scientists in all fields are also interested in international collaboration simply because of the search for possible new ideas beyond their usual neighbors (Wagner 2008).

The way researchers gain new ideas or perspectives is related to inter-institutional/inter-sectorial/international movements. The positive relationship between inter-institutional movement and the performance of researchers has not yet been fully confirmed (Dietz and

[1] Schmoch and Schubert (2008) concluded that international co-authorship could not be an indicator of the quality of scientific activities because they do not know how these variables are correlated. Therefore, we have to acknowledge that higher citation rates in international co-authorship are interpreted as indicators of higher quality but with limitations. We use the term "citation" in most cases instead of "quality"; however, in some instances we retained "quality" as this was a term used by Abramo et al. (2011b).

Bozeman 2005). Regarding international mobility, however, the rate of stay in foreign countries by Japan's most highly cited researchers was higher (73.4 %) than that of averagely cited researchers (8.9 %) (Kato 2011). In the United Kingdom, researchers who experienced international stays were more productive than who did not (BIS 2011). Therefore, it is possible that internationally mobile researchers are more productive, with international networks leading to more internationally co-authored papers compared with researchers who are not as internationally mobile (Research Question 4).

Based on the literature analysis stated above, we examined the following questions. Meanwhile, publications should be comparable within the same field; thus, the following questions can be assumed to relate to the same field:

Research Question 1: Is the positive relationship between researcher performance and international co-authorship confirmed by a data set different from that of Abramo et al. (2011b)?

Research Question 2: Does researcher performance entirely explain the higher citation rate of international papers? [Is the citation rate of international papers higher than that of domestic papers, controlling for performance (among researchers who author both types of papers)?]

Research Question 3: Does international collaboration enhance researcher performance? (Are the number and citation rate of domestic papers authored by researchers with both international and domestic papers higher than those of domestic papers authored by researchers with only domestic papers?)

Research Question 4: Are researchers with international mobility more productive than researchers without international mobility?

Data set, indicators, methodology, and model

Data set

To minimize field-specific biases, we selected only chemistry. The first reason for this selection was that internationally refereed journals serve an important role in the chemistry research community, making bibliometric analysis applicable (Van Raan 2004). The second reason was the potential linkage with industry (Defazio et al. 2009). Chemistry had a lower international collaboration rate than the average of all fields from 1995 onwards, and the rate has increased at a slower rate compared with other fields (NISTEP 2011). Thus, this field has more room for policy support for international collaboration.

We then selected the top 16 journals in chemistry based on impact factors (IF) from the Journal of Citation Records (JCR) in 2002, 2003, 2005, and 2007. We looked at journals with an average IF of 3.0 and those that published 300 or more papers per year. We obtained annual meta-information on the articles from 1985 to 2005 from Thomson Reuters Web of Science (WoS). Journal titles are listed in Table 1 and subfields are shown in Table 2.

We retrieved 245,246 articles, reduced to 188,081 after excluding those that lacked the name of the reprinted author and the number of times cited.[2] The number of publications

[2] We used author information that only appears in the reprinted authors' column because only in recent years did the names in the author column uniquely correspond with countries.

Table 1 List of journals and number of articles published (1985–2005)

Journal title	Total publications	Shares (%)
Journal of The American Chemical Society	27,103	14.41
Journal of Organic Chemistry	19,567	10.40
Journal of Physical Chemistry B	15,329	8.15
Langmuir	13,784	7.33
Inorganic Chemistry	12,284	6.53
Chemical Communications	11,522	6.13
Journal of Chromatography A	10,708	5.69
Analytical Chemistry	10,249	5.45
Angewandte Chemie-International Edition	9,608	5.11
Organometallics	9,123	4.85
Journal of Medicinal Chemistry	7,979	4.24
Organic Letters	7,902	4.20
Journal of The Chemical Society-Dalton Transactions	6,517	3.46
Chemistry of Materials	6,349	3.38
Journal of Materials Chemistry	5,290	2.81
Journal of Catalysis	5,196	2.76
Molecular Sieves: From Basic Research To Industrial Applications, PTS A and B	4,960	2.64
Electrophoresis	4,611	2.45
Total	188,081	100.00

Table 2 Subfields in chemical journals and their shares

Category	Total publications	Shares (%)
Chemistry	134,107	71.35
Chemistry; Materials Science	25,416	13.52
Biochemistry and Molecular Biology; Chemistry	15,271	8.12
Pharmacology and Pharmacy	7,978	4.24
Chemistry; Engineering	5,195	2.76
Total	187,967	100.00

and time periods are shown in Fig. 1. The number of researchers (reprinted authors only) was 49,599 (we excluded one from the empirical analysis because it did not converge with the count data models' regression). The issue here was the identification of researchers, especially those with short or popular names, or very large numbers of publications. We checked the year and affiliation of 32 researchers with 100 or more papers and found that the average number of affiliated institutions was 3.3.[3] We considered the possibility of unclear name identification but bracketed this issue for future studies.

Table 3 shows a comparison of the data between the current study and that of Abramo et al. (2011b). The main differences are the countries included and the inclusion of the IFs

[3] Six authors affiliated with only one institute. Most researchers published almost all papers in only one institute.

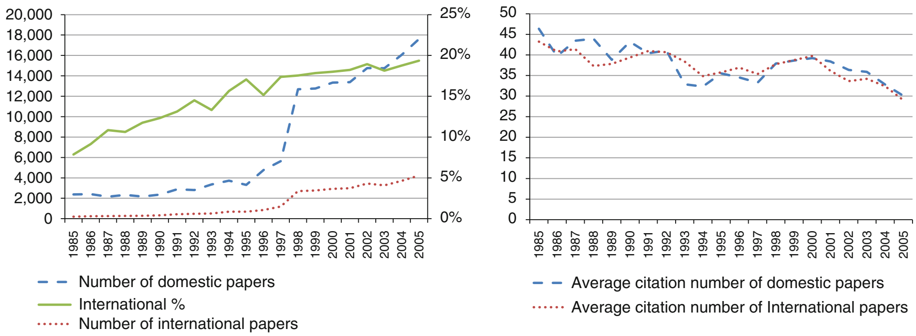

Fig. 1 Change in quantity and citation rate of chemical papers from 1985 to 2005

Table 3 Data set comparison with Abramo et al. (2011b)

	This study	Abramo et al. (2011b)
Country	87 countries	Italy
Time	1985–2005	2001–2005
People	Researcher in reprint address of paper	Faculty in Italian university (stable and publish one paper or more in the period)
Subject field	Chemistry	Nine areas in natural science
Journals	Journals with high impact factor	No mention
Original data source	Web of science	Web of science

of the targeted journals. As the relationship between research collaboration and co-authorship in developing countries is different from those in developed countries (Duque et al. 2005), we categorized countries based on OECD membership if necessary.[4]

Indicators

To examine the link between researchers' performances and internationalization, we used the six indicators created by Abramo et al. (2011b). Three of these indicators concern research performance, and three concern internationalization. However, we did slightly amend these based on the characteristics of our data. There were other indicators we could have used. Vinkler (2011) compared a variety of indicators to characterize the scientific activities in scientific publications such as h-index or π-index.[5] As Huang et al. (2011) suggested, because of the inequality of publishing performance and international collaboration, Gini-constants could be an alternative. Instead we utilized these indicators; we

[4] OECD member countries include the following, which became members before 1990: Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States, Japan, Finland, Australia, and New Zealand.

[5] h-index reflects both the number of papers and citations per publication. By definition, an author with the index X has published at least X papers, each of which has been cited at least X times. In contrast, π-index is equal to one hundredth of the number of citations obtained by the most frequently cited papers (Vinkler 2011).

used one of the most widely used indicators, the average number of citations, considering our central motive.

Performance Indicators:

- Productivity (P): total number of publications by a reprinted author in the period under observation;
- Fractional Productivity (FP): total number of contributions to publications authored by a reprinted author;
- Average Quality (AQ): the quality of each publication as proxied by number of citations (number of times each publication was cited divided by the average number of citations of all publications in the same year).

Internationalization Indicators:

- International Collaboration Intensity (ICI): total number of publications with at least one researcher from countries different than that of a reprinted author;
- International Collaboration Rate (ICR): ratio of ICI to P;
- International Collaboration Amplitude (ICA): total number of foreign countries represented in a cross-national publication.

Methodology

We referred to the methodology used in Abramo et al. (2011b). The existence of international papers and the degree of productivity were regressed using a binary logistic regression model (logit model). Abramo et al. (2011b) regarded the number of papers as count data and used binary logit, Poisson, and negative binominal methods, and then only showed the results regressed by binary logit because of the similar results they achieved with all methods. We also mainly use the binary logit regression results in our comparison. We followed Abramo et al. (2011b) and used an ordered logistic model for the analysis of the degree of internationalization. Considering the size of the data, a non-parametric method could be an alternative; however, we follow the method used by Abramo et al. (2011b) because our central motive was to confirm robustness of their results.

Model

The predicted probability of the logistic model is shown as follows:

$$p_j(0) = \frac{1}{1 + \exp\big(f(x_j)\big)},\ p_j(1) = 1 - p_j(0) \tag{1}$$

The probability for ordered logistic model is shown with $K_{(i)}$ representing the threshold between (i)th and (i + 1)th categories.

$$\begin{aligned} p_j(1) &= \frac{1}{1 + \exp\big(f(x_j) - K_{(1)}\big)} \\ p_j(i) &= \frac{1}{1 + \exp\big(f(x_j) - K_{(i)}\big)} - \frac{1}{1 + \exp\big(f(x_j) - K_{(i-1)}\big)} \quad (i = 2, \ldots, I-1) \\ p_j(I) &= 1 - \frac{1}{1 + \exp\big(f(x_j) - K_{(I-1)}\big)} \end{aligned} \tag{2}$$

Category i is selected by $\underset{i}{\text{argmax}}\, p_j(i)$ with K_0 and K_1 being defined as $-\infty$ and $+\infty$, respectively.

Based on the logistic or ordered logistic models stated above (1) and (2), we formulated our model as follows.

Research Question 1:

Dummy of ICI (DICI); DICI = 0 if ICI = 0, and DICI = 1 if 1 ≤ ICI) is formulated using logistic model (1) as

$$\text{ICI}(P) : f(x_j) = \alpha_0 + \alpha_1 P_j + \alpha_2 \text{AQ}_j \quad (3)$$

$$\text{ICI}(\text{FP}) : f(x_j) = \beta_0 + \beta_1 \text{FP}_j + \beta_2 \text{AQ}_j \quad (4)$$

Dummy of ICR (DICR); DICR = 0 if ICR = 0, DICR = 1 if 0.01 ≤ ICR ≤ 0.25, DICR = 2 if 0.251 ≤ ICR ≤ 0.5, DICR = 3 if 0.501 ≤ ICR ≤ 0.75, DICR = 4 if 0.751 ≤ ICR ≤ 1) is formulated using ordered logistic model (2) as

$$\text{ICR}(P) : f(x_j) = \gamma_0 + \gamma_1 P_j + \gamma_2 \text{AQ}_j \quad (5)$$

$$\text{ICR}(\text{FP}) : f(x_j) = \delta_0 + \delta_1 \text{FP}_j + \delta_2 \text{AQ}_j \quad (6)$$

Research Question 3:

The model is the same as Research Question 1 but targets domestic papers only.

Research Question 4:

Dummy of international mobility (Imove; Imove = 0 if the number of international moves is 0, and Imove is 1 if the number of international moves is 1 or more) is formulated using logistic model (1) as

$$\text{IMove}(P) : f(x_j) = \theta_0 + \theta_1 \text{DICI}_j + \theta_2 P_j + \theta_3 \text{AQ}_j \quad (7)$$

$$\text{IMove}(\text{FP}) : f(x_j) = \mu_0 + \mu_1 \text{DICI}_j + \mu_2 \text{FP}_j + \mu_3 \text{AQ}_j \quad (8)$$

General analysis

Papers

Table 4 shows the number of foreign countries involved in international publications.[6] Domestic papers accounted for 82.7 % of the papers and international papers accounted for 17.3 %. The percentage of cross-national publications involving single foreign countries was 86.8 %. Papers with the involvement of three or more foreign countries represented only 1.6 % of the total of cross-national publications.

Table 5 classifies countries by number of publications. We included 87 countries in our data set. The United States topped the list regarding the number of both domestic and international papers. European countries held a higher share of international papers, with countries such as Japan, China, and India holding higher shares in domestic papers among

[6] The scale effect of countries should be considered. For instance, smaller countries in terms of population have higher rates of internationally co-authored papers compared with more populated countries (Kato and Chayama 2010).

Table 4 Number of foreign countries involved in international publications

Number of foreign countries involved	Number of publications	Shares in cross-national publications (%)	Shares in publications (%)
0	155,613	–	82.7
1	28,176	86.8	15.0
2	3,785	11.7	2.0
3	444	1.4	0.2
More than 3	63	0.2	0.0
Total	188,081	100.0	100.0

Table 5 Classification of countries by number of publications

Domestic papers				International papers			
Country	Total publications	Shares (%)	Publication per 1,000 researchers	Country	Total publications	Shares (%)	Publication per 1,000 researchers
United States	60,348	38.8	47.1	United States	6,675	20.5	5.2
Japan	17,976	11.6	27.3	Germany	3,019	9.3	11.8
Germany	10,662	6.9	41.6	United Kingdom	2,914	8.9	15.7
United Kingdom	10,172	6.5	54.8	France	2,206	6.8	12.6
France	6,714	4.3	38.3	Spain	2,073	6.4	27.0
China	6,222	4.0	8.6	Italy	1,955	6.0	28.0
Spain	5,504	3.5	71.7	Japan	1,482	4.5	2.2
Canada	5,344	3.4	48.3	Canada	1,252	3.8	11.3
Italy	5,302	3.4	75.9	China	962	3.0	1.3
India	2,533	1.6	19.1	Switzerland	879	2.7	35.8
Netherlands	2,404	1.5	58.6	Netherlands	777	2.4	18.9
Korea, Rep.	2,374	1.5	18.5	Sweden	709	2.2	15.6
Australia	2,252	1.4	32.6	Australia	619	1.9	9.0
Switzerland	2,170	1.4	88.4	Belgium	552	1.7	18.4
Taiwan	2,094	1.3	–	India	550	1.7	4.1
Total	142,071	91.4	–	Total	26,624	81.7	–

the top 15 countries containing data.[7] These tendencies are similar to those found by Zitt et al. (2000). Glänzel et al. (1999) inferred that two factors could affect the shares of internationally co-authored papers: the cooperative minds inherent in the scientific

[7] These Asian countries have large populations, and their mother tongue is not English; therefore, they might publish papers in domestic journals using their own languages. However, considering that almost 80 % of Japanese doctoral dissertations in physics are written in English but only 25 % in engineering (Muraoka et al. 2003), papers in chemistry are usually published in English even for domestic papers. This could be included in our data.

Table 6 Classification of researchers by number of papers authored

Number of papers	Number of authors	Shares (%)
1	26,570	53.6
2	7,808	15.7
3	3,781	7.6
4	2,358	4.8
5–9	5,038	10.2
10–19	2,607	5.3
20–99	1,405	2.8
100 or more	32	0.1
Total	49,599	100.0

community and the size of the country.[8] When we examined publications per 1,000 researchers, the number of domestic papers was smaller in Asian countries than in other countries. However, publications per 1,000 researchers for international papers were smaller in countries with large populations, including the United States (Table 5).

Figure 1 shows the change in quantity and citation rate of papers from 1985 to 2005. The numbers of both domestic and international papers increased. The international rate more than doubled over 20 years: 7.9 % in 1985 to 19.4 % in 2005. Paper quality as proxied by number of citations was smaller in recent years, and roughly similar between domestic and international papers. This result differs from the general conception that internationally co-authored papers have higher citation rates. However, as there is a variation in citation impact among counties or fields as identified by Glänzel (2001), the level of journal might relate to the difference in the citation rate between domestic and international papers.

Researchers

Researchers who authored just one paper represented 53.6 % of the sample (Table 6). Researchers affiliated with only one country were the most represented (93.1 %) (Table 7), and among the 23,029 researchers authoring two or more papers—in other words, researchers in our data set having the possibility to move—those affiliated with more than two countries represented 14.3 % of the total. Researchers who stayed in OECD-member countries represented 83.2 % of the total, with the remainder staying in both OECD and non-OECD countries or non-OECD countries only (Table 8).

Research performance and international collaboration

Table 9 shows the descriptive statistics of the 49,599 researchers. Compared with the data shown in Abramo et al. (2011b), the mean AQ in our sample was higher [0.86 vs. 0.69 in Abramo et al. (2011b)], but the means of the other indicators were lower. Table 9 also shows the statistics with and without international mobility. The means of all six indicators were higher for researchers with international mobility than for those without.[9]

[8] Concerning the size effect, other explanations such as geography or the development stage of the scientific community could explain these phenomena.

[9] Age differences should be noted between the two groups; for instance, researchers without international mobility were younger and might not have had enough time to stay in foreign countries at that point in his/her career; however, this type of information was not available in our data set.

Table 7 Classification of researchers by number of countries researcher was affiliated with

Number of countries	Number of authors	Shares (%)
1	46,160	93.1
2	3,027	6.1
3	355	0.7
4	48	0.1
5	7	0.0
6	2	0.0
Total	49,599	100.0

Table 8 Classification of researchers who stayed in OECD or non-OECD countries

Category	Observations	Shares (%)
OECD only	41,266	83.2
Non-OECD only	6,977	14.1
Both OECD and non-OECD	1,356	2.7
Total	49,599	100.0

Table 9 Descriptive statistics of researcher indicators

CPategories variable	Total (49,599 observations)				Author without international mobility (46,160 observations)				Author with international mobility (3,439 observations)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
P	3.67	7.52	1	297	3.19	6.36	1	229	10.06	15.16	1	297
FP	1.18	2.49	0.04	95.35	1.04	2.14	0.04	89.28	3.18	4.84	0.1	95.35
AQ	0.86	1.20	0.02	80.8	0.85	1.22	0.02	80.82	1.03	0.87	0.02	14.41
ICI	0.65	1.87	0	91	0.49	1.35	0	63	2.86	4.52	0	91
ICR	0.19	0.34	0	1	0.17	0.34	0	1	0.34	0.31	0	1
ICA	0.55	1.06	0	18	0.43	0.87	0	16	2.25	1.64	1	18

Table 10 Descriptive statistics of researcher indicators categorized by internationality

Category	Number of authors	*P*	AQ
All papers	49,599	3.67	0.86
Domestic paper only	34,434	2.49	0.84
Include international paper	15,165	6.75	0.91
(International paper only)	5,864	1.37	0.82
(Both domestic and international paper)	9,301	10.15	0.97

Researchers were categorized into three groups: (i) those with domestic papers only, (ii) those with international papers only, and (iii) those with both domestic and international papers. Table 10 presents the descriptive statistics by group. Researchers with domestic papers numbered 34,434 (69.4 %), and researchers with international papers numbered 15,165 (30.6 %).

Researchers with both domestic and international papers had the highest performance in quantity and citation rate among the three groups, and researchers with only international papers were the least productive. If international papers have some kind of advantage because of internationality, researchers who only authored papers with such a "bonus" had a lower performance than those without. Considering the level of journals we chose, these researchers could author domestic papers in journals with smaller IFs.

Results

This section attempts to provide answers to the Research Questions posed earlier.

Relationship between research performance and international collaboration (research question 1)

Table 11 shows results of the Spearman correlations between indicators (H_0: no correlation between two indicators; coefficient = 0). As Abramo et al. (2011b) showed, the correlation analysis indicates a strong link between productivity and international collaboration. However, the coefficient is smaller with the exception of the relationship between ICR and ICI. The Spearman correlation coefficient between *P* and ICI was 0.4170. We found similar results for FP. The correlation between ICI and AQ was also significant and positive (0.1273) (Table 11).

The correlation between productivity and ICR, while again significant, was quite weak compared with the others (0.0835 for FP and 0.0840 for AQ). The degree of propensity for international collaboration was weakly correlated with the contribution to papers and average quality of papers. The variance inflation factors (VIFs) for *P* and FP showed relatively high values and might be the cause of multi-collinearity; therefore, the regression was followed by a check for multi-collinearity especially when these variables are included.

We applied a binary logistic regression analysis to assess the relationship between research performance and intensity of international collaboration. The dependent variable ICI was assumed to be 1 if researchers had one or more paper; otherwise, it was 0. Table 12 presents the results. The coefficient of *P* was positive and significant, but not for AQ. These results differ from those of Abramo et al. (2011b), which showed positive and significant coefficients for both variables. Assuming a difference in the relationship between developed and developing countries, we performed a regression separating countries by OECD membership (Table 12). The coefficient of AQ was positive and

Table 11 Spearman correlations and variance inflation factors

	P	FP	AQ	ICI	ICR	ICA	VIF
P	1	0.7696***	0.2246***	0.4170***	0.2553***	0.4745***	11.02
FP		1	0.1340***	0.2439***	0.0835***	0.3439***	9.09
AQ			1	0.1273***	0.0840***	0.1854***	1.01
ICI				1	0.9574***	0.8079***	2.42
ICR					1	0.7549***	1.49
ICA						1	2.55

Number of observations: 49,599; statistical significance: *** $p < 0.01$

Table 12 Binary logistic regression of international collaboration versus performance indicators (*P* and AQ)

Categories variables	Total (Number of obs: 49,598, pseudo *R*2: 0.082)				OECD only (number of obs: 41,265 pseudo *R*2: 0.0823)				Non-OECD included (number of obs: 8,333, pseudo *R*2: 0.0827)			
	Coef.	SE	*z*	Pr > *z*	Coef.	SE	*z*	Pr > *z*	Coef.	SE	*z*	Pr > *z*
P	0.146	0.003	54.34	0	0.143	0.003	49.26	0	0.160	0.007	22.32	0
AQ	0.012	0.008	1.44	0.149	0.014	0.008	1.65	0.099	0.080	0.031	2.62	0.009
Cons	−1.343	0.015	−90.29	0	−1.427	0.016	−86.84	0	−1.019	0.037	−27.4	0

Table 13 Binary logistic regression of international collaboration versus performance indicators (FP and AQ)

	Coef.	SE	z	Pr > z
FP	0.269	0.006	42.81	0
AQ	0.026	0.008	3.19	0.001
Cons	−1.161	0.014	−82.94	0

Number of observations: 49,598; pseudo $R2$: 0.0441

Table 14 Ordered logistic regression of international collaboration rate to performance indicators (P and AQ)

	Coef.	SE	z	Pr > z
P	0.037	0.001	31.39	0
AQ	0.015	0.008	1.96	0.05
/Cut1	1.010	0.013		
/Cut2	1.402	0.014		
/Cut3	1.969	0.016		
/Cut4	2.160	0.016		

Number of observations: 49,598; pseudo $R2$: 0.0119

significant at the 10 % level for OECD countries, and at the 1 % level for non-OECD countries. Therefore, the relationship between research performance and intensity of international collaboration could be slightly different depending on the level of economic development of the country involved. The mean VIFs in Table 12 are 1.10, 1.09, and 1.19, for respective categories. Thus, the variables cannot be considered as a linear combination of other independent variables.

When FP replaced P (Table 13), the coefficient of performance indicators (FQ and AQ) showed positive and significant results, though the coefficient of AQ (0.026) was quite low compared with the 0.889 found by Abramo et al. (2011b). The mean VIF is 1.09.

To examine the relationship between the international collaboration rate and performance indicators, we used an ordered logistic regression with the ICR as the dependent variable, categorized into four categories as stated earlier.

Tables 14 and 15 show the results of the ordered logistic regression. The international collaboration rate shows positive and significant dependence for both P and AQ as Abramo et al. (2011b) presented. Similar results entail when FP was used instead of P as the independent variable.

Difference of citation rates between domestic and international papers presented by researchers with both types of papers (research question 2)

To examine the possibility that factors other than researcher performance influenced the higher citation rate of international papers, we conducted Student's t tests and F tests to compare the citation rate between international and domestic papers among researchers who authored both types of papers.[10] The results of the t tests showed that both means were statistically different from each other at the 1 % level [t (9300) $= -36.239$, $p < 0.01$]. We also found that the mean value representing the citation rate of domestic papers was less than that of international papers at the 1 % level ($p < 0.01$).

[10] Figure 1 targets all researchers in data and shows that there is little difference between the average citation rate of domestic and international papers; however, we target only researchers who authored both international and domestic papers here in research question 2.

Table 15 Ordered logistic regression of international collaboration rate to performance indicators (FP and AQ)

	Coef.	SE	z	Pr > z
FP	0.076	0.003	22.94	0
AQ	0.023	0.008	2.83	0.005
/Cut1	0.957	0.013		
/Cut2	1.344	0.014		
/Cut3	1.908	0.015		
/Cut4	2.100	0.016		

Number of observations: 49,598; pseudo $R2$: 0.0061

When we compared the standard deviations (variances) between the citation rate of international and domestic papers using an F test, we could reject the hypothesis that the standard deviations were the same at the 10 % significance level [F (9300, 9300) = 0.962, $p < 0.01$]. In addition, the variance of citation rate in domestic papers was less than that of international papers at the 5 % level. Therefore, the citation rate of international papers was different and probably higher than that of domestic papers among researchers who authored both international and domestic papers.

Relationship between accumulation of S&T HC and international collaboration (research question 3)

To examine the relationship between the accumulation of S&T HC and international collaboration, we conducted a regression exactly as with Research Question 1. However, here we only used domestic papers, targeting researchers with domestic papers only and those with both international and domestic papers. We assume that if international collaboration accumulates S&T HC, then the citation rate and quantity of domestic papers authored by researchers with international collaboration is higher than that of colleagues without such collaboration. Tables 16 and 17 present the results of the regression. The

Table 16 Binary logistic regression of international collaboration versus domestic performance indicators (P and AQ)

	Coef.	SE	z	Pr > z
P (domestic)	0.134	0.003	50.62	0
AQ (domestic)	0.043	0.010	4.41	0
Cons	−1.866	0.018	−104.49	0

Number of observations: 43,734; pseudo $R2$: 0.0887

Table 17 Binary logistic regression of international collaboration versus domestic performance indicators (FP and AQ)

	Coef.	SE	z	Pr > z
FP (domestic)	0.343	0.007	47.65	0
AQ (domestic)	0.053	0.010	5.17	0
Cons	−1.799	0.018	−102.05	0

Number of observations: 43,734; pseudo $R2$: 0.0753 international collaboration rate showed a positive and significant relationship with *P*, FP, and AQ at the 1 % level. The mean VIFs are 1.10 and 1.09 for respective categories. Researchers who collaborated internationally had higher performances, including those for domestic papers.

Using ICR, categorized into five categories as stated above, as the dependent variable in an ordered logistic regression, we examined the relationship between the international collaboration rate and domestic performance indicators. Tables 18 and 19 present the results. The international collaboration rate showed a positive and significant relationship with *P*, FP, and AQ at the 1 % level. Therefore, researchers who took part in heavy international collaboration had a higher performance even in performance of domestic papers than those who did not (Tables 18 and 19).

Research performance and international mobility (research question 4)

We applied binary logistic regression analysis to assess the relationship between research performance and international mobility. We assumed the dependent variable to be 1 if researchers moved internationally (i.e., they were affiliated with two or more countries); otherwise it was 0. Independent variables were *P*, AQ, and an international collaboration dummy, which was 1 if researchers authored one or more international paper; otherwise, it was 0. Table 20 presents the results. Coefficients of all three variables were positive and significant; the international collaboration dummy was 5 % and both *P* and AQ were 1 %. Only researchers with two or more papers had the possibility of international movement in our data set. The mean VIFs of the variables were 1.53, 1.79, 1.41, and 1.39, for respective categories. Thus, multi-collinearity does not exist.

We examined the data restricted to those researchers and confirmed that the tendency was similar to the results shown in Table 21. The mean VIFs of the variables were 2.03, 2.42, 2.00, and 1.68. Thus, multi-collinearity does not exist. Therefore, researchers with international mobility had a higher performance than researchers without such movement.

Table 18 Ordered logistic regression of international collaboration rate to performance indicators (*P* and AQ)

	Coef.	SE	z	Pr > z
P (domestic)	0.054	0.001	36.5	0
AQ (domestic)	0.049	0.010	4.97	0
/Cut1	1.604	0.016		
/Cut2	2.237	0.019		
/Cut3	3.748	0.030		
/Cut4	5.441	0.063		

Number of observations: 43,734; pseudo $R2$: 0.0258

Table 19 Ordered logistic regression of international collaboration rate to performance indicators (FP and AQ)

	Coef.	SE	z	Pr > z
FP (domestic)	0.145	0.004	34.23	0
AQ (domestic)	0.055	0.010	5.43	0
/Cut1	1.583	0.016		
/Cut2	2.212	0.019		
/Cut3	3.722	0.030		
/Cut4	5.415	0.063		

Number of observations: 43,734; pseudo $R2$: 0.0227

Table 20 Binary logistic regression of international movement versus performance indicators [ICI (dummy), FP, and AQ]

	Coef.	SE	z	Pr > z
ICI (dummy)	1.255	0.023	54.03	0
P	0.023	0.002	13.91	0
AQ	0.053	0.011	4.9	0
Cons	−5.184	0.056	−92.25	0

Number of observations: 49,599; pseudo $R2$: 0.1898

Table 21 Binary logistic regression of international movement versus performance indicators among researchers with two or more papers [ICI (dummy), FP, and AQ]

	Coef.	SE	z	Pr > z
ICI (dummy)	0.789	0.027	29.28	0
P	0.011	0.002	6.82	0
AQ	0.134	0.026	5.25	0
Cons	−3.598	0.076	−47.57	0

Number of observations: 15,221; pseudo $R2$: 0.0886

Discussion and conclusion

This study used a data set in chemistry to examine the robustness of the results presented by Abramo et al. (2011b) and to determine the possible impact of international collaboration and mobility among researchers. A summary of answers to the four Research Questions follows.

Our results confirmed the positive relationship found by Abramo et al. (2011b) between researchers' performances and international collaboration (Research Question 1). However, the higher citation rate of international papers was not solely explained by the higher performance of researchers because the citation rate of international papers was higher than that of domestic papers, controlling for researchers' performances (Research Question 2). Therefore, international research collaboration seems to exert some kind of "bonus" effect because of internationalization. The results also showed that the quantity and citation rate of domestic papers by researchers with both international and domestic papers was higher than that of researchers with only domestic papers (Research Question 3). This could indicate that researchers who collaborate internationally accumulate S&T HC by acquiring diverse or new ideas from colleagues, resulting in higher citation rates for domestic papers. An alternative explanation posits the existence of selectivity for internationalization among researchers with domestic papers. This explanation would have to be explored in greater depth to be confirmed. Finally, our results show a positive relationship between international mobility and researchers' performances. The direction of cause and effect is not yet clear but indicates the possibility of an impact of international mobility on researchers' performances.

Future research should include methodological improvement and additional themes. Methodological improvements could be made to researcher identification and data collection. Data in the future should include a wider variety of journal levels based on IF, field, and countries. Including researchers' curricula vitae could enable more detailed analyses regarding international movement and collaborations. Additional themes to be explored include examining the direction of cause and effect between researchers' performances and international collaboration, considering how international co-authorship influences S&T HC accumulation. As the present definition of international research is affected when a country merges or becomes independent, an alternative measure invariant of country scales should be developed.

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