A Structural Analysis of Collaboration between European Research Institutes

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Abstract

Collaboration between research institutes has been the subject of many studies. In this study we focus on the influence of the research profile of an institute on its collaborative behaviour and pattern . The classification model developed by the authors provides a helpful tool to identify the specialisms of a research institute and to create groups of likewise institutes that ENABLE to study the relation between science fields and collaborative behaviour. First we could show the effect of research profile on different types of collaboration. Next, citation indicators are used to investigate the changes on impact and publication strategy over the different types of collaboration. And in the last part we try to find for each group the research profile of the most preferred partners.

Introduction

An extensive literature on collaborative behaviour of nations, institutes and individual researchers has been build during past decades. Many authors found a positive relation between collaboration and scientific productivity (Price and Beaver, 1966; Beaver and Rosen, 1979). These findings were extended by including also citation indicators to establish a relation between collaboration and impact or visibility of scientific output (Schmoch and Schubert, 2008). Other authors investigated collaboration patterns in specific fields or disciplines (Bordons et al. 1996, Gomez, et al., 1999). With this papers we want to study collaboration behaviour among research institutes. It still remains unclear how the research profile of an institute -the specialism of science fields in which an institute is active- influences its collaboration pattern. One of the main problems here was how to define the research profile of an institute. The classification model for institutes developed by the authors (Thijs & Glänzel, 2008) provides a unique tool to study mechanisms in collaboration by creating groups of institutes with the same research profile, active in the same fields of science.

This model uses the subject category scheme developed by Glänzel and Schubert (2003) to calculate the research profile of each institute which is the share of publications in each of 16 major fields in science. This profile is then used as input for a classification model in order to assign institutes to one out of eight different groups with their own research focus. Each group is labeled by their most typical fields (i.e. Agriculture (AGR), Biology (BIO), Technical and Natural Sciences (TNS), Chemistry (CHE), Earth and Space Sciences (GSS), General Medicine (GRM), Specialised Medicine (SPM) and a group with multidisciplinary focus (MDS)). The main goal for the creation of this model was the use in evaluative studies and benchmarking exercises(Thijs & Glänzel, 2008, 2009). However, the model has proven to be useful for other applications as well. In this study we use this model to investigate collaboration between institutes. We formulated 7 different questions to get a better understanding of inter-institute collaboration:

- Does the share of collaborative papers in an institute differ among groups?
- Do citation indicators on sets of collaborative papers differ among groups?
- Are citation indicators of sets of co-authored papers higher than those on papers with no collaboration?
- Is there a difference between groups in improvement of citation based indicators?

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- Do pairs of institutes that collaborate have a more similar research profile than those pairs that do not collaborate?
- Do institutes that are more similar in research profile collaborate more?
- Is there a difference in most preferred partners between the group?

Data sources and processing

Data were extracted from the yearly updates of the *Web of Science* database of Thomson Reuters (Philadelphia, PA, USA). Only papers of the document type article, letter, and review indexed in the 2003 to 2005 volumes have been selected. This data has undergone a detailed cleaning and processed to bibliometric indicators.

Subject classification of the publications was based on the field assignment of journals according to sixteen major fields of science developed in Leuven and Budapest (Glänzel & Schubert, 2003).

Citations were calculated for a three year citation window, the year of indexing in the database and the two subsequent year. This means for publications of 2003, citations from 2003, 2004 and 2005, for the 2005 publications the window stretches from 2005 to 2007.

Publications were assigned to countries and institutions according to the address in the by-line of the paper using a 3-step assignment procedure. For this study we selected 15 European countries (EU15 without Greece but including Switzerland). We have excluded those institutes with less than 20 publications in the publication window 2003-2005. The remaining 1736 institutes were assigned to one out of eight different groups based on their research profile using the classification model developed by the authors (Thijs & Glänzel, 2008). Each group can be characterized by an average research profile of each group. Table 1 lists the groups, their label and description together with their share in the total set of institutes. The activities of the institutes are not excluded to the mentioned fields but those are the most predominant.

Table 1. 8 Clusters of institutes with label, description and share

Label	Description	Share
BIO	Biology	6.5%
AGR	Agriculture	3.8%
MDS	Multidisciplinary	32.5%
GSS	eo & Space Sciences	3.6%
TNS	Technical & Natural Sciences	13.2%
CHE	Chemistry	3.3%
GRM	General & Research Medecine	9.5%
SPM	Specialised Medicine	27.7%

Results

Collaborative behaviour

First we want to investigate whether these groups have different collaborative behaviour. We can distinguish between different types of collaboration

- *International*: At least two different countries appear in the by-line of the paper. When looking at the collaborative behaviour this means that the papers can also be assigned to at least one other country next to the one of the country of the institute,
- *Within Europe:* there appears at least one other country from the selected European countries in the by-line of the paper,

- *Outside Europe*: at least one country is not a selected European country,
- *Extramural domestic*: at least two institutes from the same country appear on the by-line,
- *No extramural*: there is only one country mentioned in addresses on the paper and the paper could be assigned to only one institute. This type might, however, include so-called intramural collaboration between two or more research teams from the same institute.

The first 4 types of collaboration do not exclude each other, '*International*' collaboration does imply at least '*Within Europe*' or '*Outside Europe*'. '*Extramural domestic*'-collaboration does not imply nor exclude any of the three other types of collaboration .'*No extra-mural collaboration*' does exclude all 4 other types. For each institute the share of these 5 types is calculated. Table 2 shows the average share of each type within the 8 different groups.

Table 2. Average share of each type of collaboration over 8 classes

	Collaboration				
	International	Within Europe	Outside Europe	Extram. Dom.	No Extram.
BIO	46.5%	28.3%	28.1%	46.8%	25.3%
AGR	37.5%	23.2%	21.4%	46.3%	30.6%
MDS	39.5%	22.7%	24.3%	41.3%	34.4%
GSS	67.2%	47.1%	46.7%	46.4%	16.2%
TNS	43.3%	26.2%	25.9%	41.9%	30.7%
CHE	33.7%	21.3%	16.0%	42.8%	33.7%
GRM	31.8%	23.1%	18.0%	61.3%	26.2%
SPM	24.0%	15.5%	14.4%	56.6%	33.0%

Statistical tests are needed to give a clear answer on the first question. Non-parametric testing is appropriate here as the sample size of the 8 different clusters is not alike and the distribution of these shares is not normal in all 8 groups (Conover, 1999 or Sheskin, 2004). We have applied a Kruskal-test. The results are shown in Table 3. Within each type of collaboration, there's a significant difference between the eight groups.

Table 3. Kruskal-Wallis test for average of share of collaboration

Collbaration	Kruskal test df=7
International	501.13***
Within Europe	282.90***
Outside Europe	491.08***
Extramural Domestic	303.77***
No Extramural	140.50***
*** p-value less than 0.0001	

The highest share of international collaboration is in the Geo & Space Sciences group. This group also has subsequently the lowest share of papers with no extramural collaboration. These results are easily understood when looking at the peculiarities and international character of Space Sciences. Figure 1 shows the clear difference in distribution of shares of international collaboration for each group.

The lowest share of international papers is in the Specialized Medicine (SPM) group with only 24% of its total of papers. This group has, however, a quite high share of 'Extramural domestic' collaboration. Some typical institutes in this group are 'Salzburger Landeskliniken' in Austria, the *Danish Bilharziasis Laboratory or the 'National Institute of Occupational Health', 'Our Lady's Hospital for Sick Children' in Ireland. It's clear that for these institutes*

are more directed towards the local community and that therefore international collaboration is not as important as in other groups. The other medical group 'GRM' has the highest share of the 'Extramural Domestic' type of collaboration.

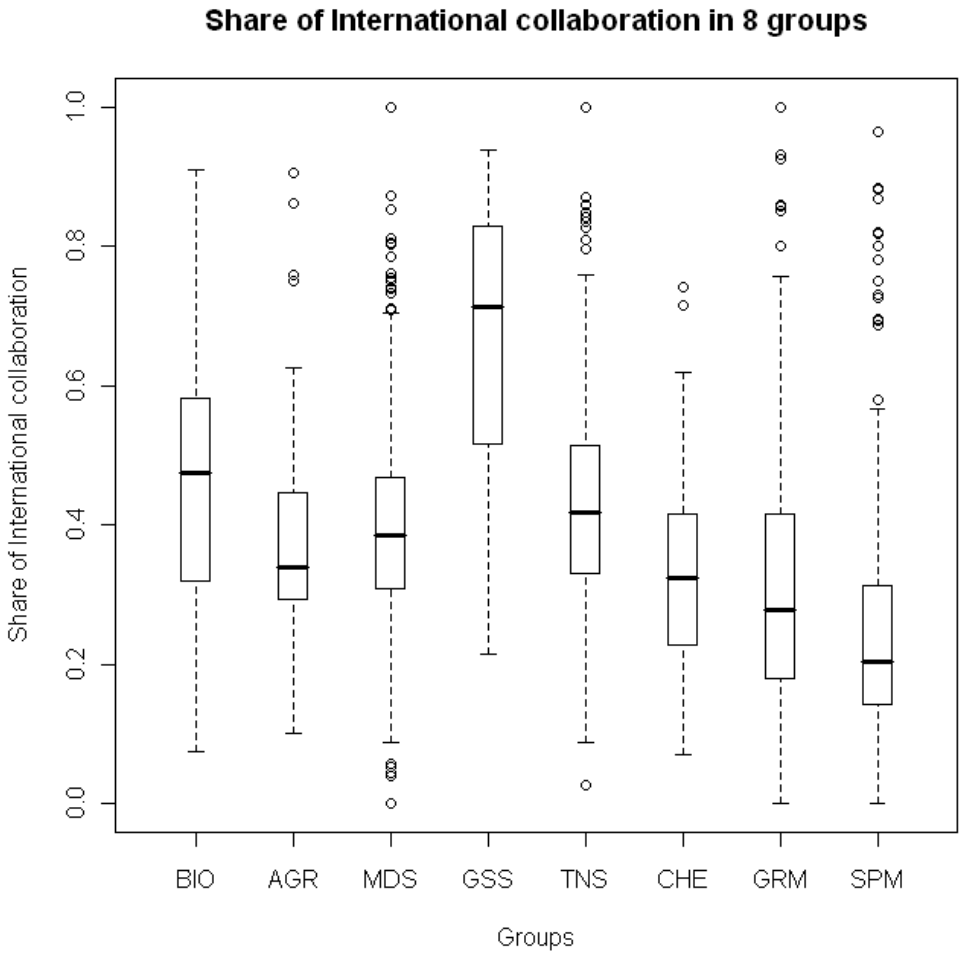

Figure 1. Boxplot with distribution of share of international collaboration

In 5 of the 8 groups about one out of three papers has no extramural collaboration. In the GRM and BIO-group the share is about 25% and as mentioned above the GSS has one out of six with no extramural collaboration. We can conclude that there's a difference in the share of co-authored papers between our 8 groups for each of the types of collaboration.

Citation indicators

The next 3 questions are about the impact of collaboration on citation indicators. In this paper three different citation indicators are used, RCR, NMCR and MECR/FECR.

First the Relative Citation Rate (RCR) is dicussed. The RCR-value compares the observed citation rate of the institutes in a 3-year citation window with the expected citation rate. This expected citation rate is calculated on the basis of the journals in which papers are published. Values above 1 indicate that the observed citation rate of the institute lies above the expected rate.

Table 4 gives the average RCR values of different sets of papers calculated within each group. The highest values can be seen in the Geo & Space Sciences (1.19) and the medical classes GRM (1.25) and SPM (1.14). The last row gives the result of a Kruskal-Wallis test to check whether the values are different over the groups within each type of collaboration. We can savely conclude that the RCR value within each set of collaborative papers differs among groups.

Table 4. RCR in different types of collaboration

	Collaboration					
	All Publications	International	Within Europe	Outside Europe	Extram. Dom.	No Extram.
BIO	1.09	1.19	1.28	1.28	1.11	0.93
AGR	1.11	1.24	1.32	1.38	1.14	0.99
MDS	1.05	1.18	1.26	1.22	1.13	0.90
GSS	1.19	1.32	1.38	1.42	1.33	0.78
TNS	1.03	1.10	1.16	1.15	1.08	0.89
CHE	1.00	0.99	1.02	1.11	0.93	0.97
GRM	1.25	1.67	1.87	1.87	1.37	0.82
SPM	1.14	1.51	1.66	1.59	1.27	0.75
Kruskal Test	65.91***	183.11***	166.33***	130.91***	120.35***	128.69***

Then comes the question about the effect of collaboration on the RCR. We could compare the averages shown in Table 4 but it is better to compare the RCR-values of the different sets of papers by each individual institutes. Table 5 gives for the percentage of institutes for which the RCR-value of the set of collaborated papers is higher than the papers without collaboration. In the last column the RCR-values of the international papers are compared with the papers with domestic collaboration. First, the share within the total set of 1736 institutes is given. A t-test is used to test whether this share is higher than 50%. About 80% of all institutes have a higher RCR value in both the set with international collaboration and the set with extramural domestic collaboration than the set with no extramural collaboration. A t-test with value 35.82 and 1735 degrees of freedom indicates that this percentage lies far above the 50%. Next, these shares are also calculated within each group and Kruskal-Wallis tests are used to check for differences between groups. For each combination of types of collaboration, the test indicates significant differences. We see in the first column that the shares of institutes with a higher RCR-value on international collaboration is well above 50% for 7 groups. Only within the Chemistry group the share is not significantly different from 50%. The same pattern can be found in the second column. It's clear that collaboration has an increasing effect on the RCR value.

Table 5. Share of institutes with a higher RCR-value

	International vs. No Extram	Extram. Dom. vs. No Extram.	International vs. Extram. Dom.
Total	82.60%	79.55%	65.67%
t-test	35.83	30.52	13.74
BIO	78.76%	73.45%	61.85%
AGR	74.24%	68.18%	63.64%
MDS	83.56%	79.68%	63.07%
GSS	85.48%	85.48%	46.77%*
TNS	76.96%	70.43%	57.82%
CHE	52.63%*	43.86%*	57.89%
GRM	85.37%	84.76%	78.66%
SPM	88.49%	88.49%	72.19%
Kruskal	58.21	91.74	42.54
* not significant different from 50%			

In the third column of table 5 we see that the share of institutes with an RCR value 'International' higher than the RCR value of 'Extramural Domestic' is still more that 50% but not as high as the two other columns. For the GSS-group, the observed value is even slightly

below 50%, but not significantly. In general, collaboration itself - no matter if it's domestic or abroad- seems enough to increase this citation indicator. The institutes from the medical clusters form an exception. Here, the share in the third column lies above 70%.
Comparing collaboration Outside vs. Within Europe did not reveal much difference. About 50% of the institutes have a RCR value of the Outside EU collaboration set that is higher than the Within EU value. This means that for the RCR-value we can give three positive answers to the above stated questions about citation indicators:

- The RCR value does differ among groups on each sets of collaborative papers.
- The RCR value is for each type of collaboration higher than on papers with no collaboration. This is not true in the Chemical cluster.
- There's a difference between groups in improvement of the RCR-value.

Next the Normalized Mean Citation Rate (NMCR) is given. This value compares the observed citation rate of the institutes in a 3-year citation window with the field based expected citation rate. This expected citation rate is calculated on the basis of the fields in which papers are published. Values above 1 indicate that the observed citation rate of the institute lies above the field average. Results are presented in table 6 and table 7. These are in line with the results of the RCR-value. The NMCR differs among the 8 groups and this within each type of collaboration.

Table 6. NMCR in different types of collaboration

		Collaboration				
	All Publications	International	Within Europe	Outside Europe	Extram. Dom.	No Extram.
BIO	1.14	1.30	1.41	1.44	1.23	0.93
AGR	1.12	1.31	1.49	1.42	1.25	0.99
MDS	1.24	1.53	1.61	1.62	1.35	0.91
GSS	1.34	1.58	1.72	1.75	1.58	0.78
TNS	1.11	1.26	1.35	1.31	1.26	0.89
CHE	0.99	1.06	1.13	1.12	1.01	0.97
GRM	1.25	1.99	2.22	2.37	1.41	0.83
SPM	1.05	1.75	1.97	1.92	1.23	0.75
Kruskal Test	66.11***	126.18***	113.52***	117.15***	50.99***	128.68***

In each group, except Chemistry, the observed average value for collaboration is higher that the NMCR value for the no extramural collaboration set. In 4 groups (BIO, AGR, GSS and CHE)) we see that for about 50% of the institutes the value of NMCR is higher in international collaboration than in extramural domestic. This means that for these grous, the effect of international collaboration is not different from the effect of domestic collaboration. The citation rates, standardized by field, are equal in both international collaboration and in extramural domestic collaboration. In the other 4 groups (MDS, TNS, GRM and SPM) there are more institutes with a higher NMCR value in the international collaboration set.

Table 7. Share of institutes with a higher NMCR-value

	International vs. No Extram	Extram. Dom. vs. No Extram.	International vs. Extram. Dom.
Total	85.65%	81.51%	70.85%
t-test	42.37	33.81	19.11
BIO	79.64%	74.34%	53.10%*
AGR	78.78%	74.24%	60.60%*
MDS	88.16%	84.45%	70.60%
GSS	91.94%	93.55%	50.00%*
TNS	83.04%	80.00%	63.04%
CHE	59.65%*	52.63%*	52.63%*
GRM	86.58%	80.49%	84.76%
SPM	88.28%	83.68%	80.54%
Kruskal	46.17	48.85	86.66
* not significant different from 50%			

The last indicator (MECR/FECR) is the ratio between the journal based expected citation rate and the field based expected citation rate. A value above 1 means that the journal based rate higher is than the rate based on the field. As journals belong –at least partially- to the given field this value higher than 1 corresponds to the fact that the set of papers is published in journals more visible than the field in average. A value lower than 1 means thus that the papers are published in journals belonging to the lower segment within the field. This value gives some indication of publication strategy of a institute or group. High values means that the entity tends to publish in journal with a higher visibility than the average fields. Table 8 gives the average values for each group with the different types of collaboration. The Multidisciplinary group has the best ratio for all papers (1.17). The values for non-domestic collaboration (International, Inside or Outside Europe) are even higher. This means that these institutes publish in the journals with the highest visibility in the fields. The ratio for the papers with extramural domestic or no extramural collaboration is still quite above 1 (1.19 and 1.13). The MDS-group is the only group with a value above 1 for the no extramural collaboration. For 5 groups (BIO, AGR, GSS, TNS, CHE) the values in the four types of collaboration are about the same. This means that we could suspect that the type of collaboration has no impact on the publication strategy. Only papers with no extramural collaboration are published in journals with the lowest visibility.

Table 8. MECR/FECR in different types of collaboration

	Collaboration					
	All Publications	International	Within Europe	Outside Europe	Extram. Dom.	No Extram.
BIO	1.04	1.09	1.10	1.12	1.11	0.94
AGR	1.00	1.07	1.13	1.03	1.09	0.89
MDS	1.17	1.29	1.28	1.32	1.19	1.13
GSS	1.13	1.20	1.23	1.23	1.19	0.90
TNS	1.06	1.14	1.17	1.13	1.12	0.92
CHE	0.98	1.05	1.08	0.98	1.04	0.88
GRM	0.99	1.18	1.17	1.25	1.02	0.82
SPM	0.91	1.13	1.16	1.15	0.96	0.79
Kruskal Test	233.14***	50.48***	166.33***	66.17***	210.5***	200.41***

In table 9, the MECR/FECR-value is compared between different sets. The pattern in this table is different from the two previous tables. The low value for Kruskal-Wallis test reported in the second column indicates that there's no difference between the groups. About 80% of all institutes, in each group has a value in the 'Extramural Domestic' set which is higher than the value in the 'No Extramural Collaboration'. More striking are the results in the last column. Only in the 'Multidisciplinary' and the Medical groups most of the institutes have a higher value in the 'International' set than in the 'Extramural Domestic' set. This is in line with the findigs of Bordons et al. (1996) who investigated collaboration in biomedical sciences. The shares of about 50% for other five groups confirm what was seen in table 8, as soon as these institutes collaborate with extramural partners the publication strategy tends towards journals with a higher impact.

Table 9. Share of institutes with a higher MECR/FECR-value

	International vs. No Extram	Extram. Dom. vs. No Extram.	International vs. Extram. Dom.
Total	84.39%	81.85%	67.40%
t-test	39.47	34.43	15.46
BIO	76.99%	72.57%	44.25%*
AGR	80.30%	81.82%	50.00%*
MDS	86.04%	83.75%	69.61%
GSS	85.48%	82.26%	41.94%*
TNS	86.09%	86.09%	56.09%*
CHE	66.67%	75.43%	49.12%*
GRM	87.80%	81.71%	78.66%
SPM	84.73%	80.54%	79.71%
Kruskal	22.34	12.83**	120.61
* not significant different from 50%			
** p-value more than 0.05			

For both indicators (NMCR, MECR/FECR) the answer is three times positive on the questions in the introduction.

Measuring similarity between pairs of institutes

For the fifth question we have to define a measure for likeliness between institutes. For each of the 1743 institutes we have calculated a vector containing 16 shares on the different fields. For each pair of institutes it is possible to calculate a cosine based on the Cauchy-Schwarz Inequality. It is defined as

$$\cos(\theta) \triangleq \frac{\langle \underline{x}, \underline{y} \rangle}{\|\underline{x}\| \cdot \|\underline{y}\|}$$

or, in our case with 16 fields in Sciences, Social Sciences and Art&Humanties,

$$\cos(\theta) \triangleq \frac{\left(\sum_{i=1}^{16} x_i y_i\right)^2}{\left(\sum_{i=1}^{16} x_i^2\right)\left(\sum_{i=1}^{16} y_i^2\right)}$$

Using this formula we calculated the similarity between 1,338,508 pairs of institutes. For each of them we also determined whether they collaborated in the period 2003-2005. This allows

us to calculated the average similarity over those institutes that collaborated and those that do not. Figure 2 shows the distribution of the shares in a boxplot. It is clear that there is a difference between collaborating and non-collaborating pairs. The average similarity for collaborating pairs is 0.68 and for the non collaborating the average similarity measure is 0.38 A Kruskal-Wallis test was used to test whether the difference is significant. This resulted in a Chi-square of 80475 with df=1. This allows us to conclude that the research profile of collaborating institutes is more alike than those pairs of institutes that have no collaborative relations.

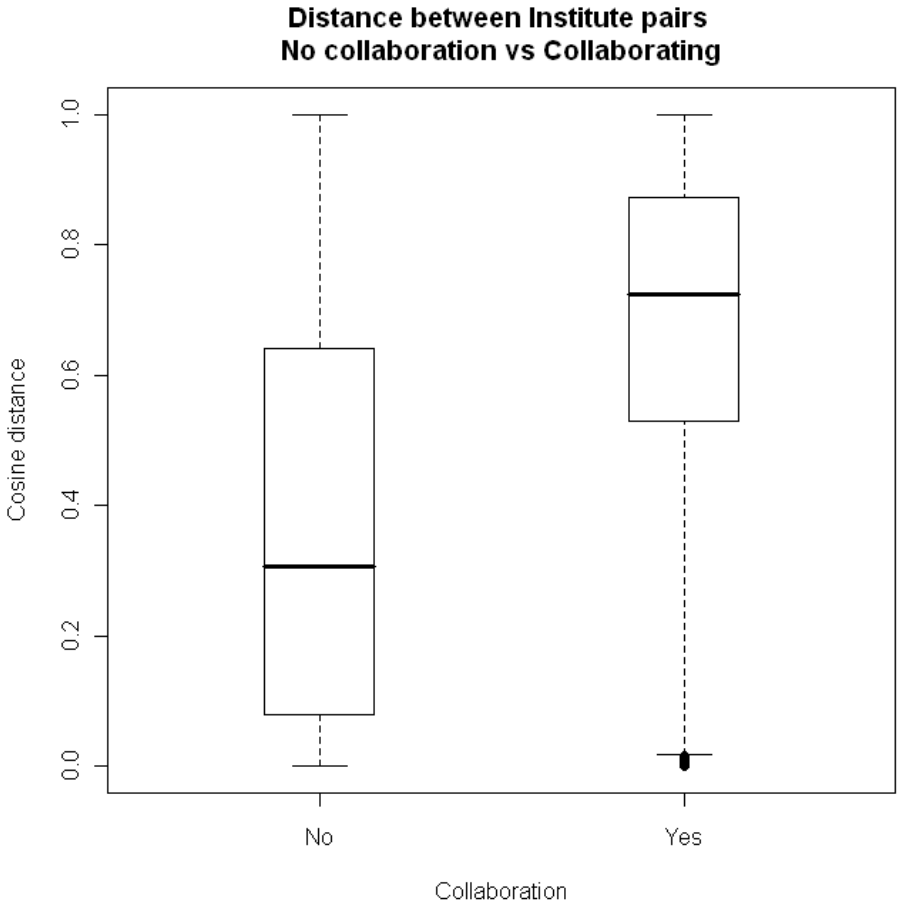

Figure 2. Boxplot comparing distance between institutes

Measuring collaboration preferences

However, we want to dig deeper into the relation between similarity and collaboration so that we try to answer a subsequent question (6th): 'Do institutes that are more similar in research profile collaborate more?'. This would mean that the most preferred partners for collaboration are those institutes that are most alike.

In order to be able to answer this question we need to add another measurement to each pair of institutes. Using the Jaccard-index we can indicate the strength of the collaborative relation.

The Jaccard index, also known as the Jaccard Similarity Index, is defined as

$$J(A, B) = \frac{|A \cap B|}{|A \cup B|}$$

with A and B denote the set of papers assigned to two institutes.
As both the similarity of research profiles and the Jaccard-index of collaboration are continuous variables a Pearson correlation is suitable as test of significance of the relation. Here we only use the pairs that have at least one joint paper (98,352 pairs).

R=0.17 (t=56.02, df=98350, p-value<2.2e-16)

The Pearson correlation of 0.17 indicates a significant positive relation but is indeed rather low. So, the answer to question six is positive, however, this low value is in fact not yet satisfactory in answering the question concerning the most preferred collaboration partners.

Identifying most preferred partners

In this section we try to find for each group of institutes the most preferred partners. In Table 10 the share of combinations of two groups are given. These shares are calculated within one group, e.g. 86.4% of all collaborative papers from an institute in the 'Biology' group are in collaboration with an institute from the 'Multidisciplinary' group.

Table 10. Preference of collaborators.

	BIO	AGR	MDS	GSS	TNS	CHE	GRM	SPM
BIO	14.2%	28.2%	6.4%	3.8%	2.4%	2.1%	1.6%	2.9%
AGR	8.0%	6.8%	1.6%	1.0%	0.9%	0.8%	0.2%	0.3%
MDS	86.4%	77.8%	67.3%	88.3%	83.4%	90.2%	93.7%	92.1%
GSS	1.5%	1.3%	2.5%	17.4%	2.2%	0.4%	0.0%	0.1%
TNS	9.3%	12.8%	24.3%	22.1%	23.8%	45.0%	2.7%	4.1%
CHE	0.4%	0.5%	1.1%	0.2%	1.9%	3.2%	0.1%	0.1%
GRM	1.4%	0.5%	6.3%	0.1%	0.6%	0.4%	16.8%	12.1%
SPM	9.5%	3.6%	22.4%	0.9%	3.5%	2.1%	43.8%	31.3%

These shares have to be compared with the expected distribution. This expected distribution is the same over all the different groups or the total of collaborated papers. So, this distribution is calculated by taking all papers with at least 2 institutes and counting the number of papers in each group. See Table 11 for this distribution.

Table 11. Expected distribution of co-authored papers.

	Expected Distribution
BIO	5.6%
AGR	1.6%
MDS	76.2%
GSS	2.2%
TNS	22.2%
CHE	0.9%
GRM	5.1%
SPM	18.5%

A Chi-Square test indicated that the observed distribution in each group diverge from the expected distribution. Comparing the observed shares with the expected ones leads to these observations:

- For each group the multidisciplinary cluster is the most likely partner,

- All shares of collaboration within groups are higher than expected,
- This observation does not hold for the Multidisciplinary group, here the within group collaboration is lower,
- For the 7 specialised groups, the share of collaboration with the MDS group is higher than expected. This allows is to conclude that members of the multidisciplinary group are the most preferred partners.
- Also closely related groups have a higher collaboration share than other groups. These closely related groups are those groups that in the hierarchical clustering are group together at a higher level of aggregation. These are the related groups AGR-BIO, TNS-CHE, GRM-SPM.
- For the multidisciplinary group the observed share of collaboration with the 'Specialized Medicine' cluster is 3.9% larger than the expected one. This is the highest increase for the Multidisciplinary group.

Conclusion

In this paper we tried to give an answer on several questions on the relation between collaboration and performance or productivity of European research institutes within the perspective of different research profiles. In earlier studies (Thijs & Glänzel, 2008 and 2009) we could show that among our 8 groups of institutes there are differences in publication and citation indicators. The first section of this paper makes it clear that differences can be found between these groups in choice of their collaborator. Institutes in the Geo and Space Sciences have 67% of their papers with an international partner while medical institutes have a share that less than the half of this. However, for these medical institutes, extramural domestic collaboration is much more important. These two groups are the only ones where the share of this type of collaboration is more than 50%.

In a second section we looked at three different citation indicators to study the impact of the different types of collaboration on the visibility of research and publication strategy. We found that the visibility of research increases in the different types of collaboration. Only in the Chemical group this effect was absent. Extramural collaboration itself was enough to raise the scores but international collaboration added to this effect. There was not much difference between within or outside Europe collaboration. Striking was the effect in the medical groups with a large difference in indicators between international and extramural domestic collaboration. Combining this with the observation of large share of domestic collaboration for medical groups leads to the observation of a deviating publication behavior for these two groups in these types of collaboration.

In the last section we tried to identify the research profile of the most preferred partners for each group. First it was shown that collaborating institutes have a profile that's more alike than those that do not collaborate. However, a rather weak correlation was found between collaborating strength and profile similarity among collaborating institutes. Looking at combinations of groups, it's clear that for each of the specialized groups the multidisciplinary institutes are the most preferred partners, even more than expected. Also the institutes from the same group and the related group are likely partners. The strong link between two medical groups and the multidisciplinary one was striking. Future research with a detailed and more indepth study can be devoted to the relation between these 3 groups.

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