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The role of guarantor in scientific collaboration: The neighbourhood matters

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ABSTRACT

Output resulting from institutional collaboration has been widely used to create performance indicators, but focusing on research guarantors has recently provided a way to recognize the salient role of certain scientific actors. This paper elaborates on this approach to characterize the performance of an institution as guarantor based not only on its guarantor output but also on the importance of the institutions with which it collaborates. Accepting that guarantorship implies in some way acknowledgement of a prominent role on the part of the collaborating institutions, and that this recognition will be more important the more important the collaborating institutions, the paper describes two approaches to measuring this acknowledgement and discusses their effectiveness in helping to recognize prominent scientific actors by using a case study in the Library and Information Science field. The results show a high assortativity in scientific collaboration relationships, confirming the original hypothesis that important institutions tend to grant prestigious institutions the recognition of their relevance.

1. Introduction

Currently it is assumed that institutional and especially international collaboration is an indicator of quality in research, and even increases the impact of scientific output (Goldfinch, Dale & DeRouen, 2003; Katz &Hicks, 1997; Narin, Stevens & Whitlow, 1991 ; Sooryamoorthy, 2009). In accordance with this principle, the output resulting from institutional collaboration has been used to create performance indicators for such bibliometric rankings of institutions as the Leiden Ranking (Waltman et al., 2012), the SCImago Institutions Rankings (SCImago Research Group, 2014), or other higher education institution rankings such as the Times Higher Education World University Rankings (Baty, 2011).

Other authors have, however, found an imbalance in the benefits the parties derive from international collaboration (Guerrero-Bote, Olmeda-Gomez & Moya-Anegon, 2013; Leimu & Koricheva, 2005). Such benefits (in terms of visibility and impact) are less evident for countries that have on average a greater impact, while countries with less scientific capacity benefit more from this type of association (Guerrero-Bote et al., 2013). Nevertheless, the indicators of institutional and international collaboration reward equally each of the parties collaborating. In this sense, we believe that the "research guarantor approach" (Moya-Anegon et al., 2013) provides a way of attributing credit to the participating parties that can improve our ability to explain the internal dynamics of institutional and international collaboration, and help to better recognize the party that has more weight in the research.

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The Research Guarantor concept introduced by Rennie, Yank and Emanuel (1997), together with the list of contributors, has been adopted as a specific element of the authoring system, especially in the field of biomedicine. According to these authors, the guarantors are "those people who have contributed substantially, but who also have made added efforts to ensure the integrity of the entire project.Ë Because of this, an author who acts as research guarantor (RG) typically receives more credit than the other collaborators (Wren et al., 2007). What is more, research guarantors are often 'identified as the persons who take responsibility for the integrity of the work as a whole, from inception to published article' (ICMJE, 1997). Thus, it is reasonable to say that the research guarantors "play a leading role in research" (Moya-Anegon et al., 2013) and that they are key players in institutional collaboration.

Despite the theoretical advantages of the contributor/guarantor system, explicit mention of the guarantor is not widespread, making it difficult to use directly. To determine which collaborator is primarily responsible for the research, Moya-Anegon et al. (2013) proposed the use of the corresponding author information and discussed the implications and possible limitations of this method. This has been used successfully to identify "leading authors" (Cova, Jarmelo, Formosinho, de Melo, & Pais, 2015), and even to develop leadership indicators for individual authors (Alvarez-Betancourt & Garcia-Silvente, 2014). However, the original idea was to assign the role of Research Guarantor only to the institution to which the corresponding author belongs as being less risky than assigning it to the author themself. Thus, we do not assume that the individual who acts as the corresponding author is the Research Guarantor, but that the group or institution to which the corresponding author belongs is the Research Guarantor. In our case, the level of analysis is that of the institutions, so we think that the research guarantor approach adapts well to our study.

The type of role that these indicators aim to describe is different from that derived from the concept, common in the literature, of superior performance in terms of output or other more qualitative indicators (Klavans & Boyack, 2008, 2010; Moiwo & Tao, 2013; Shelton, 2008). Although "research guarantorship" is not explicitly about the quality of the results published, it does introduce a new dimension related to the ability to have a salient role in the process of doing science, and therefore to the characteristics of the individual contributions of the parties.

Two indicators derived from this approach −Scientific Leadership, and Excellence with Leadership– are currently used in the SCImago Institutions Rankings (SCImago Research Group, 2014). Both indicators have been analysed in depth (Jeremić, Jovanović-Milenković, Radojičić, & Martić, 2013;Moya-Anegon et al., 2013; Manganote, Araujo & Schulz, 2014;), and there is evidence of their usefulness in identifying and describing pre-eminent actors in science (Lillo & Martini, 2013; Zacca-González, Vargas-Quesada, Chinchilla-Rodríguez, & de Moya-Anegón, 2014; Manganote et al., 2014; Chinchilla-Rodríguez, Miguel, & Moya-Anegón, 2014; Chinchilla-Rodríguez, Zacca-González, Vargas-Quesada, & Moya-Anegón, 2015).

However, although these research guarantorship based indicators are useful to describe institutions' scientific performance, there are situations in which the role of their leadership can be overestimated: when an institution systematically appears alone on the byline and when it systematically leads other institutions with much lower scientific reputations. Manganote et al. (2014) obtained results that seem to support this idea when analysing the relationship between the percentage of production as guarantor (%RG), the percentages of papers published in first quartile journals (%Q1), the percentage of papers produced under international collaboration conditions (%CI), and the normalized impact of the scientific production (NI). According to those authors, above 50% of production as RG there is a significant negative correlation between %RG and the remaining variables associated with the quality of the output. Thus, "a high value of normalized leadership may be an indicator of research isolation with the consequences on quality and impact of the corresponding research.Ë For a significant number of institutions, an important part of their production as guarantor is in the absence of international collaboration or it is with institutions whose production is not characterized by any high performance in terms of quality indicators. This could make it necessary to take not only the gross number of papers as guarantor into account but also the characteristics of the collaboration in which this production arises.

The role of research guarantor has been described by using counts of the total output and of the scientific output of excellence. Neither of these indicators, however, refers specifically to the relationship established between the guarantor and the collaborators. Instead, they describe the results of that collaboration. In the context of scientific output, guarantorship can be defined as an asymmetric relationship between one party exercising direction of the work and one or more collaborators. In this relationship, the guarantors should get more credit as recognition for the additional workload they bear, as well as receive differential recognition as appreciation for their performance in a specific function that characterizes the agents who are more autonomous and prominent. Such relationships can also be used to describe the structure of a scientific collaboration, an approach used by Cova et al. (2015), for whom information about the corresponding author could be useful "to detail collaborative fluxes, including the sense of collaboration.Ï In our opinion, these collaborative fluxes can also be used to distinguish prominent actors in the structure of scientific collaboration between institutions.

Although we make limited use of network theory in this work, the fact is that, from this point of view, research guarantors fit well with the definition of "prestigious actor" as "one who is the object of extensive ties, thus focusing solely on the actor as a recipient [of inbound ties]Ï (Wasserman & Faust, 1994:174). In our opinion, when a collaboration is established between a guarantor and one or more contributing parties, the latter can be considered to acknowledge the scientific authority of the guarantor. Furthermore, we understand that this recognition is of greater value the higher the scientific level of the collaborators involved. Thus the guarantorship skills of a scientific actor (an institution in the case of the present study) can be described through the recognized prestige that comes from the collaborators' acceptance of the role.

In this paper, we study the recognition obtained by scientific institutions from their collaborators when acting as RG. To this end, we developed two different ways of measuring this recognition as guarantor, and applied them to describe the contributions of a large number of institutions to worldwide scientific production. We then compared these data with other well-known scientific indicators so as to be able to contextualize and interpret the characteristics of the proposed measures. Our hypothesis is that, in scientific collaboration, important institutions tend to grant prestigious institutions the recognition of their authority, that this recognition can be measured, and that institutions which obtain a high level of recognition are also characterized by high scores on quality and scientific performance indicators.

2. Methods

The method we used to assign the Research Guarantor to each paper can be summarized in the following three steps, which we shall discuss using an example published by Moya et al. (2013):

1. If both the corresponding author and his affiliation can be determined from the record, then the role of research guarantor is assigned to that institution (94.24% of the cases in 2010).

2. If the corresponding author can be determined from the record but his affiliation can not, then the role of research guarantor is assigned to the affiliation institution of that author (4.5% in 2010).

3. If the corresponding author can not be determined, then the role of research guarantor is assigned to the affiliation institution of the first author (0.41% in 2010).

Exceptions were made to this general method, though, when multiple affiliations of a single corresponding author where found, or when multiple corresponding authors from different affiliations where identified. In these cases, we have assigned the research guarantor to the respective institutions. Another exception was made when the corresponding author was missing and the authors appeared in alphabetical order. In this case, the option of assigning the research guarantor to the first author does not look reasonable, and thus, we have preferred to assign no research guarantor at all.

To develop a measure of the acknowledgement of the scientific authority of a guarantor, first we needed a suitable indicator to describe the scientific level of the institutions. In this sense, we understand that the normalized impact of institutions acting as RG (Lundberg 2007) is the best indicator of the scientific category of each of the collaborators. Second, a mechanism is needed to transmit this prestige to the RG in the form of recognition. In this sense, we understand that the individual recognition of each collaborator should not be given directly to the guarantor because the mean number of collaborators would become a determining factor. Since some scientific fields (and therefore the institutions specialized in those same fields) show very distinct patterns of co-authorship, it is to be expected that those patterns would decisively impact the recognition that the guarantors receive, which seems incorrect.

We considered that the problem could be represented more simply by taking the papers as the source through which the guarantors obtain prestige (instead of getting it directly from the collaborators), and by defining this quality as a characteristic associated with the collaborators' scientific category. This indirect mechanism is similar to that used by Newman (2001) to create collaboration networks between authors, but adapting it to an asymmetric relationship as proposed by Opsahl (2013). Thus, we use the normalized impact as RG of the collaborators to define their scientific capacity, and the average of this indicator for all the collaborators of an article as a measure of the recognition received by the guarantor from the collaborators in that particular article, as shown in Fig. 1. We also understand that when more than one author is from the institution acting as RG then there is self-acknowledgment of this capacity. In such cases we therefore consider the institution to be both RG and collaborator. There would still be self-acknowledgment in a single affiliation paper, as long as there is more than one author. Once recognition has accumulated in the papers, it is transmitted to the guarantors. We believe it is useful to measure both the cumulative and the average recognition, as this allows the guarantors to be evaluated in two different ways, as also shown in Fig. 1.

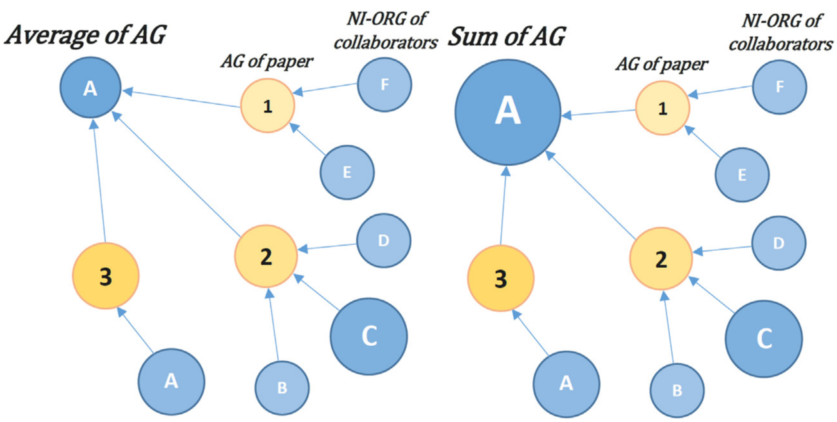

Fig. 1. Origin, transmission, and measurement of the Acknowledgment as Guarantor.

Formally, the acknowledgment as research guarantor provided by a paper (Acknowledgment as Guarantor) is:

$$AAG_i = \frac{\Sigma_{k=1}^{N} NI\text{-}ORG_k}{N}$$

where:

AG_{ij} is the acknowledgment of the i-th institution as guarantor in the j-th paper;

N is the number of collaborating institutions (including the institution acting as RG if there is more than one author with that affiliation);

$NI\text{-}ORG_k$ is the normalized impact as research guarantor of the k-th institution.

To obtain an overall measure of the acknowledgment an institution receives for its entire output as a guarantor, one can average the 'acknowledgment as guarantor' obtained for all papers as research guarantor (Average of Acknowledgment as Guarantor):

$$AAG_i = \frac{\Sigma_{j=1}^{m} AG_{ij}}{M}$$

where:

AAG_i is the average acknowledgment of the i-th institution as guarantor in all its papers as research guarantor;

M is the number of papers of the i-th institution as research guarantor.

As will be discussed below, this metric has a weak correlation with the volume of output as a guarantor. Thus one can qualify it as size-independent. However, we believe that the output volume is an important characteristic that can also be used to explain the credit an institution has as guarantor. For this reason, we use a second, size-dependent, measure accumulating the acknowledgment rather than averaging it (Sum of Acknowledgment as Guarantor):

$$SAG_i = \sum_{j=1}^{M} AG_{ij}$$

where:

SAG_i sum of acknowledgments of the i-th institution as guarantor in all its papers as research guarantor;

M is the number of papers of the i-th institution as research guarantor.

We consider that this pair of measures allows one to describe in a balanced manner the capacities of an institution as "research guarantor", and to go deeper into a more qualitative vision of this influential role. At the same time, these measures should avoid overestimation of the groups of scientific actors who almost exclusively collaborate among themselves or with institutions that are not characterized by having a high quality scientific production.

In the present work, we analysed the influence that this acknowledgment as guarantor may have on a number of indicators that we divided into two groups – indicators related to the output size, and indicators independent of the output size. We have used the same thematic classification of journals used in *SCImago Journal & Country Rank*, available at http://scimagojr.com. This classification has a broader level of 26 subject areas and a narrower level of 309 subject categories, which we have used as scientific fields for normalization purposes as well as in the context of excellence related indicators. Among the indicators related to the output size, we used the following:

- Output: whole citable scientific output.
- ORG: output as research guarantor, as defined in Moya-Anegon et al. (2013).
- EO: excellent output, which comprises the papers belonging to the 10% most cited in a category for the same year of publication (Bornmann, Moya-Anegón & Leydesdorff, 2012).
- EORG: excellent output as research guarantor, for the fraction of excellent output published as research guarantor.

Among the size-independent indicators, we used the following:

- NI: normalized impact, or Item Oriented Field Normalized Citation Score, as defined by Lundberg (2007).
- NI-ORG: normalized impact of the output as research guarantor.
- %EO: percentage of excellent output, fraction of excellent papers relative to the total number of papers.
- %EORG: percentage of excellent output as research guarantor, or number of excellent papers produced as research guarantor relative to the total number of papers produced as research guarantor.

3. Data

The data used for this study correspond to the types of output with higher citation averages in the Scopus database (Guerrero-Bote & Moya-Anegón, 2014) which includes articles, reviews, conference papers and short surveys for the period 2003–2012. Data regarding corresponding authors is available for this database, and its high quality has already been reported in previous studies (Moya-Anegon et al., 2013). Only the institutions that have acted as guarantors on at least one occasion

Table 1
Distribution of institutions and ORG by sector.

Sector	Instit.	Output	ORG	% of ORG	ORG/Instit.	Instit. ORG 10K+	% Instit. ORG 10K+
Government	929	4 774 302	2 539 741	15.5%	2 734	31	8.2%
Health	790	3 493 921	1 823 512	11.1%	2 308	25	6.6%
Higher edu.	2 296	19 518 330	11 687 180	71.2%	5 090	322	84.7%
Others	53	131 314	48 386	0.3%	913	0	0%
Private	187	656 969	317 099	1.9%	1 696	2	0.5%
Totals	4 255	28 574 836	16 415 918	100%	3 858	380	100%

were considered for this study. This initially allowed us to consider 21 886 institutions. Of these, a very large number (almost a third) have only acted as research guarantor once or twice a year on average, and nearly half have produced fewer than ten papers per year. It is difficult to determine a minimum number of publications for an institution to be considered relevant to this study, although we believe that a minimum of 100 publications per year would be reasonable. This leaves us with a total of 4255 institutions, which is 19.4% of the total institutions for which we have data. However, these institutions are responsible for about 90% of world scientific production during the years studied, and 91% of world production as research guarantor for the same period. In this sense, although the number of institutions studied is greatly reduced after the application of the threshold, their capacity to represent global production remains very high. All the indicators and subsequent tables were therefore calculated with the remaining 4255 institutions.

The institutions covered in this study mostly belong to the higher education sector, which is also the sector with the highest ratio of papers per institution (Table 1). The largest institutions (in terms of ORG) are also concentrated in this sector, with only about 15% of all the institutions with 10 000 or more ORG belonging to other sectors (Table 1).

The institutions are also unevenly distributed among a total of 117 countries, forming a long tail to the right, and broadly following an "80-20" rule. Just the first 10 countries account for 71% of the total output. The USA provides the largest number of institutions (718), about a 17% of all the institutions involved. Its primacy is even more evident in terms of the output of the institutions serving as guarantors, amounting to almost a quarter of the total (Table 2).

4. Results

Fig. 2 shows plots of the logarithm of the size-dependent indicators of the output against the logarithm of their rank. One observes in the figure that the different indicators undergo an evident change of slope at values of the rank somewhere between 4 and 9, with the top-ranking institutions represented by steeper slopes indicating their markedly greater scores on

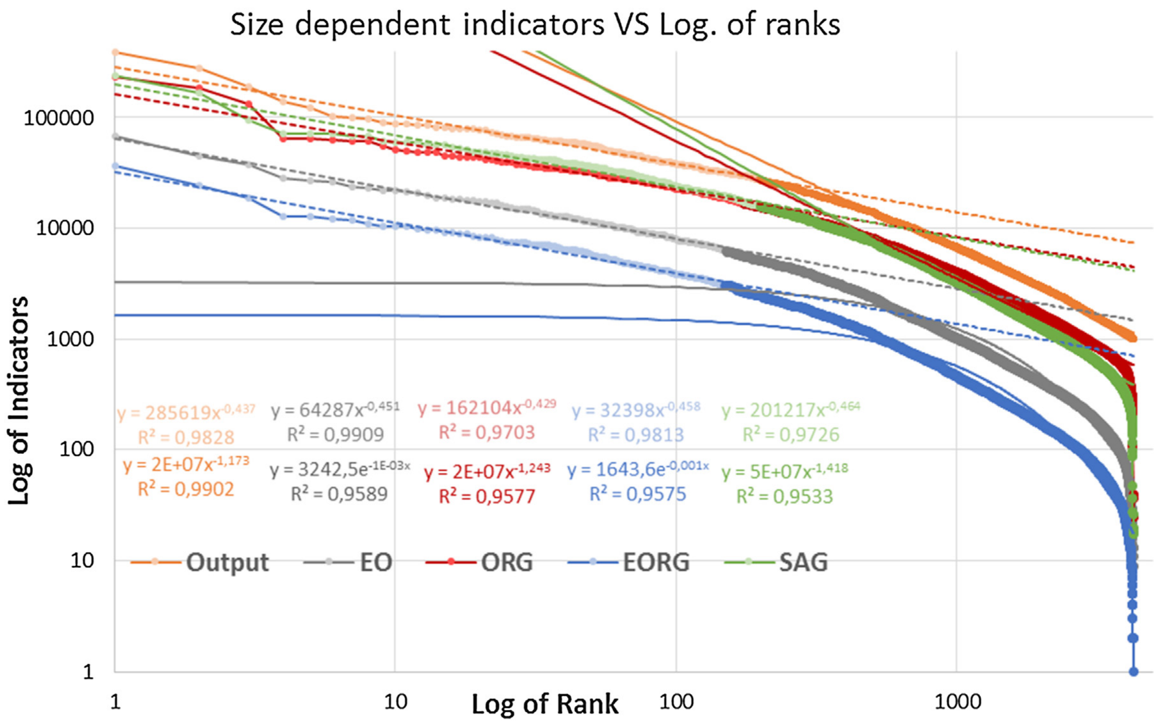

Fig. 2. Logarithm of the scores for size-dependent indicators versus the logarithm of their range.

Table 2
The ORG values and number of institutions for the 10 countries with the greatest ORG.

Country	Institutions	Output	ORG	% ORG	% of total institutions
USA	718	7 183 418	3 878 270	23.6%	16.9%
CHN	500	3 356 173	2 373 504	14.5%	11.8%
FRA	321	2 016 063	1 035 336	6.3%	7.5%
JPN	235	1 546 133	875 356	5.3%	5.5%
DEU	214	1 726 072	935 753	5.7%	5.0%
GBR	185	1 468 787	805 718	4.9%	4.3%
ESP	171	807 673	447 343	2.7%	4.0%
ITA	146	969 657	505 169	3.1%	3.4%
IND	141	452 468	316 516	1.9%	3.3%
CAN	111	896 863	503 241	3.1%	2.6%
Top 10 totals	2742	20 423 307	11 676 206	71.1%	64.4%

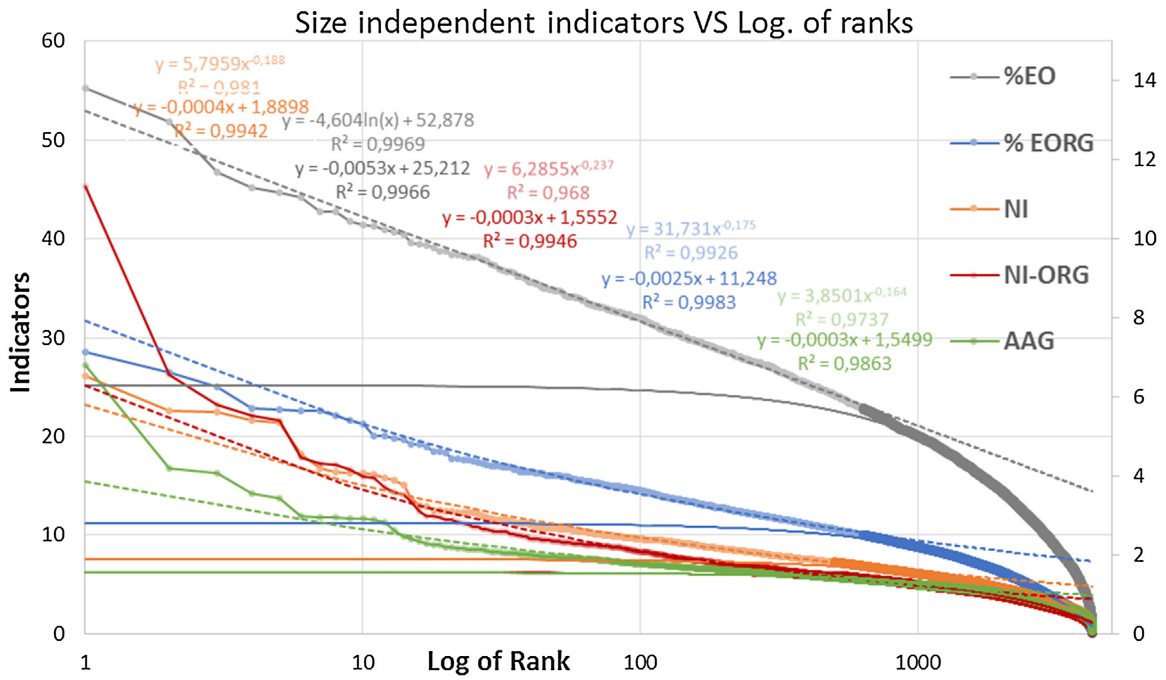

Fig. 3. Size-independent indicators versus the logarithm of their range; %EO and %EORG on the secondary axis, at the left.

these indicators than the other institutions. The indicators with the greatest change in slope are Output, ORG, and SAG, while EO and EORG show a change that is less steep. Overall, the progression of the curves seems to be of a power type, although there is a better fit when describing the series using two curves. The first is exponential for EO and EORG and ends above the range 150, but is a power type for the other indicators and ends above the range 200 for SAG and Output and above 175 for ORG. The second curve is a power type in all cases, describing a scenario in which there is an obvious imbalance between a relatively small number of very important institutions and the much lower importance of the remaining institutions in regard to these indicators.

Fig. 3 shows semi-log plots of the size-independent indicators of the output that relate the scores to the logarithm of the rank. In this case, we used two axes due to the difference in magnitude between %EO and %EORG and the other indicators. In the highest ranges, all the indicators can be described by a linear regression, although %EO and %EORG have a much steeper slope and fit well up to about the range 630, while NI and NI-ORG have a much lower slope and reach the range 500. The linear regression that describes AAG has a similar slope to these last two indicators, but fits well up to the range 1000. The first ranges of all the indicators except %EO can be well described with a power curve. The exception, %EO, is fitted best with a logarithmic curve. In general, the differences between institutions are far sharper from the perspective of the size-dependent indicators than from that of the size-independent indicators, with (except for the cases of NI-ORG and AAG) there being no changes in slope as sharp as those of the size-dependent indicators for the first ranges. One also observes that SAG and AAG behave very similarly to ORG and NI-ORG, respectively, in both magnitude and the curves of the fit.

The correlation matrix given in Table 3 shows positive correlations between all the indicators, with the *p*-values being very close to zero. The (Pearson) correlation coefficients between the size-dependent indicators are very high, and their correlations with the size-independent indicators are weak. Notable are the correlations between EORG and EO, EORG and

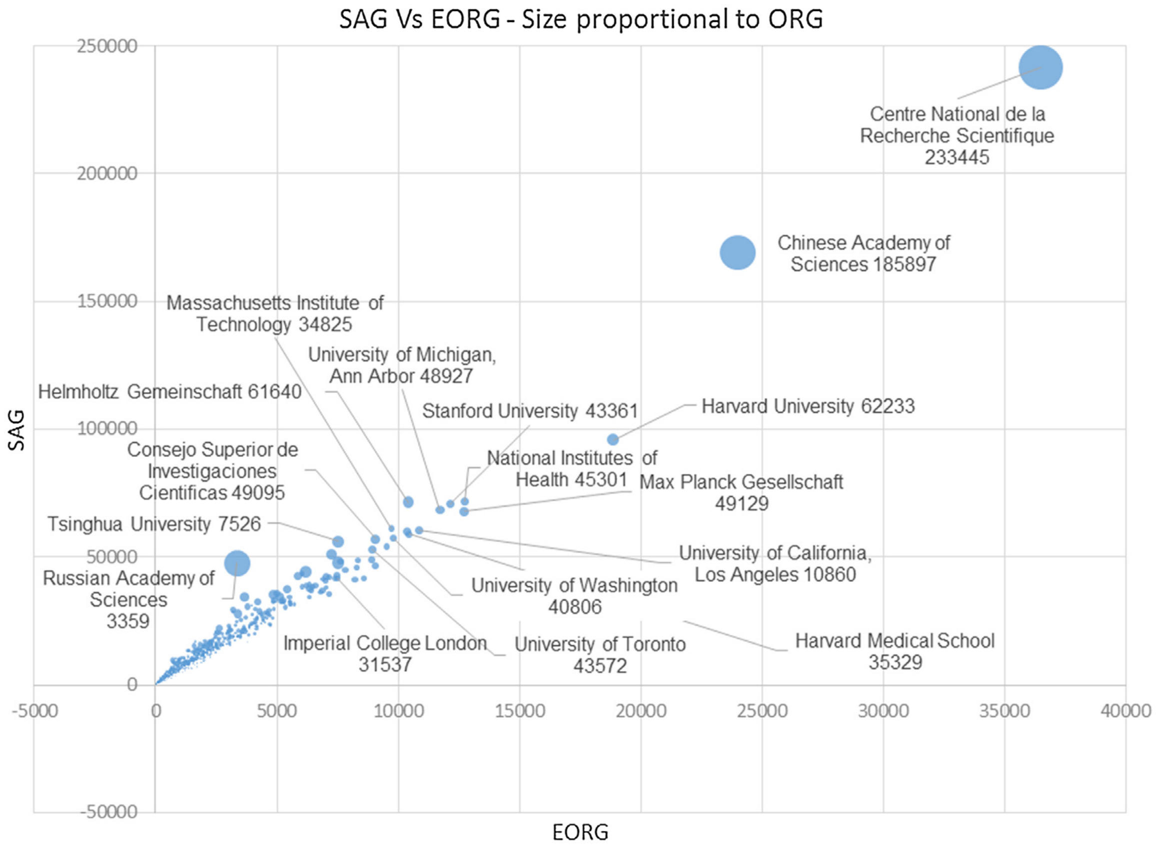

Fig. 4. Bubble chart with SAG on the y-axis and EORG on the x-axis. The bubble diameter is proportional to the institution's output as research guarantor.

Table 3
Correlation matrix (Pearson) between the different indicators.

Pearson	Output	EO	ORG	EORG	SAG	NI	%EO	NI-ORG	%EORG	AAG
Output	1	0.93	0.98	0.94	0.97	0.15	0.17	0.16	0.25	0.18
EO	0.93	1	0.88	0.99	0.97	0.29	0.31	0.29	0.36	0.32
ORG	0.98	0.88	1	0.91	0.95	0.10	0.12	0.12	0.23	0.13
EORG	0.94	0.99	0.91	1	0.99	0.25	0.28	0.27	0.37	0.29
SAG	0.97	0.97	0.95	0.99	1	0.21	0.23	0.23	0.33	0.25
NI	0.15	0.29	0.10	0.25	0.21	1	0.94	0.90	0.70	0.92
%EO	0.17	0.31	0.12	0.28	0.23	0.94	1	0.85	0.80	0.89
NI-ORG	0.16	0.29	0.12	0.27	0.23	0.90	0.85	1	0.79	0.96
%_EORG	0.25	0.36	0.23	0.37	0.33	0.70	0.80	0.79	1	0.80
AAG	0.18	0.32	0.13	0.29	0.25	0.92	0.89	0.96	0.80	1

SAG, and ORG and Output. The SAG indicator has very strong correlations with size-dependent indicators although both SAG and the two excellence-based indicators have stronger correlations with the group of size-independent indicators than with ORG and Output. This was to be expected given that citation is directly or indirectly determinant for all of them.

The correlations between size-independent indicators are relevant, although generally not as strong as between the size-dependent indicators. The strongest are between AAG and NI-ORG and between NI and %EO. The strong correlation between AAG and NI-ORG surely points to a high assortativity of the institutions that act as guarantors with respect to the institutions that collaborate with them.

The existence of two groups of indicators is somewhat less evident in the Spearman correlations of Table 4. The correlations between all the indicators are positive and their p-values very close to zero. Overall, although AAG and SAG are more strongly correlated with their respective groups, the difference is smaller than in the case of the Pearson correlations.

We would note that, as was indicated by Manganote et al. (2014), the correlation between %ORG and the size-independent indicators is negative in all cases, and is especially strong in relation to NI (−0.59) and NI-ORG (−0.46). However, neither SAG nor obviously AAG are negatively correlated with these indicators. We can thus conclude in essence that the negative effect which the isolation of institutions with high%ORG had on other quality indicators is not occurring for the institutions with high AAG and SAG scores, which we understand to reinforce the usefulness of these measures.

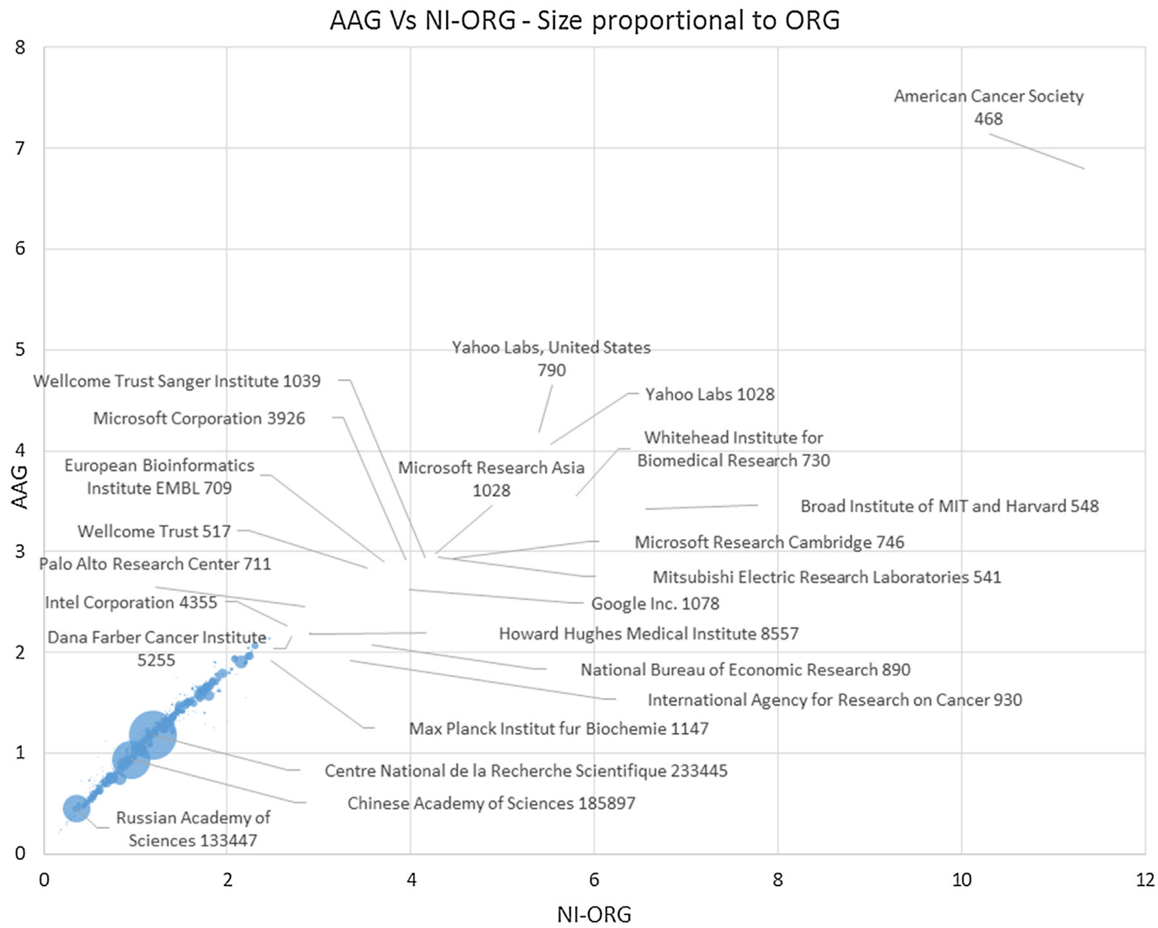

Fig. 5. Bubble chart with AAG on the y-axis and NI-ORG on the x-axis: the bubble diameter is proportional to the institution's output as research guarantor.

Table 4
Correlation matrix (Spearman) between the different indicators.

Spearman	Output	EO	ORG	EORG	SAG	NI	%EO	NI-ORG	%EORG	AAG
Output	1	0.85	0.96	0.85	0.92	0.20	0.21	0.24	0.33	0.21
EO	0.85	1	0.75	0.95	0.91	0.64	0.66	0.64	0.67	0.62
ORG	0.96	0.75	1	0.81	0.90	0.06	0.07	0.12	0.31	0.09
EORG	0.85	0.95	0.81	1	0.96	0.52	0.57	0.62	0.75	0.58
SAG	0.92	0.91	0.90	0.96	1	0.39	0.41	0.48	0.60	0.45
NI	0.20	0.64	0.06	0.52	0.39	1	0.97	0.92	0.74	0.93
%EO	0.21	0.66	0.07	0.57	0.41	0.97	1	0.92	0.81	0.93
NI-ORG	0.24	0.64	0.12	0.62	0.48	0.92	0.92	1	0.87	0.97
%EORG	0.33	0.67	0.31	0.75	0.60	0.74	0.81	0.87	1	0.84
AAG	0.21	0.62	0.09	0.58	0.45	0.93	0.93	0.97	0.84	1

We show in two bubble charts the comparison between SAG and AAG with respect to the two indicators which they are most strongly correlated with – respectively, EORG (Fig. 4), and NI-ORG (Fig. 5). It is clear at first glance that in both cases the institutions form a clear pattern showing the correlation between the two indicators. In Fig. 4, one can define an upper right quadrant in which the institutions have simultaneously a SAG above 50 000 and an EORG above 10 000. Although this quadrant covers a significant part of the plane, it only includes 11 institutions. Of these, only 1 has an ORG of less than 40 000, although 6 of the 10 institutions with a greater ORG lie outside this quadrant. All of the institutions with high SAG scores are well recognizable at first glance (Appendix A), although some very prominent institutions (such as the Russian Academy of Science) rank better than expected according to this criterion. We therefore believe that the confluence of institutions with high values of SAG and EORG can (with few exceptions) intuitively represent the main world scientific actors.

Unlike the previous case, Fig. 5 shows a significant lack of institutions with a large output as guarantors. Indeed, as one may observe from the data given in Appendix B, the top positions for the AAG indicator are very susceptible to a reduced but very successful output. This was to be expected, since this indicator is an average with a very low correlation with output

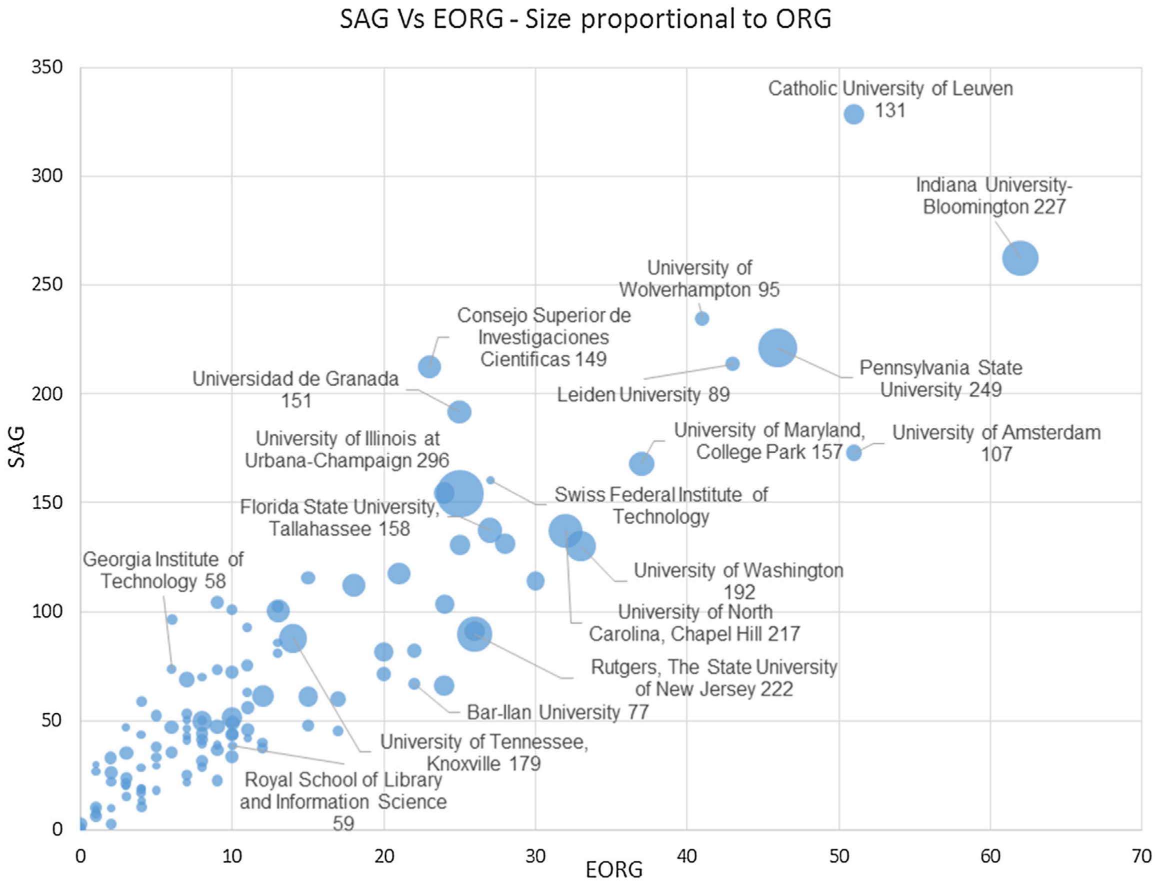

Fig. 6. Bubble chart with SAG on the y-axis and EORG on the x-axis: the bubble diameter is proportional to the institution's output as research guarantor in the LIS field.

as RG. One can define an upper right quadrant of 40 institutions by selecting those that combine scores over 2 in both AAG and NI-ORG. In this case the quadrant only includes 4 institutions that could be defined as large (with an ORG greater than 10 000). Only 22 of the 40 institutions have greater ORG than 1000, and, of these, only 12 have an RG production above 2000. Another aspect to highlight is the proliferation in this quadrant of private institutions associated with ICT together with some medical research institutions.

4.1. A library and information science case study

We would also like to introduce a short reflection on the description of the institutions in the field of Library and Information Science in order to give our impressions on the characterization of institutions that can be carried out with AAG and SAG applied to vary familiar ground. To carry out this check, we used data on the 113 institutions which had a minimum ORG of 50 for the entire period.

Similarly, we show in two bubble charts the comparison between SAG and EORG (Fig. 6), and the comparison between AAG and NI-ORG (Fig. 7). In both cases, the institutions form a clear pattern showing the correlation between the two indicators, although they are somewhat more spread out in the first case. The Pearson correlation coefficient for SAG and EORG is slightly smaller (0.90 vs 0.99) but remains almost the same for AAG and NI-ORG (0.95 vs 0.96) as shown in Table 3. The case is similar for the Spearman coefficients in Table 4 (0.86 vs 0.96 and 0.93 vs 0.97). In Fig. 6, one can again define an upper right quadrant in which the institutions have simultaneously a SAG above 100 and an EORG above 20. Although this quadrant covers a significant part of the plane, it only includes 20 institutions. Of these, only three have an ORG of less than 100 (not large for LIS standards), whereas 17 of the 30 institutions with a greater ORG lie in this quadrant. Most of the institutions with high SAG scores are again well recognizable at first glance by any practitioner in the field (Appendix C). There is nevertheless a noticeable difference regarding the distribution of SAG and EORG scores through their ranks, so that in the LIS case there does not exist such a great gap between the first institutions and the rest, as is visually explicit in comparing Figs. 4 and 6.

In Fig. 7, one can again define an upper right quadrant of approximately the same dimensions by selecting the institutions that combine scores of over 2 in NI-ORG and 1.5 in AAG. In this case, the quadrant covers only 11 institutions of different

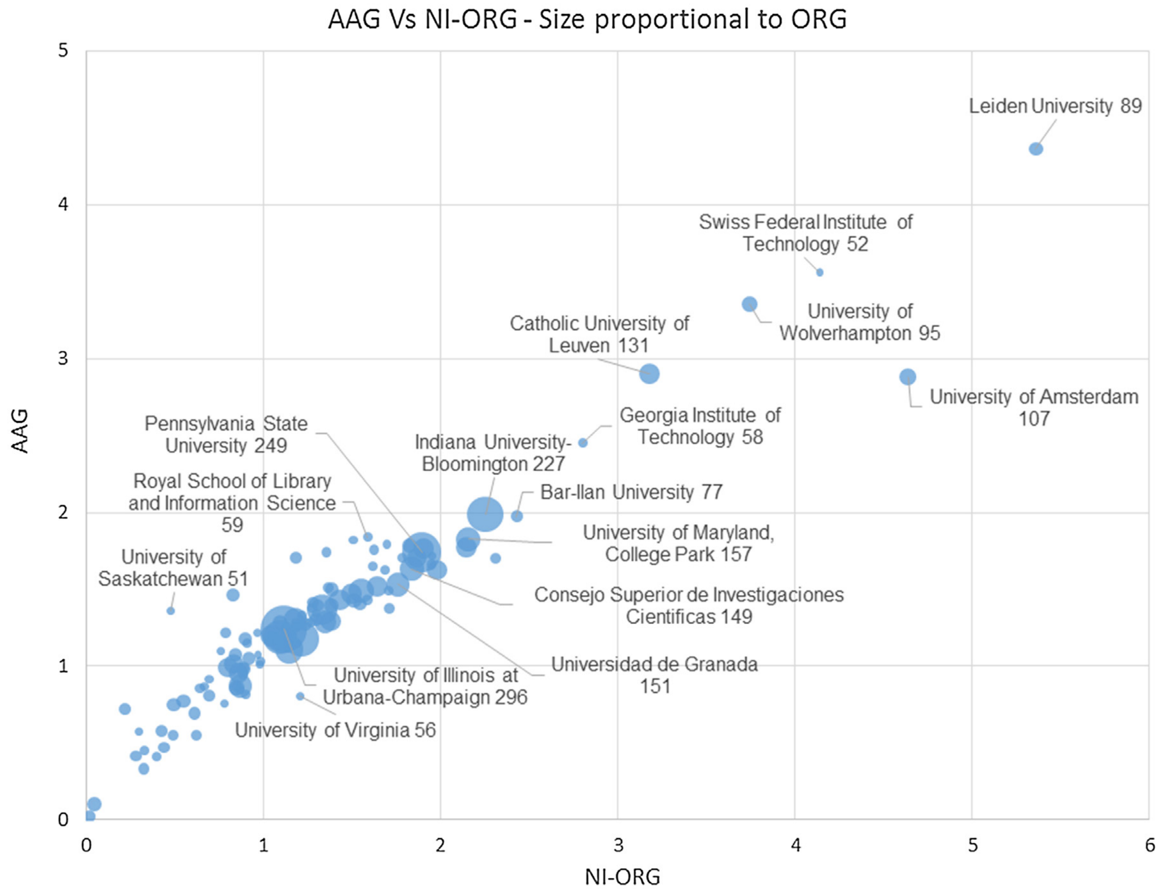

Fig. 7. Bubble chart with AAG on the y-axis and NI-ORG on the x-axis: the bubble diameter is proportional to the institution's output as research guarantor in the LIS field.

sizes. It is interesting to note that at least half of these institutions are truly outstanding in this field, which is not globally the case for these indicators (Fig. 5). In this sense, there is a major degree of coincidence between the SAG and AAG scores, with 7 of the top 10 institutions in both rankings being the same (see Appendix C and D). There is a substantial increase in the correlation between AAG and SAG in the LIS data, from 0.25 to 0.72 for the Pearson and from 0.44 to 0.75 for the Spearman coefficients. This coincidence in scores occurs therefore much less frequently overall, which seems to indicate that measuring AG delimited to each particular scientific field could allow for better integration of SAG and AAG, and be particularly useful in identifying the key actors in a scientific discipline.

5. Conclusions

There are relevant positive correlations between all the indicators analysed. Thus, in particular, there is a substantial positive correlation of all the indicators with the Acknowledgment as Guarantor (AG). Naturally, the effect size is greater between the average of the AG and the size-independent indicators and smaller between this measure and the size-dependent indicators. On the other hand, the effect size is greater between the sum of the AG and the size-dependent indicators and much smaller in relation with the size-independent indicators. The distribution of the institutions in terms of the averaged AG can be well described as a combination of linear regression for the lowest ranks and a power law for the highest, as they also are for most of the other size-independent indicators analysed. In contrast, a combination of two power laws fits better the distribution of institutions according to their summed AG, as well as most of the rest of the size-dependent indicators.

The fact that there are positive Pearson and Spearman correlations of all the indicators with the AG (although with the mentioned differences in effect size) shows the high assortativity of these scientific collaboration relationships. Specifically, the high correlation of NI-ORG with AAG shows that the institutions with high normalized impact tend to act as guarantors for institutions also with high normalized impact. Something similar can be said about the correlation of EORG with SAG. I.e., institutions which accumulate a large "excellent output" as RGs also accumulate much Acknowledgment as Guarantor. Logically, this excellent output will include the collaboration of prestigious institutions with high normalized impact, which will lead the RG institution to accumulate Acknowledgment as Guarantor. But since this Acknowledgment as Guarantor occurs beforehand, at the time of completing the work, one can say that to a large extent it anticipates the subsequent acknowledgment of citations.

This high assortativity in scientific collaboration relationships confirms our initial hypothesis. Also, all the results are consistent with the ideas behind the "research guarantor approach", and thus also imply a certain validation of that approach.

Authors contributions

Rodrigo Sánchez-Jiménez—Conceived and designed the analysis; Preformed the analysis; Wrote paper.
Vicente P. Guerrero Bote—Conceived and designed the analysis; Preformed the analysis; Wrote paper.
Félix Moya-Anegón—Conceived and designed the analysis; Preformed the analysis; Wrote paper.

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Appendix A. SAG ranking of institutions (top 50)

R	Institution	Country	Output	ORG	NI-ORG	EORG	%EORG	SAG
1	Centre National de la Recherche Scientif.	FRA	391 104	233 445	1.19	36 495	9.33	241 739
2	Chinese Academy of Sciences	CHN	277 760	185 897	0.95	24 014	8.65	169 122
3	Harvard University	USA	140 662	62 233	2.15	18 861	13.41	95 913
4	National Institutes of Health	USA	88 707	45 301	1.95	12 740	14.36	71 949
5	Helmholtz Gemeinschaft	DEU	121 747	61 640	1.36	10 420	8.56	71 397
6	Stanford University	USA	76 322	43 361	2.24	12 134	15.90	70 713
7	University of Michigan, Ann Arbor	USA	82 359	48 927	1.78	11 721	14.23	68 494
8	Max Planck Gesellschaft	DEU	103 115	49 129	1.80	12 717	12.33	67 953
9	Massachusetts Institute of Technology	USA	62 417	34 825	2.31	9 734	15.60	61 172
10	University of California, Los Angeles	USA	79 993	44 506	1.81	10 860	13.58	60 523
11	Johns Hopkins University	USA	79 747	43 633	1.70	10 358	12.99	60 142
12	Harvard Medical School	USA	88 205	35 329	2.07	10 444	11.84	59 019
13	University of Washington	USA	76 708	40 806	1.84	9 800	12.78	57 464
14	Consejo Superior de Investigaciones Cient.	ESP	89 270	49 095	1.31	9 069	10.16	57 147
15	Tsinghua University	CHN	86 486	64 953	0.87	7 526	8.70	56 133
16	University of California, Berkeley	USA	64 643	35 165	2.22	9 524	14.73	54 236
17	University of Toronto	CAN	85 634	43 572	1.54	8 925	10.42	52 884
18	University of Tokyo	JPN	99 180	55 380	1.06	7 246	7.31	51 097
19	University of Pennsylvania	USA	66 327	36 724	1.76	8 903	13.42	48 907
20	University of California, San Diego	USA	61 403	32 711	1.90	8 341	13.58	48 807
21	University of Illinois at Urbana-Champaign	USA	55 649	34 850	1.72	7 607	13.67	48 283
22	Ministry of Education of the P.R. of China	CHN	96 245	65 245	0.83	7 514	7.81	47 864
23	Russian Academy of Sciences	RUS	188 712	133 447	0.36	3 359	1.78	47 643
24	University of Cambridge	GBR	67 243	37 329	1.75	9 063	13.48	46 699
25	Columbia University	USA	62 135	33 531	1.85	8 286	13.34	45 850
26	University of Wisconsin, Madison	USA	61 645	35 889	1.57	7 836	12.71	44 991
27	Zhejiang University	CHN	78 547	61 601	0.75	6 200	7.89	44 381
28	Georgia Institute of Technology	USA	43 382	29 501	1.73	6 039	13.92	43 707
29	Cornell University	USA	59 611	33 248	1.67	7 472	12.53	42 925
30	Consiglio Nazionale delle Ricerche	ITA	80 309	39 603	1.15	5 859	7.30	42 720
31	Pennsylvania State University	USA	61 302	37 504	1.41	7 048	11.50	42 337
32	University of Minnesota, Twin Cities	USA	59 183	33 406	1.59	7 158	12.09	42 174
33	Imperial College London	GBR	59 485	31 537	1.70	7 512	12.63	41 885
34	Duke University	USA	54 123	30 099	1.78	7 383	13.64	41 830
35	University of Oxford	GBR	65 935	35 244	1.73	8 583	13.02	41 789
36	Swiss Federal Institute of Technology	CHE	47 130	27 170	1.88	6 895	14.63	41 443
37	University College London	GBR	64 831	34 227	1.64	8 219	12.68	41 282
38	National University of Singapore	SGP	52 026	32 274	1.50	7 018	13.49	40 939
39	Veterans Affairs Medical Centers	USA	73 566	30 180	1.48	6 338	8.62	39 245
40	The University of British Columbia	CAN	58 242	32 845	1.46	6 577	11.29	38 882
41	University of Florida	USA	57 974	35 210	1.27	6 204	10.70	38 873
42	University of Texas, Austin	USA	46 484	28 713	1.72	6 040	12.99	38 410
43	University of California, San Francisco	USA	49 386	25 264	1.89	7 014	14.20	38 328
44	University of California, Davis	USA	54 980	31 444	1.46	6 445	11.72	38 198
45	Ohio State University, Columbus	USA	54 463	32 261	1.44	6 337	11.64	37 699
46	Kyoto University	JPN	70 108	41 693	1.05	5 432	7.75	37 495
47	Inst. Nat. de la Sante et de la Rech. Medicale	FRA	71 847	33 351	1.40	6 876	9.57	37 073
48	Mayo Clinic	USA	42 477	28 601	1.57	6 403	15.07	37 045
49	Northwestern University, Evanston	USA	46 600	26 617	1.79	6 808	14.61	36 385
50	Seoul National University	KOR	56 744	35 668	1.08	5 003	8.82	35 755

Appendix B. AAG ranking of institutions (top 50)

R	Institution	Country	Output	ORG	NI-ORG	EORG	%EORG	AAG
1	American Cancer Society	USA	1 131	468	11.34	193	17.06	6.80
2	Yahoo Labs, United States	USA	1 584	790	5.40	250	15.78	4.18
3	Yahoo Labs	MUL	2 139	1 028	5.53	321	15.01	4.07
4	Whitehead Institute for Biomedical Research	USA	1 557	730	5.80	389	24.98	3.55
5	Broad Institute of MIT and Harvard	USA	3 116	548	6.56	320	10.27	3.42
6	Microsoft Research Asia	CHN	3 208	1 028	4.27	345	10.75	2.98
7	Mitsubishi Electric Research Laboratories	USA	1 075	541	4.30	141	13.12	2.95
8	Wellcome Trust Sanger Institute	GBR	3 291	1 039	4.16	393	11.94	2.95
9	Microsoft Research Cambridge	GBR	1 703	746	4.47	260	15.27	2.93
10	Microsoft Corporation	USA	8 114	3 926	3.95	1 199	14.78	2.93
11	European Bioinformatics Institute EMBL	GBR	1 653	709	3.71	263	15.91	2.89
12	Wellcome Trust	GBR	1 198	517	3.53	165	13.77	2.84
13	Google Inc.	USA	2 604	1 078	3.99	286	10.98	2.62
14	Palo Alto Research Center	USA	1 253	711	2.84	181	14.45	2.46
15	Cold Spring Harbor Laboratory	USA	2 122	942	2.97	421	19.84	2.39
16	J. Craig Venter Institute	USA	1 460	437	2.97	173	11.85	2.34
17	Institute for Systems Biology	USA	1 145	422	2.88	174	15.20	2.29
18	Intel Corporation	USA	9 537	4 355	2.65	884	9.27	2.27
19	National Cent. for Biotechnology Information	USA	1 421	767	3.09	302	21.25	2.25
20	Genentech Inc.	USA	3 857	1 835	2.66	632	16.39	2.20
21	Howard Hughes Medical Institute	USA	23 673	8 557	2.90	3 785	15.99	2.18
22	Dana Farber Cancer Institute	USA	12 204	5 255	2.70	2 056	16.85	2.16
23	Hoffmann-La Roche, Inc., United States	USA	6 240	2 550	2.35	795	12.74	2.16
24	Carnegie Mellon University	USA	27 049	16 651	2.40	3 958	14.63	2.14
25	IBM Switzerland Research Laboratory	CHE	1 798	1 075	2.50	311	17.30	2.14
26	IBM United Sates	USA	20 390	11 663	2.46	2 468	12.10	2.14
27	National Library of Medicine	USA	1 974	1 193	2.28	325	16.46	2.14
28	The Rockefeller University	USA	7 266	3 180	2.40	1 213	16.69	2.10
29	Salk Institute for Biological Studies	USA	3 216	1 596	2.33	572	17.79	2.07
30	National Bureau of Economic Research	USA	3 586	890	3.58	389	10.85	2.07
31	Massachusetts Institute of Technology	USA	62 417	34 825	2.31	9 734	15.60	2.06
32	AT&T Labs Research	USA	2 679	1 381	2.35	275	10.27	2.05
33	IBM Research	MUL	27 634	16 481	2.23	3 184	11.52	2.04
34	F. Hoffmann-La Roche	MUL	9 214	3 579	2.13	1 035	11.23	2.04
35	European Molecular Biology Lab. Heidelberg	DEU	2 636	1 140	2.41	403	15.29	2.04
36	Max Planck Institut fur Kohlenforschung	DEU	1 573	910	2.62	416	26.45	2.02
37	Memorial Sloan-Kettering Cancer Center	USA	15 901	9 248	2.27	3 020	18.99	2.02
38	IBM Israel Research Laboratory	ISR	1 123	649	2.27	106	9.44	2.01
39	Natl. Inst. on Alcohol Abuse and Alcoholism	USA	1 997	871	2.72	366	18.33	2.01
40	Harvard-MIT Div. of Health Sci. and Tec.	USA	2 371	541	2.21	171	7.21	2.01
41	Brigham and Women's Hospital	USA	33 412	14 982	2.25	4 573	13.69	1.99
42	Harvard Pilgrim Health Care	USA	1 005	399	2.38	149	14.83	1.98
43	World Health Organization Switzerland	CHE	5 296	1 919	2.79	608	11.48	1.98
44	Stanford University	USA	76 322	43 361	2.24	12 134	15.90	1.96
45	Institut Catala d'Investigacio Quimica	ESP	1 002	506	2.53	226	22.55	1.96
46	Fraunhofer Institut fur Nachrichtentechnik Heinrich Hertz Institut	DEU	1 814	1 160	2.95	162	8.93	1.96
47	University of California, Berkeley	USA	64 643	35 165	2.22	9 524	14.73	1.96
48	Joslin Diabetes Center	USA	1 574	836	2.25	275	17.47	1.96
49	Massachusetts General Hospital	USA	37 482	19 088	2.08	5 530	14.75	1.95
50	Harvard Medical School	USA	88 205	35 329	2.07	10 444	11.84	1.94

Appendix C. SAG ranking of LIS institutions (top 50)

R	Institution	Country	Output	ORG	NI-ORG	EORG	%EORG	SAG
1	Catholic University of Leuven	BEL	210	131	3,18	51	24,29	328,33
2	Indiana University-Bloomington	USA	296	227	2,25	62	20,95	262,31
3	University of Wolverhampton	GBR	129	95	3,74	41	31,78	234,77
4	Pennsylvania State University	USA	308	249	1,89	46	14,94	221,04
5	Leiden University	NLD	115	89	5,36	43	37,39	213,82
6	Consejo Superior de Investigaciones Científicas	ESP	230	149	1,84	23	10,00	212,42
7	Universidad de Granada	ESP	223	151	1,76	25	11,21	191,60
8	University of Amsterdam	NLD	147	107	4,64	51	34,69	172,89
9	University of Maryland, College Park	USA	215	157	2,16	37	17,21	167,97
10	Swiss Federal Institute of Technology	CHE	68	52	4,14	27	39,71	160,24
11	Nanyang Technological University	SGP	155	133	1,50	24	15,48	154,37
12	University of Illinois at Urbana-Champaign	USA	391	296	1,11	25	6,39	154,16
13	Florida State University, Tallahassee	USA	201	158	1,55	27	13,43	137,30

14	University of North Carolina, Chapel Hill	USA	344	217	1,09	32	9,30	137,04
15	Drexel University	USA	174	128	2,14	28	16,09	131,31
16	University of Michigan, Ann Arbor	USA	194	129	1,90	25	12,89	130,74
17	University of Washington	USA	255	192	1,33	33	12,94	130,22
18	The University of Sheffield	GBR	179	141	1,35	21	11,73	117,27
19	Chinese Academy of Sciences	CHN	145	87	1,39	15	10,34	115,54
20	University of Western Ontario	CAN	160	122	1,86	30	18,75	114,13
21	Loughborough University	GBR	185	147	1,18	18	9,73	112,14
22	Consiglio Nazionale delle Ricerche	ITA	111	79	1,18	9	8,11	104,20
23	University College London	GBR	157	128	1,64	24	15,29	103,47
24	Hasselt University	BEL	91	73	2,31	13	14,29	102,15
25	National Taiwan University	TWN	93	67	1,35	10	10,75	100,94
26	Centre National de la Recherche Scientifique	FRA	225	148	0,87	13	5,78	100,38
27	Wuhan University	CHN	102	69	1,36	6	5,88	96,61
28	Tsinghua University	CHN	84	62	1,68	11	13,10	92,79
29	University of Pittsburgh	USA	217	129	1,98	26	11,98	91,06
30	Rutgers, The State University of New Jersey	USA	285	222	1,21	26	9,12	89,66
31	University of Tennessee, Knoxville	USA	224	179	1,15	14	6,25	87,69
32	Hong Kong Polytechnic University	HKG	83	58	1,62	13	15,66	85,84
33	University of Tampere	FIN	111	92	1,82	22	19,82	82,17
34	University of Arizona	USA	182	127	1,38	20	10,99	81,39
35	The University of Manchester	GBR	90	67	1,62	13	14,44	80,87
36	McGill University	CAN	108	80	1,30	11	10,19	75,32
37	Georgia Institute of Technology	USA	88	58	2,80	6	6,82	73,58
38	National Institutes of Health	USA	107	71	1,28	9	8,41	73,52
39	City University London	GBR	111	86	1,24	10	9,01	72,49
40	University of Alberta	CAN	118	90	1,38	20	16,95	71,35
41	University of New South Wales	AUS	81	57	1,69	8	9,88	70,00
42	Universidad Carlos III de Madrid	ESP	129	96	0,88	7	5,43	68,91
43	Bar-Ilan University	ISR	99	77	2,43	22	22,22	67,16
44	University of California, Los Angeles	USA	184	132	1,43	24	13,04	65,91
45	The University of British Columbia	CAN	101	65	1,95	11	10,89	63,12
46	University of Texas, Austin	USA	188	139	1,04	12	6,38	61,14
47	University of Wisconsin, Milwaukee	USA	171	126	0,86	15	8,77	61,06
48	Cornell University	USA	135	99	1,51	17	12,59	59,99
49	Universidad Politecnica de Valencia	ESP	86	66	1,12	4	4,65	58,68
50	Syracuse University	USA	132	87	1,30	11	8,33	56,11

Appendix D. AAG ranking of LIS institutions (top 50)

R	Institution	Country	Output	ORG	NI-ORG	EORG	%EORG	AAG
1	Leiden University	NLD	115	89	5,36	43	37,39	4,36
2	Swiss Federal Institute of Technology	CHE	68	52	4,14	27	39,71	3,56
3	University of Wolverhampton	GBR	129	95	3,74	41	31,78	3,35
4	Catholic University of Leuven	BEL	210	131	3,18	51	24,29	2,91
5	University of Amsterdam	NLD	147	107	4,64	51	34,69	2,88
6	Georgia Institute of Technology	USA	88	58	2,80	6	6,82	2,45
7	Indiana University-Bloomington	USA	296	227	2,25	62	20,95	1,99
8	Bar-Ilan University	ISR	99	77	2,43	22	22,22	1,98
9	Royal School of Library and Information Science	DNK	77	59	1,59	10	12,99	1,84
10	University of Maryland, College Park	USA	215	157	2,16	37	17,21	1,83
11	University of Copenhagen	DNK	76	57	1,51	11	14,47	1,82
12	University of New South Wales	AUS	81	57	1,69	8	9,88	1,79
13	University of Tampere	FIN	111	92	1,82	22	19,82	1,79
14	Drexel University	USA	174	128	2,14	28	16,09	1,77
15	University of Michigan, Ann Arbor	USA	194	129	1,90	25	12,89	1,77
16	The University of Manchester	GBR	90	67	1,62	13	14,44	1,76
17	Pennsylvania State University	USA	308	249	1,89	46	14,94	1,74
18	National Taiwan University	TWN	93	67	1,35	10	10,75	1,74
19	Northwestern University, Evanston	USA	69	53	1,95	7	10,14	1,72
20	Consiglio Nazionale delle Ricerche	ITA	111	79	1,18	9	8,11	1,71
21	University of California, Berkeley	USA	86	60	1,78	8	9,30	1,71
22	University of Western Ontario	CAN	160	122	1,86	30	18,75	1,70
23	Hasselt University	BEL	91	73	2,31	13	14,29	1,70
24	The University of British Columbia	CAN	101	65	1,95	11	10,89	1,66
25	Hong Kong Polytechnic University	HKG	83	58	1,62	13	15,66	1,65
26	Consejo Superior de Investigaciones Científicas	ESP	230	149	1,84	23	10,00	1,63
27	Tsinghua University	CHN	84	62	1,68	11	13,10	1,63
28	University of Pittsburgh	USA	217	129	1,98	26	11,98	1,63
29	Universidad de Granada	ESP	223	151	1,76	25	11,21	1,53
30	University College London	GBR	157	128	1,64	24	15,29	1,52

31	Wuhan University	CHN	102	69	1,36	6	5,88	1,51
32	Chinese Academy of Sciences	CHN	145	87	1,39	15	10,34	1,50
33	Florida State University, Tallahassee	USA	201	158	1,55	27	13,43	1,49
34	Indiana University-Purdue University Indianapolis	USA	73	57	1,70	9	12,33	1,49
35	Nanyang Technological University	SGP	155	133	1,50	24	15,48	1,47
36	Harvard University	USA	104	83	0,83	9	8,65	1,46
37	University of California, Irvine	USA	90	69	1,58	12	13,33	1,44
38	University of California, Los Angeles	USA	184	132	1,43	24	13,04	1,43
39	Cornell University	USA	135	99	1,51	17	12,59	1,43
40	National Institutes of Health	USA	107	71	1,28	9	8,41	1,41
41	University of Illinois, Chicago	USA	104	78	1,54	15	14,42	1,40
42	University of Alberta	CAN	118	90	1,38	20	16,95	1,40
43	McGill University	CAN	108	80	1,30	11	10,19	1,39
44	Purdue University	USA	93	68	1,27	12	12,90	1,38
45	University of Kentucky	USA	89	70	1,71	17	19,10	1,38
46	University of Washington	USA	255	192	1,33	33	12,94	1,37
47	University of Saskatchewan	CAN	57	51	0,47	1	1,75	1,36
48	University of Nebraska, Lincoln	USA	60	53	1,29	7	11,67	1,35
49	Michigan State University	USA	83	65	1,22	5	6,02	1,33
50	Syracuse University	USA	132	87	1,30	11	8,33	1,30

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