Referencing patterns of individual researchers: do top scientists rely on more extensive information sources?

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Abstract

This study presents an analysis on the use of bibliographic references by individual scientists in three different research areas. The number and type of references that scientists include in their papers are analyzed; the relationship between the number of references and different impact-based indicators is studied from a multivariable perspective; and the referencing patterns of scientists are related to individual factors such as their age and their scientific performance. Our results show inter-area differences in the number, type and age of references. Within each area, the number of references per document increases with journal impact factor and paper length. Top performance scientists use in their papers a higher number of references, which are more recent and more frequently covered by Web of Science. Veteran researchers tend to rely more on older literature and non-Web of Science sources. The longer reference lists of top scientists can be explained by their tendency to publish in high impact factor journals, with stricter reference and reviewing requirements. Long reference lists suggest a broader knowledge on the current literature in a field, which is important to become a top scientist. From the perspective of the "handicap principle theory" the maintained use of a high number of references in one author's oeuvre is a costly behavior that may indicate a serious, comprehensive and solid research capacity, but that only the best researchers can afford. Boosting papers' citations by an artificial rise of the number of references does not seem a feasible strategy.

Introduction

Bibliometric indicators describe properties of the scientific communication process through the use of mathematical and statistical analyses. They are frequently used to support research assessment at the macro, meso and micro levels (see for example Braun et al, 1995; Vinkler, 2006; Costas & Bordons, 2005), but also to obtain a better understanding of the behavior and dynamics followed by researchers when communicating new knowledge (Budd & Magnuson, 2010).

This study focuses on the analysis of the referencing practices of scientists, which may provide interesting information about the communication in their field

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as well as about scientists themselves. Different aspects of the referencing process have been studied in the literature, such as how researchers cite other papers, the median age of their references and the different typologies of cited literature according to the different fields (Clements & Wang, 2003; Amat & Yegros-Yegros, 2009; Larivière et al, 2006); scientists' ways of searching and using bibliographic material (Shanmugam, 2009; Budd & Magnuson, 2010); attitudes and reasons for citing (Oppenheim & Smith, 2001, Clarke & Oppenheim, 2006) and limitations and bad uses of referencing practices (Roth & Cole, 2010; Kidd, 1990). However, there is still an important lack of knowledge about the conceptual relationship between citations and references (Wouters, 1999) as well as about the referencing behavior of researchers at the individual level (Nicolaisen, 2007).

Within the bibliometric scientific community there is also an important debate about the reasons for the frequently observed correlation between the number of references and the number of citations (Alimohammedi & Sjjadi, 2009). The discussion about this relationship goes back in the bibliometric literature. In 1965, Price claimed that "we know little about any relationship between the number of times a paper is cited and the number of bibliographic references it contains" (Price, 1965). In 1983, Stewart reported that articles in Geology and Plate Tectonics were "more likely to be cited if they have more references or more recent references" (Stewart, 1983). Since then several papers have addressed the topic offering different theories and answers. For example, Steele & Stier (2000) suggested that the higher level of references can be related to more interdisciplinary approaches; Uzun (2006) related it to higher degrees of authorship; and Abt (2000) and Abt & Garfield (2002) associated it to the length of the articles among other aspects. According to Moed & Garfield (2004), the reference conventions in a discipline, individual styles, the amount of information contained in the papers, the paper's length or the limits imposed by journals editors may influence the frequency with which researchers cite other literature. Also a possible "network effect" or "reciprocal altruism" according to which by citing others you get cited by them has been suggested –"I cite you, you cite me" (Webster et al, 2009)[2]. More recently it has been even argued that the impact of papers could be "boosted" just by including more references in the bibliographic list of publications (Corbyn, 2010).

From our perspective, another plausible **hypothesis** to explain this phenomenon is that a large reference list could be a characteristic of "top" researchers, since they could have a broader knowledge of the literature in their disciplines and as a result they could document their papers more and better, being able to surpass the most strict peer review processes of the best journals, and therefore gaining more visibility and receiving more citations.

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[2] According to the hypothesis suggested by Webster et al (2009) if an author cites one of your papers "you might be more likely to cite [the papers of this author] in the future, provided it is on a related topic. Thus, the more references an author includes, the greater the likelihood that more authors will in turn cite his or her work."

As suggested by Moed (2005), a reference list in a paper marks the "socio-cognitive location" of that paper. Small (1978) also suggested that cited documents can be seen as "concept symbols"' of the ideas contained in the cited works. Taking these ideas from a more general perspective, it can be assumed that the body of references used by individual authors in their "oeuvres" signal their "socio-cognitive location" or "socio-cognitive environment" as well as the set of "concepts" that they are using for developing their own research. In other words, references used by scientists indicate what their conceptual framework is, what their influences are and what knowledge are they managing about their respective fields of work. From this point of view, longer reference lists in the oeuvres of researchers might suggest a broader knowledge of the field and a firm grounding in the preexisting literature.

In this context, the present paper addresses the study of referencing patterns at the individual level. A recent paper by Frandsen & Nicolaisen (2012) dig the first spit in this line of research focusing on the effects of experience and prestige of researchers on their citing behavior in the field of econometrics and provided some initial results and hypothesis. Their paper concludes with a call for further empirical research and theoretical analyses on the topic, since only two journals in a single specialty were studied. In this paper we adhere to this research line by extensively analyzing different aspects related with the use of information by individual researchers in three different research areas and with a different methodology. Thus, this study represents a step forward in the analysis of the referencing patterns of scientists at the individual level, assuming the perspective that referencing (citing) is a human behaviour that is better analyzed from the point of view of individuals; and with the aim of gaining new insights into the topic.

Objectives

The main objective of this paper is to analyze the use of references in the oeuvres of individual researchers, focusing on the number and type of references that they include in their papers; on how it changes by areas; and whether it could be related to individual factors such as age and research performance.

The main research questions addressed can be summarized as follows:

- Are there inter-area differences in the use of scientific literature (cited references) by scientists?

- Does the use of references vary according to individual factors such as age and research performance? In other words, do "top" researchers use more references in their publications as compared to other scientists? What about more veteran researchers?

- Is there any relationship between the number of references that a scientist uses in his/her papers and other bibliometric indicators (scientific production, impact, collaboration)? If so, what are the most influential factors?

The answers to these questions will provide important insights into the referencing behavior of researchers, useful for policy makers and research managers, but also for library policies, editors of scientific journals and scientists themselves.

Methodology

This study is based on the bibliometric analysis of the scientific publications of 1,064 researchers employed with a permanent position ("civil servants") at the Spanish National Research Council (CSIC) in 2004. These researchers are organized in the institution in three main scientific areas: Biology & Biomedicine (388 scientists), Natural Resources (348) and Materials Science (327). The classification of the researchers in these three main scientific areas corresponds to the disciplinary organizational scheme at the CSIC, in which eight different scientific areas[3] are distinguished with a certain degree of homogeneity in their research profiles and scientists' behaviors.

For each researcher, the scientific production published in journals covered by the *Web of Science* (WoS) during the period 1994-2004 was downloaded and correctly assigned to their authors (several methodologies for the proper matching of authors and documents were considered - Costas & Bordons, 2006). Documents published from Spanish centers, but also from abroad during the stay of scientists in foreign countries were considered to build the bibliometric profile of each person.

Indicators based on research performance

The bibliometric profile of every scientist comprises the number of publications, citation related indicators (citations per publication, number of citations, % highly cited papers, h-index), journal impact factor based indicators (median of impact factor and normalized journal position) and relative measures of impact. A detailed description of these indicators is provided in Appendix I.

To assess whether there is a relationship between research performance and use of references, scientists were classified following a classificatory methodology (described in Costas et al, 2010) for the analysis and research evaluation of individual scientists. Based on this methodology, scientists are grouped in three classes: top, medium and low; according to their "balanced" performance across three bibliometric dimensions (Production, Observed Impact

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[3] Agriculture; Biology & Biomedicine; Chemistry; Food, Science & Technology; Materials Science; Natural Resources; Physics; and Social Sciences & Humanities.

and Journal Quality)[4]. Top researchers are those with a high performance in at least two of the three dimensions; medium class present an intermediate performance in two of the three dimensions and low class researchers have a low performance in at least two of the three dimensions described (cfr. Costas et al, 2010).

Indicators based on the cited references

For each scientist, a set of indicators based on the number of cited references included in their documents was obtained. Indicators based on cited references were calculated with a window of 11 years. This window is set considering the year of publication of the source papers and goes 11 years backwards in the cited references[5]. Thus for papers published in 1994 only cited references between 1994-1984 are considered, 1995-1985 for papers in 1995, 1996-1986 for papers in 1996 and so on. With this reference window possible biases due to differences in the age of researchers and/or in the years of publication of documents are minimized. In any case it is also important to mention that almost all researchers under analysis (91%) had publications already in the years 1994-1995, so we can assume a quite homogenous population in terms of publication age during the whole period of analysis (1994-2004).

- *References per document*: mean number of references included in the source documents of each researcher. It is calculated as total number of references divided by total number of publications.
- *References per article*: mean number of references per WoS document type *article*.
- *External references per document*: mean number of references to documents that do not belong to any of the co-authors of the source documents (in this indicator only references to 1994-2004 WoS documents were considered since only in these cases they could be identified with no error).
- *Total distinct references*: total number of unique references cited by every researcher.
- *Distinct references per document*: for each scientist the number of total unique references is divided by the number of publications.
- *Average publication year of the cited references*: this is the mean value of the publication year of the cited references.
- *Percentage of references to non-WoS literature*: this is the percentage of references to documents not included as source documents in WoS (i.e. books, non-WoS journals, reports, theses, etc.).

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[4] In the mentioned methodology, the nine variables described in Appendix I are grouped in three dimensions by means of factor analysis. The Production dimension includes number of publications, number of citations and the h-index. The Observed Impact dimension comprises CPP, %HCP and CPP/FCSm. Finally, the Journal Quality dimension groups IFmed, NJP and JCSm/FCSm.

[5] The percentage of cited references within the last eleven years per area is as follows: 80% in Biology & Biomedicine, 66% in Materials Science and 59% in Natural Resources.

Indicators based on paper length and coauthorship

In previous studies, the number of references per publication has been also linked to the degree of authorship (Uzun, 2006) and to the length of the articles (Abt, 2000; Abt & Garfield, 2002). In this study the mean number of authors per document at individual level (*Authors/document*), and the mean number of pages per document of individuals (*Pages/document*) have been also included in some analyses. This last indicator (*Pages/document*) has been considered only as a "proxy" of the paper length, as the raw number of pages per document can vary depending on the page format of every journal[6].

Review papers indicator

One additional indicator is the *Total number of review papers*[7] per researcher, assuming that this document type tends to reflect the state of the art in a particular field and that the presence of review papers in the profile of a researcher can be an indication of his/her expertise and esteem among their peers (Lewison, 2009), as well as evidence that the author has achieved a noteworthy level of recognition from her/his scientific papers (Ketchman & Crawford, 2007) as a knowledgeable scientist (Weed, 1997). In a way, authors of review papers can be considered also as "trend setters" with respect to future research (Sagar et al, 2009) as they provide not only a comprehensive literature perspective but also establish some (new) order among the facts.

Scientists by age

Finally, researchers were also classified in three groups of age (considering their age in 2004):

- *Young*: researchers with ages between 32 and 43 years old.
- *Senior*: researchers between 44 and 56 years old.
- *Veteran*: researchers with ages between 57 and 69 years old.

Age-group limits are determined by the percentile values in the distribution of scientists by age (P25 = 44 years old and P75 = 56 years old). We would like to remark that the "young", "senior" and "veteran" labels should be understood in relative terms. In this sense, one could argue that a 40-year scientist is not very young, but from the point of view of this study he/she is young, as belonging to the youngest cohort in the population under study. The purpose of categorizing

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[6] The number of words per paper could be a more accurate measure of paper length (as for example in Frandsen & Nicolaisen, 2011). Unfortunately, since we had not access to the full text of all the publications we relied on the number of pages as a "proxy" measure of the paper length.
[7] In the total set of publications 3% of the publications are review papers. This percentage varies per area as follows: Biology & Biomedicine 6%, Materials Science 1%, and Natural Resources 2%.

age in a three-class category was to remark differences along three distinct stages in the life of scientists.

Results

The researchers of the three areas account for a total of 24,982 publications: 9,660 in Materials Science, 9,318 in Biology & Biomedicine and 6,102 in Natural Resources; receiving 80,546, 189,699 and 56,940 total citations respectively (in this case, including self-citations). For additional results about this set of scientists we refer to Costas et al (2009, 2010).

1. Inter-area differences in reference based indicators

As shown in Figure 1, there are clear inter-area differences in the rate of references per document, percentage of references to non-WoS literature and average year of references.

Figure 1. Inter-area differences in the reference based indicators

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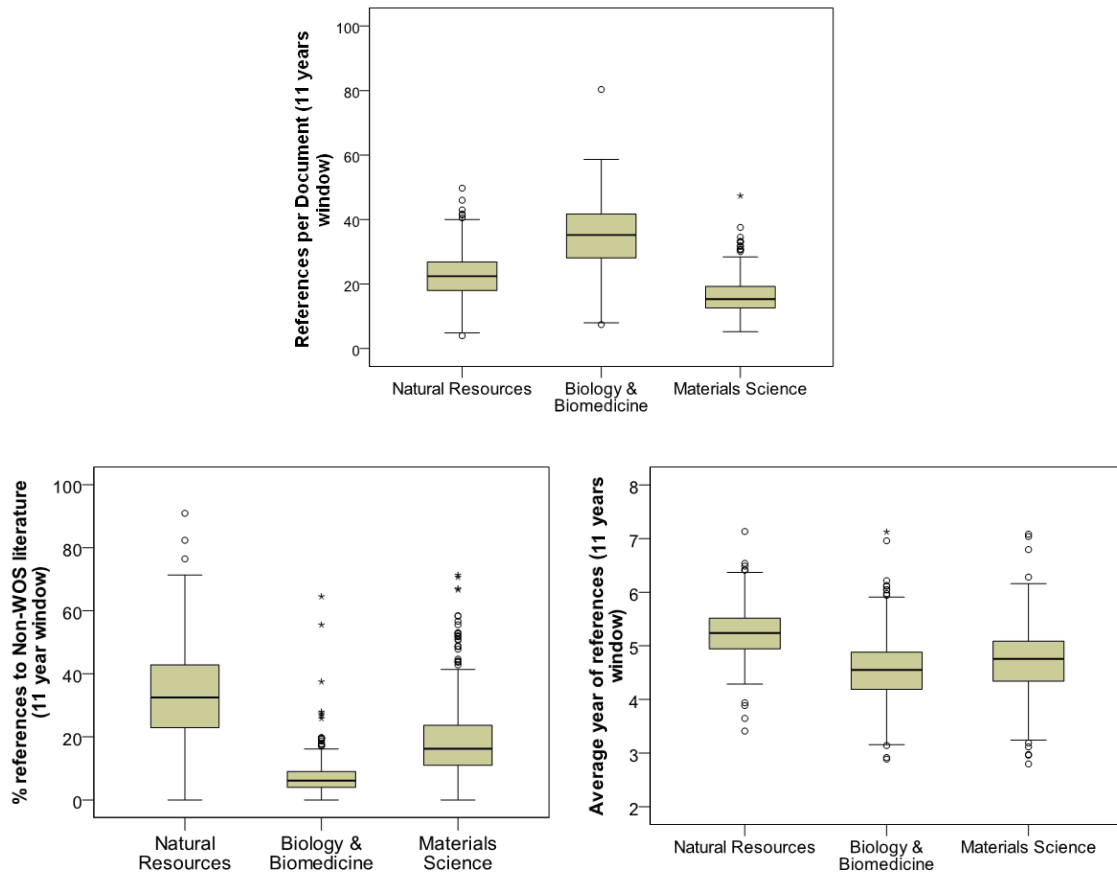
Biology & Biomedicine is the area where researchers use on average more references per document as compared to the other two, followed by Natural Resources and Materials Science. Statistically significant differences have been found among the researchers of the three areas (Mann-Whitney U test, $p < 0.05$).

The references used in Biology & Biomedicine tend to be more recent and are more frequently covered by WoS than in the rest of the areas. On the other side of the spectrum is located Natural Resources, where the highest percentage of non-WoS literature is observed and the references used are older on average than in the other two areas (differences statistically significant -$p<0.05$- in all the cases).

These data show that the literature used by scientists is area-dependent and therefore the first element that determines the referencing behavior of a researcher comes from the area where she/he is working. Accordingly, the stress on the following sections is put on differences among classes of scientists within each area, rather than on inter-area comparisons.

2. Do "top" researchers use more references in their publications as compared to the other scientific performance classes?

As seen in the previous part of the analysis, the number of references per document of individual researchers is clearly area-dependent. Within each area, we hypothesize that top scientists may have a better knowledge of their research topics than the rest of scientists; therefore we expect to find a higher number of references in their papers. In order to verify this issue, Figure 2 presents the distributions of the rates of references per publication considering different elements of the scientific output of researchers.

Figure 2. Reference based indicators by scientific performance class and area
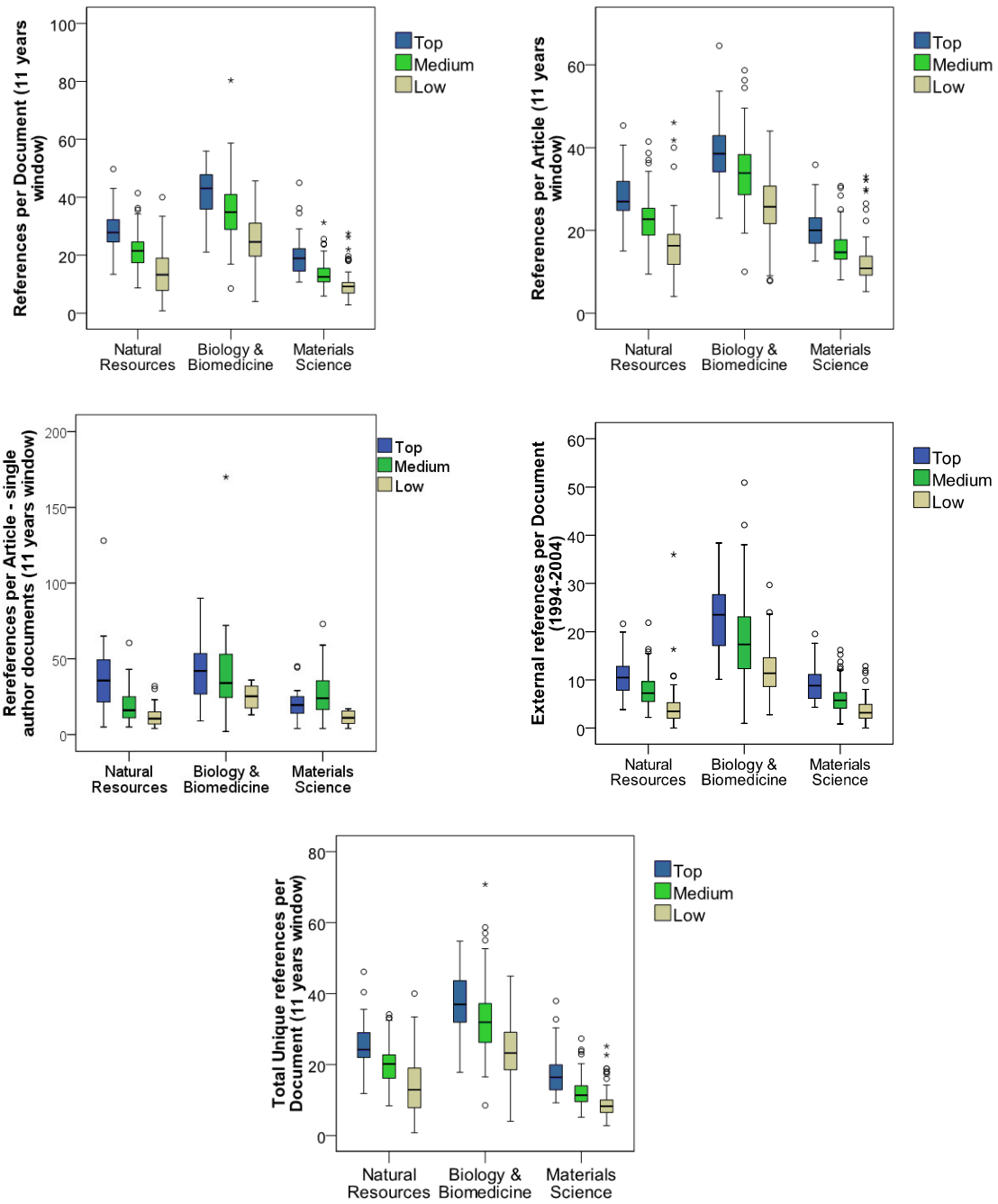
As expected, we observe in Figure 2 (top left graph) that top researchers present overall more references per document than the other two scientific performance

classes in the three areas, these differences are statistically significant in all cases (Mann-Whithney U, p<0.000)[8].

The same analysis was performed including only the document type "article" (graph on the top right of Figure 2) in order to avoid possible bias due to specific document types such as "reviews" that will be studied later. Again, top researchers present the highest number of references per article (p<0.000), thus proving that top researchers consistently use more references in their regular articles than medium and low class scientists.

In order to control for possible influences produced by the collaboration of researchers (e.g. researchers with a high degree of collaboration might cite more references in their papers as some of them are included by their co-authors), an analysis based only on single authored articles was performed (middle left graph in Figure 2) (a similar approach was followed also by Frandsen & Nicolaisen, 2012). In this analysis of the single-authored articles it can be fairly assumed that the researchers only use the references and literature that they know by themselves. We can see that top researchers tend to present more references per article in two areas, although the differences are statistically significant only in Natural Resources (p<0.05). In addition, low class researchers present the lowest levels of cited references per article in all cases. The limitation of this approach is that single-authored articles are quite scarce in current scientific publication (Ma & Guan, 2005; van Leeuwen, 2009), especially in experimental sciences. As a consequence, the number of researchers involved in the analysis is lower (only 20% of the total in this study) and more than half of them present only one single-authored article, which means that in many cases we are relying on a single paper to know how the referencing behavior of an author is like.

To avoid the potential influence of "self-citing" practices, the number of external references used by the authors is shown (middle right graph in Figure 2). Again it can be clearly seen how top researchers present the highest level of external references in their publications (p<0.05).

Finally, the total number of unique references used by each researcher was obtained and normalized by the total number of publications per person (bottom graph in Figure 2). The distribution of distinct references per paper shows again that top researchers present the highest rate (p<0.000 in all the cases), thus indicating that top researchers use a broader range of literature in their oeuvres as compared to the other classes of scientists.

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[8] All the analyses included in Figure 2 were also performed considering the total number of cited references (i.e. without any reference window or document type restriction) and basically the same results as with the 11-year window were obtained (data not shown).

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3. Does the number of references per document vary according to the age of scientists?

We hypothesize that the age of scientists may be also an influencing factor on the number of references, since initially the longer experience and professional career of veteran scientists might result in a wider knowledge of their research field.

Figure 3. Number of references per document by age and scientific area
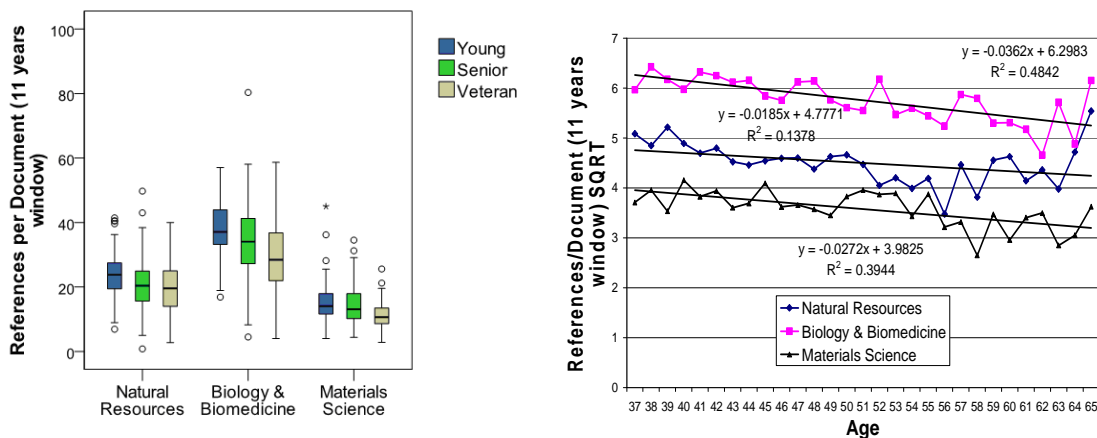

Contrary to the initial expectations, younger researchers tend to present more references per document as compared to their older counterparts (Figure 3) (left-hand side figure, $p<0.05$ in Natural Resources and Biology & Biomedicine). The decreasing trend in the average number of references per document as scientists get older is also observed in the right hand graph in Figure 3, where age is maintained as an independent quantitative variable.

Following the scheme presented in Figure 2, the analysis of reference-based indicators by age class and area was performed (data not shown). In general terms, younger researchers presented more references per article, more external references and more unique references per document than veteran researchers ($p <0.05$ in nearly all cases). The only exception to this pattern was observed in the distribution of references of single-authored publications, where no significant differences by groups of age were observed.

4. Does the use of WoS-covered material vary by age or scientific performance class of researchers?

The percentage of references to non-WoS literature (i.e. references to books, non-WoS journals, PhD theses, scientific reports, etc.) is analyzed in relation to the age and scientific performance class of researchers in Figure 4. In this figure a clear pattern is found: top and younger researchers present the lowest percentages of references to non-WoS literature, while the contrary pattern is found for low-class and older researchers in the three areas analyzed ($p<0.05$).

Figure 4. Distribution of the percentage of references to non-WoS literature
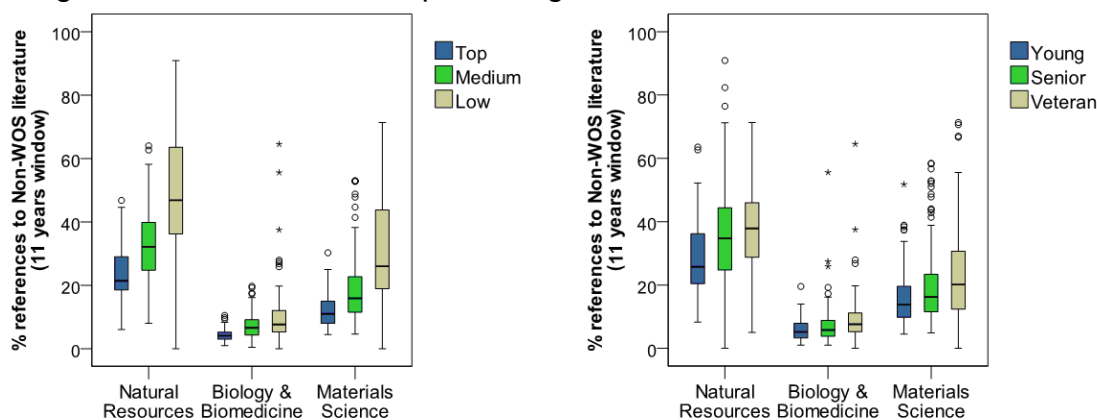
5. Does the age of the references vary by age or scientific performance class of researchers?

Assuming that top researchers do probably work at the forefront of science, we would expect to find that they support their research on very recent literature in their fields. To explore this issue, the average of the ordinal age (within the 11 years reference window) of the cited references of the papers of every researcher has been computed and the distribution of this variable for the different areas is presented in Figure 5.

Figure 5. Average age of references by age and scientific performance class of researchers
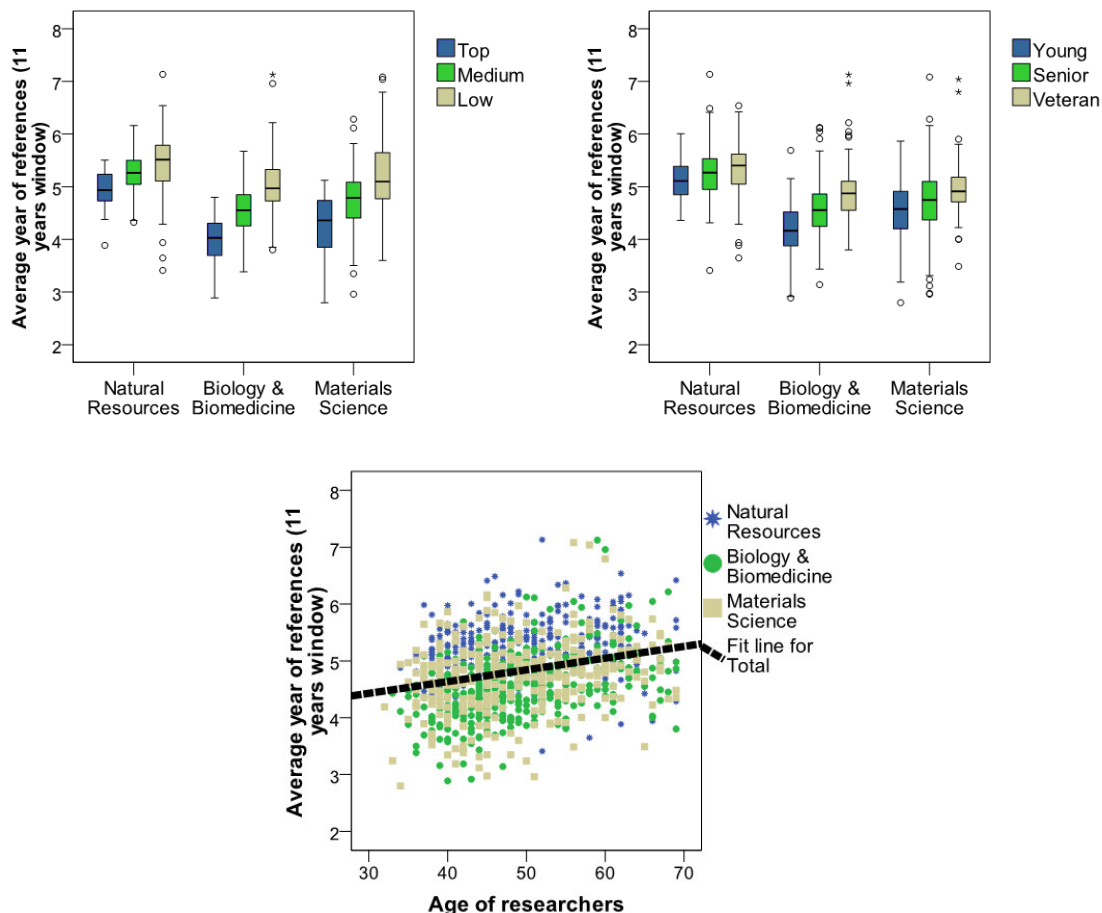
Focusing on scientific performance classes and age groups (top graphs in Figure 5) we can observe how low class (left graph) and older researchers (right graph) use older literature as compared to top class and younger researchers (statistical significant differences have been found in almost all cases, p<0.05). This is also supported by the graph on the bottom where a slight positive correlation between the age of researchers and the age of their references is detected.

6. Do researchers who write reviews also include more references in their regular articles?

Writing review papers is usually considered a sign of prestige and esteem of scientists to the extent that authorship of review papers is positively assessed in the evaluation of researchers (Lewison, 2009). Assuming that scientists who write review papers have a comprehensive knowledge of their research field and sometimes even beyond the regions of one's own expertise (Ketcham &

Crawford, 2007), we wonder whether these researchers have also a higher number of references per paper in their regular articles (Figure 6).

Figure 6. Number of references per article for researchers with and without review papers
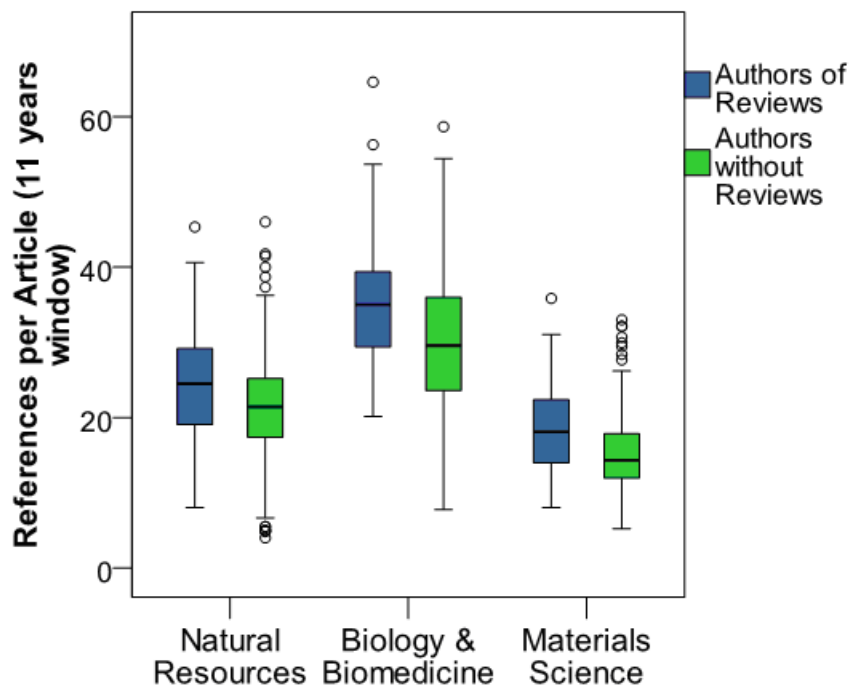
The latter hypothesis is confirmed in Figure 6. Researchers who write review papers tend to present also a broader use of references in their normal articles ($p<0.05$), this outcome supports the hypothesis on the usefulness of the number of references as a measure of the knowledge of an author in his/her field(s).

Moreover, our data support the importance of review papers in the academic profile of scientists, since top class researchers present proportionally more review papers than researchers in the other two scientific performance classes in the three areas analysed. In general, it can be stated that at least 50% of top researchers have published one or more review papers, while lower reviewing activity is found in the other classes (Table 1).

Table 1. Crosstab analysis of researchers with and without reviews by scientific performance class

	Scientific Performance Class			Total
	Top	Medium	Low	
Natural Resources				
Authors of reviews	39 (59.1%)	38 (19.9%)	15 (16.3%)	92 (26.4%)
Authors without reviews	27 (40.9%)	153 (80.1%)	77 (83.7%)	257 (73.6%)
Total	66 (100%)	191 (100%)	92 (100%)	349 (100%)
Biology & Biomedicine				
Authors of reviews	53 (75.7%)	145 (62.8%)	29 (33.3%)	227 (58.5%)
Authors without reviews	17 (24.3%)	86 (37.2%)	58 (66.7%)	161 (41.5%)
Total	70 (100%)	231 (100%)	87 (100%)	388 (100%)
Materials Science				
Authors of reviews	35 (50.0%)	38 (21.8%)	10 (12.0%)	83 (25.4%)
Authors without reviews	35 (50.0%)	136 (78.2%)	73 (88.0%)	244 (74.6%)
Total	70 (100%)	174 (100%)	83 (100%)	327 (100%)

Note: percentages in columns. Pearson Chi-square p<0.000 in the three areas.

On the other hand a somewhat surprising result is observed as the researchers who publish review papers tend to be relatively younger than those without reviews (Figure 7) (statistically significant differences in Natural Resources and Biology & Biomedicine, p<0.05). Therefore, it seems that is not necessary to be a veteran scientist to gain the experience and recognition needed to write reviews in a field.

Figure 7. Distribution of the age of researchers with and without reviews
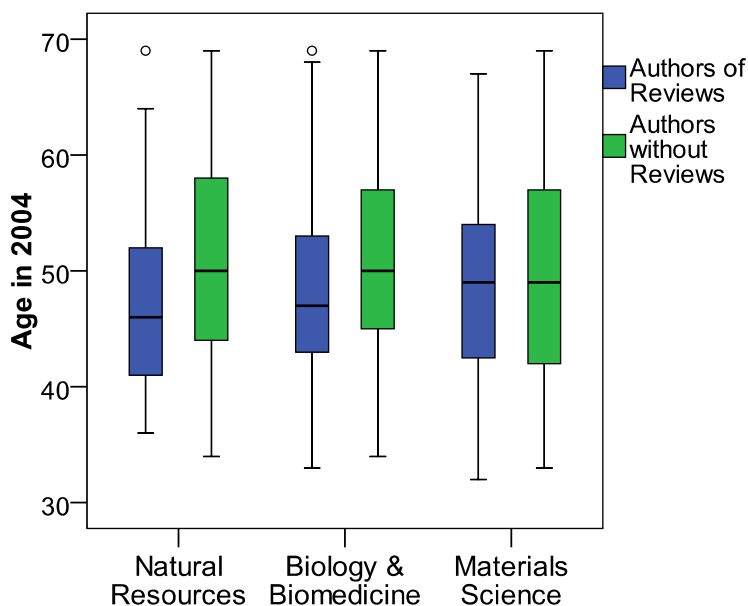
7. Does the number of references per document correlate with other bibliometric indicators at the individual level?

Pearson's correlations of the number of references per document and other bibliometric indicators at the individual level are presented in Appendix II for the three research areas separately. In this correlation matrix we can see how there is a moderate positive correlation (Pearson's generally higher than 0.400) between the rate of references per document and almost all the other bibliometric indicators. The correlation coefficient is below 0.400 only for the number of publications (P), pages/document and authors/document.

In particular, a positive correlation between number of references per document and a) observed impact indicators (C, CPP, CPP/FCSm, etc.); b) journal impact indicators (Median Impact Factor, NJP and JCSm/FCSm); and c) indicators of "citation density" of journals (JCSm) and fields (FCSm) is observed.

- *'Predictors' of the rate of references per document. Model 1*

In order to analyze more in depth the relationship between bibliometric indicators and the rate of references per document of scientists, a linear regression analysis has been performed to obtain a model that could "predict" the rate of references/document ("dependent variable") considering the other bibliometric indicators ("independent variables"). Two different models are shown in Table 2.

In model 1 only indicators related with the impact of journals (i.e. Median Impact Factor, NJP and JCSm/FCSm), the indicators related with the "citation density" of the publication journals of researchers (JCSm) and their fields (FCSm), and the number of pages/document and authors/document have been included[9]. Squared root values were used for all the variables included in the linear regression analysis. The final solution for this model was accepted when the Durbin-Watson statistic was between 1.5 and 2.5. Redundant variables were omitted to avoid multicollinearity. To reject the presence of multicollinearity we examined the values of tolerance, variance inflation factor (VIF) and condition index[10], and only those variables not highly correlated were left in the model.

The best predictors for the rate of references per document of individual researchers are the Median of the Impact Factor, together with the pages per

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[9] The indicators of observed impact (C, CPP, CPP/FCSm) were not included in the model, as we considered that the number of references in a document may contribute to explain its subsequent citation rate, while the inverse relationship has no sense. In a way, the number of citations is not a determining factor of the level of references per document, but a consequence of it.

[10] Durbin-Watson statistics between 1.5 and 2.5 generally indicate that autocorrelation is low enough to draw adequate conclusions from the regression analysis (see for example Milne, 1969). It is usually accepted that tolerance less than 0.10 and VIF greater than 10 suggest multicollinearity. Moderate to strong collinear relations are associated with condition indexes of 30 to 100 (see for example Belsley et al, 1980).

document rate and the number of publications -in Natural Resources and Biology & Biomedicine-. The citation density of the fields of the researchers (FCSm) presents also some influence over the rate of references per document at individual level. The relatively high Adjusted R Squares (0.41, 0.68 and 0.53) suggest that the model is reasonably good in the three areas for the "prediction" of the references per document of individual researchers (Table 2).

According to model 1, it is possible to calculate the "predicted" (or expected) values of references per document for every researcher and calculate the difference between the observed rate of references per document versus the expected rate ("*Dif. O-E*"). Based on this difference it is possible to study which researchers have more references than expected as the "predictions" derived from model 1.

In the light of these observed-expected differences in references, the following question can be raised: do top researchers still tend to include more references than expected according to model 1? Figure 8 presents the Dif. O-E of scientists by research performance class in each of the three areas under analysis. Here, we can observe that top and medium class researchers tend to present more references per document than estimated by the models (statistically significant differences observed among the three classes in Materials Science, $p<0.05$-, and also between Low class and the rest in the other two areas, $p<0.05$).

Figure 8. Distribution of the difference between the observed and the expected reference rate (Dif. O-E) by scientific performance class

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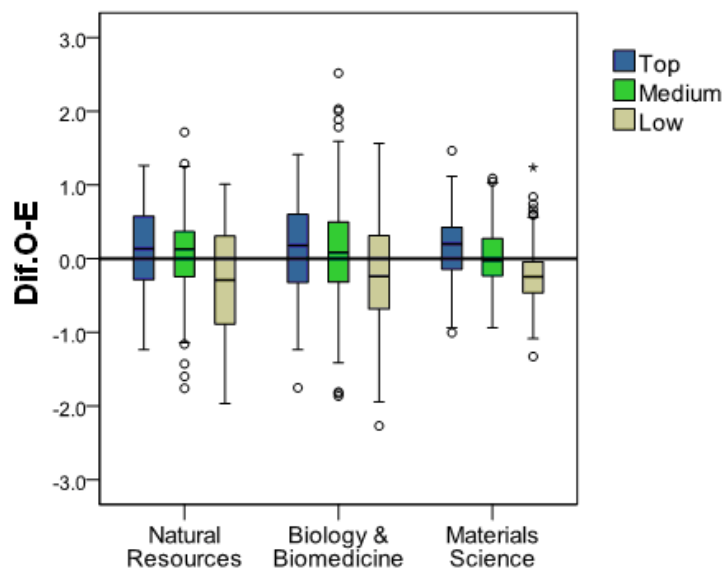
- *'Predictors' of the rate of references per document. Model 2*

Model 2 is obtained including in the regression analysis new variables: age of scientists, experience writing reviews and research performance class (top, medium, low). Concerning the research performance class, several dummy variables are built to indicate whether the scientist is top ("top_dummy": 1=yes; 0=no) or medium ("medium_dummy": 1=yes; 0=no) (with "low" defined as the reference category). The variable "reviews" indicates whether a given scientist has at least 1 review among their papers ("review"=yes). The number of reviews was not used because most of the scientists have no reviews at all. The presence of collinearity was discarded by means of tolerance and VIF (Variance Inflation Factor) tests.

As observed in Table 2, the research performance class and age are significant in the three areas. Medium and top class scientists tend to use a higher number of references than low class scientists, and the greater standardized beta coefficient of top scientists indicate the greater weight of this variable on the final number of references in this class of scientists. As far as the age is concerned, it is negatively correlated with the average number of references per document. It means that older scientists tend to use a lower number of references per document in the three areas.

The variable "review" is significant in Biology & Biomedicine and Materials Science, where the number of references per document tend to be higher for those scientists who have review experience. However, the variable is not significant in Natural Resources, where the effect of reviews is subsumed by effect of other variables such as impact factor, research performance class and paper length.

Table 2. Regression analysis using number of references per document (SQRT) as dependent variable

	Model 1			Model 2		
	Coef.	Standard error	Stand. coeff.	Coef.	Standard error.	Stand. coeff
Biology & Biomedicine						
(Intercept)	0.065	(0.425)		2.210	(0.631)	
IF median (SQRT)	0.803***	(0.091)	0.424	0.450***	(0.106)	0.238
Pages/doc (SQRT)	0.937***	(0.122)	0.306	0.807***	(0.113)	0.263
P (SQRT)	0.083***	(0.021)	0.159	-0.054	(-0.227)	0.220
FCSm (SQRT)	0.248***	(0.078)	0.153	0.174**	(0.073)	0.108
Age				-0.131*	(0.067)	-0.081
medium_dummy				0.507***	(0.101)	0.269
top_dummy				0.607***	(0.144)	0.256
Review				0.516***	(0.081)	0.274
Adjusted R-squared	0.413			0.519		
F score	67.86***			52.240***		
Materials Science						
(Intercept)	-1.610***	(0.334)		-0.374***	(0.413)	
IF median (SQRT)	1.766***	(0.102)	0.710	1.413***	(0.111)	0.568
Pages/doc (SQRT)	0.810***	(0.100)	0.274	.808***	(0.095)	0.273
P (SQRT)	0.028***	(0.011)	0.088	-0.010	(0.011)	-0.033
FCSm (SQRT)	0.357***	(0.088)	0.163	0.314***	(0.085)	0.143
Age				-0.115**	(0.038)	-0.094
medium_dummy				0.295***	(0.066)	0.196
top_dummy				0.493***	(0.095)	0.276
Review				0.222***	(0.055)	0.137
Adjusted R-squared	0.677			0.727		
F score	162.71***			103.56***		
Natural Resources						
(Intercept)	-0.945**	(0.336)		0.806	(0.602)	
IF median (SQRT)	2.044***	(0.171)	0.521	1.179***	(0.202)	0.301
Pages/doc (SQRT)	0.563***	(0.071)	0.310	0.541***	(0.068)	0.298
P (SQRT)	0.115***	(0.021)	0.220	0.024	(0.024)	0.046
FCSm (SQRT)	0.318***	(0.099)	0.138	0.320**	(0.094)	0.139
Age				-0.131*	(0.063)	-0.082
medium_dummy				0.681***	(0.104)	0.369
top_dummy				0.965***	(0.151)	0.426
Review				0.075	(0.084)	0.038
Adjusted R-squared	0.527			0.591		
F score	91.51***			59.644***		

***p<0.001; **p<0.01; *p<0.05
Data expressed as coefficient (standard error)

Some interesting findings emerge from the comparison of model 1 and 2. First, the addition of some variables in model 2 improves slightly the explanatory power of the model (Adjusted R-squared). Secondly, we can observe that impact factor, which is the most influential factor in model 1 (according to the values of the standardized coefficients which allow comparison among variables expressed in different units), is less relevant in model 2. Moreover, the number of publications is significant in model 1, but it drops in the model 2 in the three areas. The underlying reason for these changes is the weight of the new variables introduced in model 2. Top scientists usually have a high number of publications and/or tend to publish in high impact factor journals, to the extent that P is no more needed in model 2. The fact that impact factor is maintained in the second model suggests that even within the class of top scientists there are differences in this value that can be associated to differences in references per document rate.

Discussion and conclusions

In this paper different aspects related with the use of information by individual researchers have been analyzed, assuming that bibliographic references are key elements in the communication of scientific research and new ideas.

In the first place, we would like to make some comments regarding the methodology followed in this study. As mentioned before; Frandsen & Nicolaisen (2012) first explored this line of research, focusing on the effects of experience and prestige of researchers on their citing behaviour in the field of econometrics. It is interesting to note that they analyzed the referencing behavior of authors through the study of their single-authored publications in order to avoid the influence of co-authors on the referencing pattern of the studied authors. The limitation of this approach is that only those scientists who have single-authored publications can be studied, fact that can be very restrictive in the hard sciences, where very few documents are single-authored. In this paper, we have adopted a novel approach by focusing on the total scientific journal publications of researchers during an 11-year period to analyze their referencing practices, since we consider the use of references as a characteristic of the behavior of authors in the production of their "oeuvres", instead of as a property of individual papers. A limitation of our approach is that we cannot completely discard the potential influence of co-authors on the referencing practices of a given researcher, but we focus on the "average behavior" of scientists, which is drawn from the study of their individual bibliometric profiles, instead of relying only on their scarce single-authored publications[11]. In any case, further research on the influence of co-authors on the referencing practices of researchers would be needed in the future.

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[11] In our study only 20% of scientists had single-authored publications and half of them presented only one, which clearly reduces the usefulness of the single-authored publication- based approaches.

On the other hand, while the main bibliometric indicators used by Frandsen & Nicolaisen (2012) include the total number of publications and citations (both size-dependent, see for example Franceschet, 2009; Waltman & van Eck, 2009; Costas et al, 2010); here a broader set of indicators has been used, including also some citation density indicators (citation density of fields and journals) as well as some indicators about the authors (age and performance level of the researchers).

It is also important to bear in mind that both approaches present the limitations coming from the populations studied: a sample of papers from two econometric journals in the Frandsen & Nicolaisen (2012) paper, and the oeuvres of individual researchers in three different research areas in the present paper. Although the three areas here analyzed present quite consistent and similar patterns still some organizational or country influences could play a role, therefore the results here presented would benefit from further research in other populations of researchers.

Inter-areas differences in cited references

From this study it can be concluded that individuals use references mainly as a function of their journals and fields, something that has been previously suggested in the literature (see for example, Moed 2005).

Our study shows that the distribution of the number of references per document of researchers varies per area, with Biology & Biomedicine scholars presenting the longest reference lists, followed by Natural Resources and finally by Materials Science researchers. The shortest reference list of Materials Science is consistent with the claims of Kidd (1990), who observed that engineering fields have less comprehensive bibliographies in their works.

The three areas under study present differences in the use of non-WoS literature as well as in the age of the cited material. Inter-area differences were previously described in the literature. In particular, in the study of Butler & Visser (2006) on Australian universities, the lowest use of WoS sources was observed in Humanities and Social Sciences (less than 10% in some disciplines such as Architecture or Law and close to 30% in the case of Economics) while the best WoS coverage corresponded to Biology, Physics and Chemistry (80-90%). Main inter-field differences were due to the different weight of non-journal sources (i.e. books, book chapters, conference papers) in the dissemination of research.

In our study, Biology & Biomedicine researchers are the ones who rely more heavily on WoS-covered material and also present the strongest focus on more recent literature, which can be linked to the fact that this is a very internationally oriented area. This is in line with the observation of Tenopir et al (2009) that medical/health scholars tend to read more and more recent publications than scholars from other fields.

On the other side of the spectrum are located researchers in Natural Resources, who tend to cite more non-WoS publications as well as older literature than in the other two areas, which is consistent with the results of previous studies in natural resources-related fields (Velho & Krige, 1984; Rey Rocha et al, 1999; Garg et al, 2006), and can be partly explained by the more local orientation of the area in some of its research topics (Costas & Bordons, 2005).

Relationship between cited references and other bibliometric indicators from an individual level perspective

A positive correlation between the number of references per document and both indicators of observed impact (CPP, CPP/FCSm, %HCP, C, etc.) and indicators of journal impact (Median Impact Factor, NJP, JCSm/FCSm) is observed. The relationship between references and citations is an issue of great current concern (Alimohammadi & Sajjadi, 2009). A positive correlation between the number of references per article and the number of times it was cited has been observed at the document level (Uzun, 2006; Webster et al, 2009) and at the journal level (Biglu, 2008). Dependence between reference frequency and impact factor was described in different sciences by Abt (2000), who also observed a positive relationship between the number of references and the normalized paper length. This relation was steeper in high-impact factor journals, in which the same increase in paper length produced a higher increase in number of references (higher slope of the regression line). The "stricter" referencing requirements of high impact factor journals can be the underlying reason (Bordons et al, 2002).

Our regression analysis (model 1) shows that the impact factor is the most influential variable, followed by the number of pages per document. The influence of the number of pages should be analyzed with caution because this variable was not normalized according to the number of words/page, which can vary from journal to journal. As a consequence, it only provides some orientative information in this study. In any case, it shows some "predictive" power on the number of references per document of researchers, in a way that longer papers tend to include more references (Abt & Garfield, 2002). One potential explanation for this relationship is that longer papers could have a more comprehensive content and discuss more varied ideas; thus supporting the hypothesis that a larger number of pages and references in the publications of an author can be an indication of the greater amount of ideas, concept symbols or knowledge that he/she is managing and discussing in his/her papers. In this line, it is interesting to mention that both number of references and article length have been identified as strong predictors of impact in the field of psychology (Haslam et al, 2008).

All in all, these findings are in agreement with the claim of Nicolaisen (2007) that the "act of citing" is "embedded within the socio-cultural conventions of collectives". As seen in this study, the journals and the fields where an author is working constitute important determinants on the number of references that

he/she includes in the papers, which somehow establish the "sociocultural convention" of the author as a member of a collective. However, the influence of individual factors is also observed in model 2, where top performance and older age have respectively a positive and negative effect on the number of references per document.

Use of literature and age of researchers

From the individual point of view, younger researchers present a higher number of references per document and tend to rely more on recent literature, while the contrary holds for older researchers. A possible explanation to this issue was provided by Frandsen & Nicolaisen (2012), who suggested that as authors gain experience and become more respected among their peers they might feel less need for supporting all their claims by bibliographic references. In addition, the idea of older scientists being more likely than younger ones to cite older publications was initially mentioned by Zuckerman & Merton (1973) and Barnett & Fink (2008) who suggested two potential explanations for this phenomenon: first, an age bias in the receptivity of scholars to new ideas, with younger scientists being more receptive than older ones to new ideas and publications; and second, the possible accumulated knowledge of scientists who created their base knowledge when they began their professional careers (i.e. when they were younger). Another complementary explanation is that younger researchers are more likely to access their readings from electronic sources (where normally the newer publications are contained) than their older counterparts, who proportionally read more printed sources (Tenopir et al, 2009). The increasingly competitive environment of research may also contribute to explain the described use of references by younger scientists, who are obliged to demonstrate an important competence and excellence in internationally-oriented research topics to obtain a permanent position at the CSIC (Costas et al, 2010). This relationship between the use of more recent literature and the probability of being in the forefront of research has been also suggested by Gingras et al (2008).

It is important to highlight again that our conclusions are limited to the population of scientists that we have studied. Although we distinguish between "young", "senior" and "veteran" scientists, these labels should be understood in relative terms, since the existence of very young scientists (in absolute terms) is limited because all the researchers considered in the study have already a permanent position, which means they have been able to demonstrate a relevant scientific track and to compete for tenure. In this sense, exploring whether younger researchers (e.g. PhDs, recent postdoctoral researchers, etc.) show different patterns in their referencing behavior as compared to other more established colleagues as the ones studied here remains a pending matter to be studied in the future.

Use of literature and scientific performance class

An initial conclusion is that top researchers use in their papers a broader range of scientific literature as compared to other researchers, and also more than expected by their journals and fields. They cite more references per document, they also tend to cite more references in their single-authored publications, use more external references and they also use a wider variety of unique references in their total set of publications. Moreover, top scientists use more recent literature and rely more heavily on WoS-covered material than the rest of the researchers.

A plausible explanation for this pattern is that top researchers have (or display) a broader knowledge of the current literature existing in their respective fields. This explanation can be supported by the fact that they tend to be also more frequently authors of review papers and that the authors of review papers tend to have more references in their regular publications. In this line, Rames Babu & Singh (1998) indicated that it is almost impossible to be a productive scientist without awareness of what others are doing in your area of specialization, and that an acquaintance with recent trends of research in the context of a global situation is inevitable for raising one's own research output.

Besides, top researchers are also younger researchers (cfr. Costas et al, 2010) and it has been confirmed in this study that younger scientists also tend to use more references in their papers as compared to their older colleagues. These results are in line with the findings of Tenopir & King (2000) and Tenopir et al (2009) who observed that in general high achievers and younger researchers read more articles than other scientists, thus suggesting that reading habits and literature acquaintance are key elements in the success of scientific research.

These conclusions have important implications from the perspective of library and information access policies, as they should provide tools and resources in order to facilitate the access to the new knowledge published in the fields of researchers and thus allowing them to be able to keep up high standards of referencing in their scientific work and publications. Although electronic tools have notably improved the accessibility to scientific knowledge in the modern world, the claim for the establishment of adequate information access services (Ramesh Babu & Singh, 1998) is still valid in order to allow researchers to be aware of the most important ongoing literature in their fields

The authorship of review papers as a proxy of the knowledge of the researchers in their fields

Authorship of reviews has been considered in the literature as an indicator contributing to the high esteem or experience in which a scientist is held (Lewison, 2009; Frandsen & Nicolaisen, 2012), since reviews are frequently

commissioned to experts who are supposed to have a specially broad and up-to-date knowledge of the literature in their fields. The fact that review authors present more references than the remaining authors in their non-review publications and that top researchers are among the most prone to write review papers suggest the relevance of the number of references per document in the oeuvres of scientists as an indication of a genuine broader knowledge of the relevant literature in their disciplines.

An interesting finding in this study is that the authors of reviews are not necessarily the more veteran researchers in their areas, something that was also observed by Gingras et al (2008) who suggested that the production of reviews increases until 50, and gradually decreases afterwards. This implies that relatively younger scientists can also be experts in their fields and attain enough esteem to become authors of reviews. As Squires (1989) stated about biomedical review articles, "well-prepared descriptive and evaluative review articles of important topics or questions are always welcome but involve research and preparation efforts that many authors are unwilling to make". In fact, according to Ketcham & Crawford (2007) an editorial invitation to write a review is an important event for a younger or mid-career scientist, as the reviews give opportunity to provide the scientists' unique appraisal of knowledge in his/her area of expertise, while for more senior authors, reviews may or may not have career value. In any case, the study of the determinants of review authorship is an interesting topic which is beyond the objectives of the present paper and deserves a specific and detailed analysis in the future.

Integrating data under the regression model

Our regression model shows that scientists who use a relatively high number of references per document tend to be young, top or medium as far as their research performance concerned, publish relatively long documents in relatively high impact factor journals and work in fields of high citation density. In the areas of Biology & Biomedicine and Materials Science these scientists show some experience in writing reviews, while it is not significant in the case of Natural Resources. In summary, our results indicate that the number of references per document is partly explained by the characteristics of the field (citation density), characteristics of the paper (article length, review paper) and journal prestige (impact factor). Moreover, some personal factors seem to have some explanatory power, such as the age and the research performance of scientists.

Theoretical discussion

A general explanation for the positive correlation between cited references and observed impact at individual level can be suggested: researchers who have a comprehensive referencing behavior (and implicitly also an important knowledge of the literature in their fields) get their papers published in the best journals - as

they surpass the higher standards and more difficult peer review requirements of these journals (Bordons et al, 2002) - and as a result they get a higher degree of visibility and receive more citations. From our point of view, a plausible hypothesis is that those scientists who present longer reference lists in their publications rely on more diverse sources of knowledge for their research and write more comprehensive and strong studies. It can be proposed then that the correlation between cited references and observed impact at individual level is intermediated by the high impact of the journals that these researchers are targeting, which explains in turn the higher impact that they eventually achieve.

Nevertheless, following Corbyn's "boosting" argument (Corbyn, 2010), it could still be argued that some authors could simply include more references in their papers (in a somehow manipulative or "perfunctory" way) in order to get them published in better journals and obtain also more citations. In this regard it must be taken into account that "stacking" masses of references is not sufficient to appear serious and strong (Latour, 1987). Authors need to "modalize" or "qualify" the references[12] to get them adequately attached to the argument of the citing paper (implying also that the citing authors need to "know" at some degree the cited papers). From this perspective, it seems quite unlikely that an author just by "dropping" some more secondary or unrelated references could get a not very relevant paper published in a high impact journal (and becoming highly cited afterwards). And this possibility appears even less likely if the oeuvres of researchers are considered (as done in this study), since the systematic manipulation of the referencing behavior in an oeuvre seems an unfeasible task.

The idea that top researchers present genuinely a higher rate of references in their oeuvres can be framed in the theory of the "handicap principle" or the "theory of costly signaling" (Nicolaisen & Frandsen, 2007; Nicolaisen, 2007). This theory has been recently used in information science (e.g. Small, 2010[13]), where its potential validity for the understanding of the reference behavior of authors has been pointed out (Frandsen & Nicolaisen, 2012).

This principle was described by Zahavi (2003) in the context of sociobiological studies and is of use to explain the evolution of all communication systems. From this perspective, different aspects of social behavior can be explained, such as the relevance of social prestige, which is understood as the respect awarded to an individual who has demonstrated his/her strength and abilities. According to Zahavi "if an individual is of high quality and its quality is not known, the individual may benefit from investing a part of his/her advantage in advertising that quality, by taking on a handicap, in a way that inferior individuals would not

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[12] According to Small (1978) scientists need to "create a link between a concept and a document" and "the work cited cannot be appended without some explicit or implicit context".

[13] In the perception of Henry Small (2010), the "generosity" of citing may also entail differentiation of one's works from the work of others, in order to establish one's own niches by showing that what one presents is original and unique by comparing it with others with similar ideas.

be able to do, because for them, the investment would be too high"[14]. Besides "the selective process by which individuals develop their handicap increases their fitness, rather than decreases it. Only cheaters would decrease their fitness if they were to take on a handicap that does not match their qualities, hence the efficacy of the handicap in discouraging dishonest signaling". In this line of reasoning, Nicolaisen (2007) suggests that references are a sign of confidence and that a stack of references is a "handicap" that only an honest author can afford. Authors who are uncertain of themselves will usually not risk the potential loss of reputation that the discovery of fraudulent citation habits would carry (especially if done systematically in their oeuvres). Accordingly, without proposing that all references are always honest, Nicolaisen suggests that the handicap principle ensures that authors honestly credit their inspirations and sources to a tolerable degree. In other words, in the light of the results presented in this paper, it can be conveyed that the capacity of including more references in the papers is a costly signal primarily preferred by stronger (or top) researchers, who genuinely manage more ideas and knowledge, and as a result of this they are able to publish in higher impact journals, thus obtaining more visibility and citations from their colleagues. In addition, systematic dishonest long reference lists, such as those based in the mere (or random) stacking of references, should be avoided by scientists, as these can be on their own detriment and may make the work of readers, reviewers and journal editors more difficult, and will hardly contribute to the final quality of documents.

Finally, further research on this topic would still be necessary. First, by extending this type of analysis to other sets of researchers (from other research organizations, countries and fields) in order to corroborate and/or discuss some of our results and conclusions here presented. Second, the analysis of other factors and variables that could also have an influence on the type and amount of knowledge managed by researchers (e.g. interdisciplinarity, network effects, working conditions, etc) will be also an important line of development in this area of research. Such analyses would contribute to improve our understanding of the scientific communication and referencing patterns of researchers and how they transfer their knowledge and ideas through their scientific publications.

Acknowledgments

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[14] Note that Zahavi's observations referred initially to animals, although afterwards extended to explain social behaviour of humans.

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Appendix I. Bibliometric indicators used for the analysis of scientists' performance

For each individual researcher, a bibliometric profile comprising several indicators was produced. Some of said indicators are based on the *CWTS[15] standard methodology* (van Raan, 2004).

(a) Total number of publications (**P**) during the period 1994-2004 considering only *articles*, *letters* and *reviews*. Full counting has been used for the calculation of this indicator when multi-authored papers are considered.

(b) Total number of citations (**C**) received by publications (**P**) during the period 1994-2004. Note that the citation window is variable and shorter for the most recent publications (e.g. for publications in 1994, citations from 1994 to 2004 are considered; while for publications in 2004, only citations in 2004 are taken into account).

(c) Citations per Publication (**CPP**). This is the citation-per-document rate for each researcher. This indicator is again slightly different from the original **CPP** by CWTS as it is based on **C**, as defined before (excluding self-citations), divided by **P**.

(d) Percentage of Highly-Cited Papers (***%HCP***). Highly-Cited Papers (HCP) are those publications (only articles and reviews are included here) cited above the 80-percentile in their respective CSIC research areas (Biology & Biomedicine, Materials Science and Natural Resources). In other words, HCP are those papers among the 20% most cited within each of the three CSIC areas.

(e) ***h-index***. A scientist's h-index is the highest number of papers that he/she has published which have each amassed at least the same number of citations (Hirsch, 2005).

(f) Median Impact Factor of publications (***IF med***). Considering all the papers published by each researcher, the median value of the publication journal Impact Factor (as defined by Garfield 1955) distribution is calculated. The median has been preferred to the mean due to the reported 'skewness' of this indicator (Solari & Magri, 2000). The Impact Factor is obtained through the *Journal Citation Reports* (JCR) as published by Thomson Reuters.

(g) Normalized Journal Position (***NJP***). This is a measure of the average position of the publication journals in their scientific categories (Thomson subject categories) according to their impact factor (Bordons & Barrigón, 1992). Unlike the ***IF med***, it allows for inter-field comparisons as it is a field-normalized indicator.

(h) ***CPP/FCSm***. This indicator measures the impact of a research unit (in this case, individual researchers), compared to the world citation average in the fields in which the unit is active (van Raan, 2004). The rate of citations per publication (***CPP***) (self-citations removed) is compared with the ***F***ield ***C***itation ***S***core ***m***ean (***FCSm***) that is the field-based worldwide average impact used as reference – this indicator (***FCSm***) also measures the 'citation density' of the field/s of publication of a given unit. Here again we use the

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[15] CWTS-Center for Science and Technology Studies (Centrum voor Wetenschaps-en Technologie Studies) in Leiden University.

definition of fields based on the classification of scientific journals into categories developed by Thomson Reuters. Although this classification is not perfect, it provides a clear and 'fixed' consistent field definition suitable for automated procedures within any given data-system.

(i) ***JCSm/FCSm***. This indicator measures the impact of the publication journals within their scientific fields. The journal-based worldwide average impact (***J****ournal* ***C****i*tation ***S****core mean –****JCSm****-*, thus this indicator also measure the 'citation density' of the publication journals or a unit) for an individual researcher is compared to the average citation score of the fields (***FCSm****)*.

Note that for the last indicators (***CPP/FCSm***, ***JCSm/FCSm***, ***JCSm*** and ***FCSm***), only *articles*, *letters* and *reviews* (excluding *book reviews*) are considered, and only external citations (citations that are not produced by any of the co-authors of the source document) were taken into account.

Appendix II. Correlation between the number of references per document and other bibliometric indicators

Pearson correlation	Indicators	Refs/Doc	P	C	h-index	CPP	CPP/FCSm	%HCP	JCSm/FCSm	IF Median	NJP	JCSm	FCSm	Pag/Doc	Auth/Doc
Natural Resources	Refs/Doc	1													
	P	.285**	1												
	C+sc	**.517****	.882**	1											
	h-index	**.508****	.887**	.949**	1										
	CPP	**.640****	.288**	.635**	.542**	1									
	CPP/FCSm	**.572****	.320**	.581**	.518**	.871**	1								
	%HCP	**.485****	-.033	.424**	.301**	.846**	.668**	1							
	JCSm/FCSm	**.475****	.317**	.481**	.470**	.544**	.555**	.287**	1						
	IF Median	**.629****	.228**	.473**	.460**	.594**	.439**	.425**	.673**	1					
	NJP	**.577****	.312**	.466**	.495**	.534**	.540**	.332**	.716**	.809**	1				
	JCSm	**.524****	.256**	.518**	.460**	.704**	.436**	.495**	.790**	.725**	.612**	1			
	FCSm	.333**	.051	.270**	.211**	.518**	.076	.469**	.099	.442**	.160**	.664**	1		
	Pag/Doc	.272**	-.199**	-.137*	-.133*	-.004	-.014	.08	.065	-.007	.049	.022	-.031	1	
	Auth/Doc	.276**	.066	.174**	.187**	.198**	.182**	.148*	.220**	.193**	.288**	.209**	.071	.283**	1
Biology & Biomedicine	Refs/Doc	1													
	P	.127*	1												
	C+sc	**.423****	.731**	1											
	h-index	**.431****	.852**	.891**	1										
	CPP	**.528****	.015	.651**	.370**	1									
	CPP/FCSm	**.447****	.058	.628**	.366**	.906**	1								
	%HCP	**.406****	-.242**	.365**	.150**	.795**	.675**	1							
	JCSm/FCSm	**.438****	-.103*	.361**	.196**	.696**	.708**	.613**	1						
	IF Median	**.536****	-.122*	.337**	.223**	.651**	.502**	.645**	.767**	1					
	NJP	**.540****	.107*	.356**	.360**	.505**	.465**	.529**	.609**	.725**	1				
	JCSm	**.519****	-.106*	.401**	.218**	.776**	.555**	.714**	.827**	.856**	.600**	1			
	FCSm	**.432****	-.028	.289**	.184**	.525**	.151**	.485**	.274**	.574**	.369**	.753**	1		
	Pag/Doc	.362**	.013	.028	.058	.067	.027	.140*	.172**	.141**	.122*	.193**	.152**	1	
	Auth/Doc	-0.043	.153**	.144**	.096	.033	.111*	-.09	.044	-.045	-.02	-.05	-.125*	.08	1

Pearson correlation	Indicators	Refs/Doc	P	C	h-index	CPP	CPP/FCSm	%HCP	JCSm/FCSm	IF Median	NJP	JCSm	FCSm	Pag/Doc	Auth/Doc
Materials Science	Refs/Doc	1													
	P	.200**	1												
	C+sc	**.462***	.838**	1											
	h-index	**.512***	.844**	.940**	1										
	CPP	**.592***	.310**	.718**	.641**	1									
	CPP/FCSm	**.433***	.285**	.642**	.568**	.922**	1								
	%HCP	**.628***	.158**	.587**	.610**	.797**	.719**	1							
	JCSm/FCSm	**.588***	.160**	.371**	.417**	.584**	.540**	.519**	1						
	IF Median	**.769***	.212**	.457**	.496**	.590**	.437**	.595**	.764**	1					
	NJP	**.488***	.240**	.345**	.415**	.439**	.374**	.481**	.752**	.764**	1				
	JCSm	**.711***	.228**	.478**	.485**	.684**	.455**	.594**	.800**	.835**	.625**	1			
	FCSm	**.563***	.253**	.420**	.409**	.542**	.241**	.426**	.385**	.605**	.364**	.844**	1		
	Pag/Doc	.084	-.199**	-.238**	-.224**	-.184**	-.150**	-.126*	-.193**	-.195**	-.237**	-.146**	-.034	1	
	Auth/Doc	.334**	.299**	.426**	.384**	.330**	.232**	.310**	.200**	.366**	.196**	.274**	.234**	-.389**	1

Note: SQRT normalization for all the bibliometric indicators; loadings > 0.40 for Refs/Doc are in bold
**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed)