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Is g-index better than h-index? An exploratory study at the individual level

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The ability of g-index and h-index to discriminate between different types of scientists (low producers, big producers, selective scientists and top scientists) is analysed in the area of Natural Resources at the Spanish CSIC (WoS, 1994–2004). Our results show that these indicators clearly differentiate low producers and top scientists, but do not discriminate between selective scientists and big producers. However, g-index is more sensitive than h-index in the assessment of selective scientists, since this type of scientist shows in average a higher g-index/h-index ratio and a better position in g-index rankings than in the h-index ones. Current research suggests that these indexes do not substitute each other but that they are complementary.

Introduction

In the most advanced countries there is a high and increasing interest in how to assess objectively the research performance of research teams and individual scientists. The increasing costs of research and the scarce economic resources available make research assessment essential for policy makers. Although a huge debate exists about which is the best methodology for the assessment of research performance of individual scientists, the use of different quantitative bibliometric indicators to support expert judgment is widely accepted as a good approach to improve objectivity and fairness in

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the evaluative process [MARTIN, 1996; LEWISON & AL., 1999; VAN LEEUWEN & AL., 2003]. Specifically, the combined use of multiple quantitative indicators, instead of relying in just a single indicator, is strongly recommended by different authors (i.e. [VAN RAAN, 2006; GLÄNZEL, 2006]). However, several simplified indexes to characterize the significance of the scientific output of researchers have been suggested recently. The h-index proposed by Jorge Hirsch [HIRSCH, 2005] is one of the most popular ones. This index has been very well accepted by the scientific community [BALL, 2005] and has been calculated for scientists of different fields: biomedicine [BORMANN & DANIEL, 2005], information science [CRONIN & MEHO, 2006; OPPENHEIM, 2007] or business [SAAD, 2006]. Its application for the study of journals [BRAUN & AL., 2006] has also been suggested.

The main strength of the h-index is that it measures quantity and impact by means of a single indicator. It is supposed to perform better than other single-number indicators used to evaluate the scientific output of researchers, such as impact factor, total number of documents, total number of citations, citations per document rate and number of highly cited papers [HIRSCH, 2005]. In addition, the h-index is robust, since it is insensitive to one or several extreme values, such as uncited papers or highly cited papers. However, the feature that has contributed most to the popularization of this indicator is its simple calculation.

Different disadvantages and drawbacks of the h-index have also been suggested [VINKLER, 2007], such as the influence of the length of the scientific career on the h-index, which puts newcomers at a disadvantage [KELLY & JENNIONS, 2006]; the need to take into account the number of co-authors signing the documents [BATISTA & AL., 2006]; the inadequateness of comparing scientists from different scientific fields [HIRSCH, 2005]; its inability to differentiate clearly between active and inactive scientists [SIDIROPOULOS & AL., 2007]; its insensitivity to highly cited papers [EGGHE, 2006], or the fact that other bibliometric dimensions, such as journal quality or international performance – as a reference – are completely ignored in the calculation of the h-index [VAN RAAN, 2006; COSTAS & BORDONS, 2007].

One of the most important limitations of h-index is its size-dependent nature [VAN RAAN, 2006], as well as the fact that researchers with selective publication strategies – those who do not publish a very high number of documents but who do attain a high impact [COLE & COLE, 1967; MOED, 2000; COSTAS & BORDONS, 2005] – can be unfairly assessed through the h-index. In fact, this type of scientist would be in disadvantage as it is more difficult for them to get a high h-index [COSTAS & BORDONS, 2007]. This is because the maximum value of h-index that a scientist can achieve is that of his/her total number of published documents and because highly cited papers or "flag papers" of a scientist are not properly considered in its calculation [EGGHE, 2006; MOED, 2005]. Although highly cited papers are important for the determination of the h-index, once a paper is assigned to the "h-core" category, the number of citations it receives is no longer relevant.

In order to smooth some of the above mentioned limitations, different modifications to the h-index have been suggested [BATISTA & AL., 2006; SIDIROPOULOS & AL., 2007]. One of the most interesting improvements is the "g-index", defined by EGGHE [2006], which shows two main advantages: it takes into account the weight of the citations received by the top articles of a scientist (his/her most frequently cited papers) and the total number of documents does not limit the value of the index, as it is in the case of the h-index.

Egghe defines g-index as "the highest rank such that the top g papers have, together, at least g^2 citations. This also means that the top $g + 1$ have less than $(g + 1)^2$ papers". The g-index is always higher or equal to h-index, as has been also stated by EGGHE [2006].

Objectives

Our main objective is to analyse g-index as compared with h-index and with other more traditional bibliometric indicators in their ability to discriminate among different types of scientists. Moreover, we determine whether the g-index is more sensitive than h-index in the assessment of scientists with a selective publication strategy (scientists with intermediate productivity but a high impact). Our hypothesis is that the g-index might suit selective scientists better, since: a) the latter usually have a high percentage of Highly Cited Papers, which are considered in the calculation of the g-index, and b) the value of the g-index is not limited by the total number of documents.

Methodology

Research performance of 348 researchers working in 2004 in the Natural Resources Area at the CSIC is analysed. Accurate data about the scientific production of these scientists during the period 1994–2004 were obtained from the Web of Science (WoS), including those publications signed by these scientists as a result of a temporary stay in a foreign center.

Bibliometric profile of scientists

The research performance of each scientist has been described through a bibliometric profile composed by the following indicators:

- Total number of documents, considering all types of documents published in the period 1994–2004.

- Total number of citations. The citation window is the period ranging from 1994 until 2004. Self-citations were not excluded.
- Citations per document rate. This is the average number of citations per document for every author.
- Percentage of Highly Cited Papers (HCP>=15 citations). This threshold corresponds to the 20% most cited documents in the area under study.
- Relative Citation Rate (RCR) [SCHUBERT & BRAUN, 1986], that is, citations of documents as compared with their publication journal. An RCR higher than 1 means that the article has been cited more often than the average document in its publication journal. From this measure the indicator Percentage of documents with an RCR above 1 (%RCR>=1) is obtained, which is the percentage of a scientist's production that is cited more often than its publication journal.
- Median Impact Factor, the median of the impact factor of the publication journals of the documents of each scientist. This measure is more accurate than the average value, due to the impact factor's skewed distribution.
- Normalised Journal Position (NJP), calculated according to the position of the publication journal in the ranking of journals, in decreasing order of impact factor, within each discipline [BORDONS & BARRIGON, 1992]. The weighted average NJP for all the publication journals of every author was calculated:

  NPJ = 1 (Position of the publication journal / Total number of journals in the category).

  It ranges from 0 (low expected impact factor) to almost 1 (high expected impact factor).
- h-index, as described by HIRSCH [2005] to quantify scientists' achievements through a single number which takes into account both the number of publications and the number of citations.
- g-index, as described by EGGHE [2006].

The SPSS software (version 12.0.1) was used for the statistical analysis.

g-index and h-index calculation

From a practical point of view, in order to obtain the g-index of a scientist or other unit of analysis, it is necessary to rank by decreasing order of citations all the documents of the unit. The position where the square of the rank position is equal to the accumulated number of citations corresponds to the g-index. If the number of documents is not enough for the g-index calculation, the existence of a few "fictitious" documents with 0 citations is supposed in order to complete the calculation (several examples of its calculations can be examined in EGGHE [2006]). An example of the calculation of h-index and g-index for a hypothetical scientist with 4 documents is shown in Table 1. As it can be seen, this scientist would get an h-index of 4 and a g-index of 6. Two "fictitious" documents with 0 citations are necessary (documents 6 and 7) in order to calculate the g-index properly (documents in italics are "fictitious").

Table 1. Example of calculation of h- and g-index

Rank doc	No. citations	h-index	Rank^2	Sum citations	g-index
1	15		1	15	
2	10		4	25	
3	7		9	32	
4	4	X	16	36	
5	0		25	36	
6	*0*		*36*	*36*	X
7	*0*		*49*	*36*	

Typology of scientists

A classification of scientists in four classes according to the analysis of research performance by means of traditional bibliometric indicators is used. For this classification, only 253 intermediate-high productive scientists were considered. These correspond to the top 75% scientists in production, who had at least 12 publications within the period under analysis (P25=11 documents). Following COLE & COLE [1967, 1973], scientists can be classified in four groups according to their publication strategy; for this study, the original denomination of the dichotomous cross-classification of COLE & COLE [1967] has been slightly modified: a) type I, prolific scientists or "top scientists", who show a large production and a high impact; b) type II, mass producers or "big producers", who publish a high number of documents, but do not attain high impact; c) type III, perfectionists or "selective scientists", who show intermediate-low production but high impact; d) type IV, silent scientists or "low producers", who show low production and impact. Since only scientists with at least 12 documents are considered in our study, the original denominations of Cole & Cole classes have been adapted. Thus, the so-called silent scientists are relatively not so silent in our study, and this is the reason why they have been renamed as "low producers".

To set the thresholds for the different classes the median of the indicators "total number of documents" (P50=26) and "citations per document rate" (P50=8.79) were calculated. According to these values scientists were classified in the four different typologies described above, as shown in Table 2.

Table 2. Criteria for the classification of scientists

Number of documents P50=26		Citations per document rate P50=8.79: High	Citations per document rate P50=8.79: Low
	High	**Type I** "**Top researchers**" No. Documents > 26 & Cit/Doc. Rate > 8.79 No.Total scientists = 72	**Type II** "**Big producers**" No. Documents > 26 & Cit/Doc. Rate <= 8.79 No.Total scientists = 52
	Low	**Type III** "**Selective researchers**" No. Documents <= 26 & Cit/Doc. Rate > 8.79 No.Total scientists = 54	**Type IV** "**Low producers**" No. Documents <= 26 & Cit/Doc. Rate <= 8.79 No.Total scientists = 75

The results of this study are shown as follows. Firstly, the bibliometric profile of scientists in the area is shown. Secondly, the relationship between variables is analysed with especial emphasis on g- and h-index. Thirdly, the four types of scientists are compared considering their research performance by means of traditional indicators and g- and h-indexes. Finally, the hypothesis that the g-index might be fairer with "selective" scientists than the h-index is tested.

Results

A total of 6093 documents were retrieved from the Web of Science (1994–2004) as scientific publications of the scientists in the Natural Resources area of the CSIC.

Research performance of scientists in the area

Main features of research performance of CSIC Natural Resources scientists are shown in Table 3. These data refer to 337 scientists who had at least 1 document in the studied period.

Table 3. Research performance of CSIC Natural Resources scientists

	N	Mean±SD	Median	Range (Min-Max)
Activity				
No. documents	337	25±19.50	22.00	1–162
Expected impact				
IF median	327	1.27±0.53	1.18	0.20–3.69
NPJ	337	0.65±0.14	0.67	0.05–0.96
Observed impact				
No. Citations	337	240.28±280.57	163.00	0–2862
No. citations/document	337	8.45±5.38	7.71	0–41.87
HCP rate	337	0.18±0.16	0.15	0–1
Relative impact				
RCR median	314	0.89±0.56	0.84	0–6.29
%RCR≥1	303	45.14±18.89	44.44	7.14–100
Global indicators				
g-index	332	12.31±6.88	12.00	1–44
h-index	332	7.98±4.51	8.00	1–29

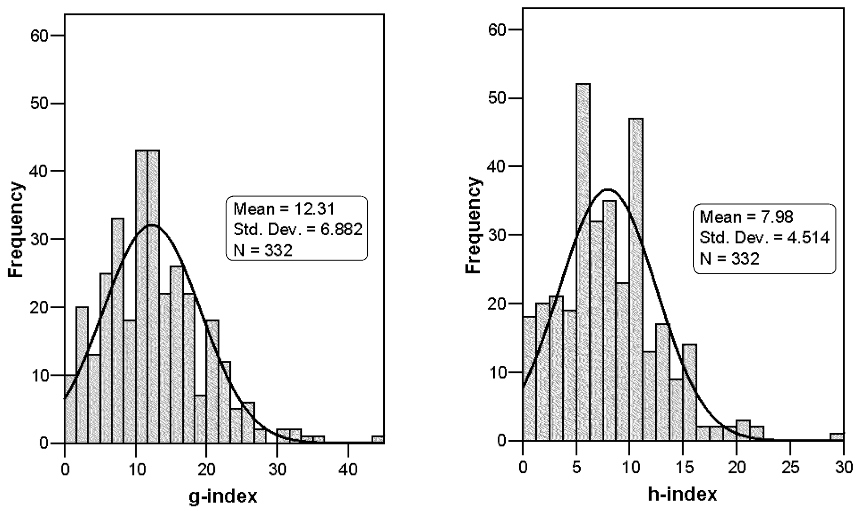

Figure 1. Distribution of authors by g-index and h-index

As it can be seen in Table 3, Natural Resources scientists present a median of 22 documents per scientist, their productivity ranging from 1 to 162 documents. A very skewed distribution of citations per document rate is observed with a number of citations per document varying from 0 to 42. The h-index varies from 1 to 29, while g-index values range from 1 to 44 (Figure 1). It is interesting to remark that g-index is 1.5 times higher than h-index. The distribution of both indexes is somewhat skewed, with a right tail due to the presence of some individuals with very high indexes.

Relationship between variables

The relationship between the indicators shown in Table 3 has been studied through factor analysis. Variables were normalized through the square root. Four factors were obtained which accounted for 94% of the explained variance (Table 4). The contribution of the variables to the different factors is shown in Table 5.

Table 4. Factor analysis. Total variance explained

	Initial eigen values			Rotation sums of squared loadings		
	Total	% Variance	Cumulative %	Total	% Variance	Cumulative %
1	5.988	59.877	59.877	3.560	35.596	35.596
2	1.540	15.400	75.277	2.024	20.236	55.832
3	1.273	12.729	88.006	1.976	19.757	75.589
4	0.544	5.439	93.445	1.786	17.856	93.445
5	0.232	2.320	95.765			
6	0.203	2.035	97.800			
7	0.115	1.147	98.947			
8	0.064	0.637	99.584			
9	0.026	0.260	99.845			
10	0.016	0.155	100.000			

Extraction Method: Principal Component Analysis.

Table 5. Rotated component matrix

	Component			
	1	2	3	4
No. documents	**0.980**	0.067	0.005	0.049
h-index	**0.894**	0.248	0.191	0.261
No. citations	**0.870**	0.229	0.200	0.345
g-index	**0.823**	0.275	0.208	0.428
NJP	0.224	**0.907**	0.110	0.137
IF median	0.170	**0.890**	0.060	0.271
%RCR>=1	0.062	0.080	**0.913**	0.215
Median RCR	0.202	0.086	**0.904**	0.159
HCP rate	0.357	0.241	0.263	**0.829**
No. citations/document	0.338	0.379	0.346	**0.750**

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

It is interesting to see that h- and g-index appear in the first dimension (Table 5), together with the total number of documents and citations, showing that both indexes are size-dependent indicators. However, as we can see in Table 3, this first dimension only explains 36% of the total variance; therefore the remaining dimensions are necessary. These other dimensions provide information on the quality of publication journals (Component 2, 20% of explained variance), the international relative impact of documents (Component 3, 20%) and the relative impact of documents (Component 4, 18%). Interestingly, g-index contributes not only to the first dimension, but also slightly to the fourth, which includes relative indicators of impact in which selective scientists tend to obtain good scores. In summary, the information provided by the ten original variables can be reduced to four dimensions, but not to just a single variable, such as the h- or g-index.

The relationships between h- or g-index and the rest of the variables are graphically shown in Figure 2.

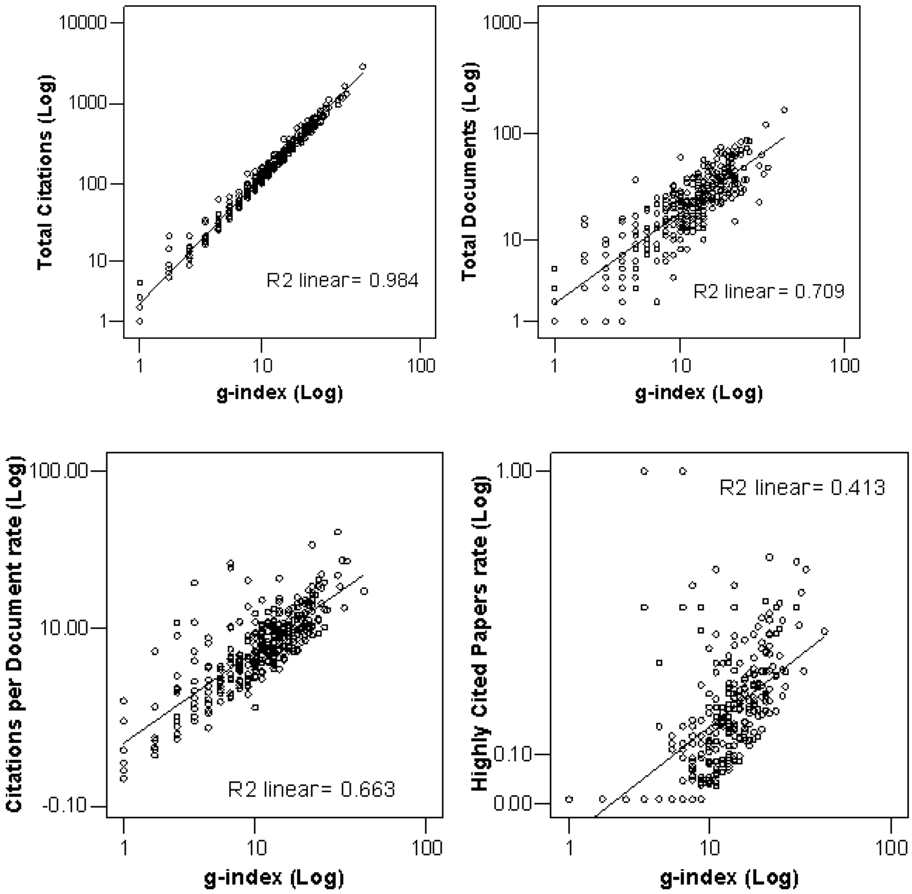

Figure 2a. Correlation between g-index and the rest of bibliometric indicators

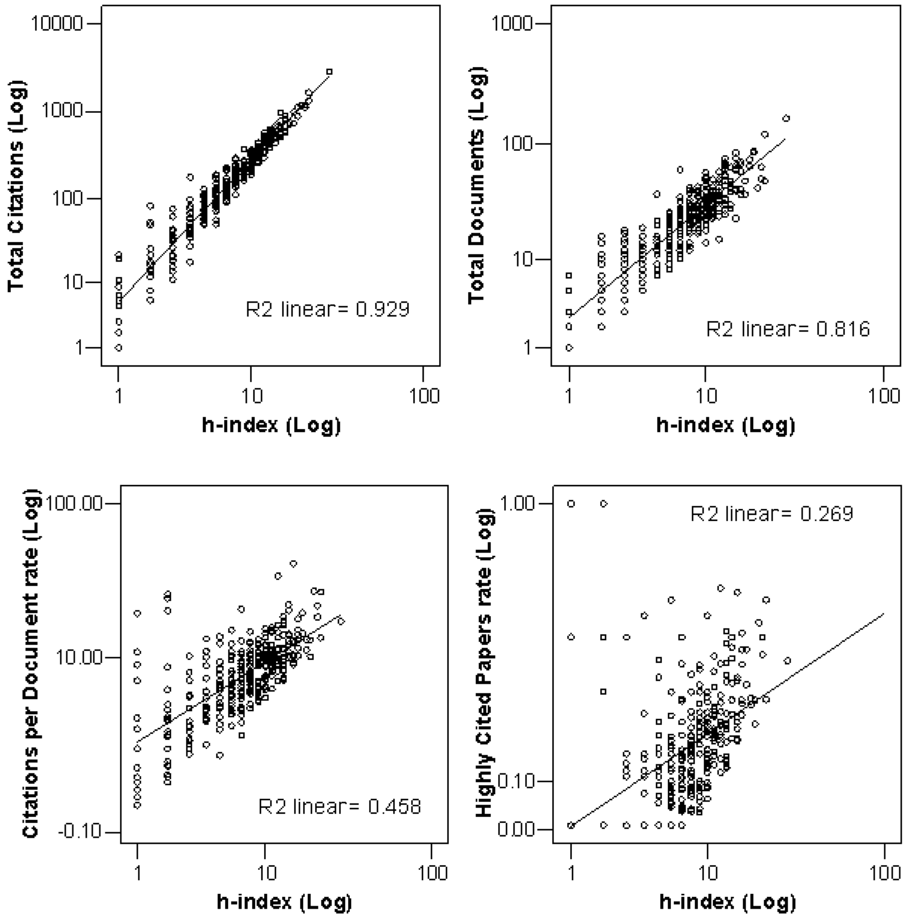

Figure 2b. Correlation between h-index and the rest of bibliometric indicators

Concerning h-index, a strong positive correlation is observed with the number of citations (R^2=0.929); a moderate correlation exists with number of documents (R^2=0.816); a poor correlation with number of citations per document (R^2=0.458), and no correlation at all with HCP. In the case of g-index the correlations follow a similar pattern, although a slightly better correlation between this index and the number of citations per document is found (R^2=0.663).

On the other hand, as it can be expected, a good positive correlation is observed between g-index and h-index (Figure 3). In this Figure both indicators were standardized: all h-index values were divided by the maximum value in the distribution to obtain a new distribution ranging between 0 and 1. The same standardization was applied to the g-index ("S" stands for this standardization).

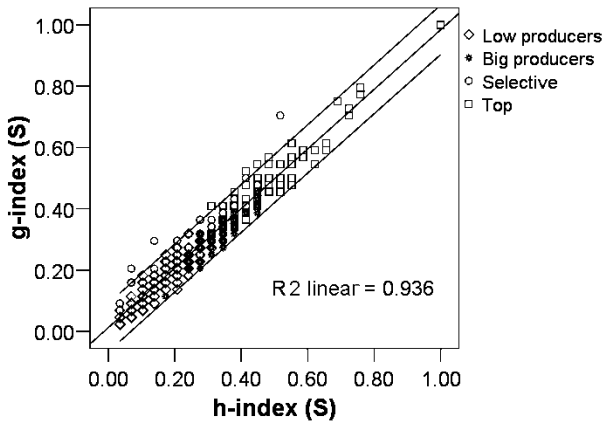

Figure 3. Correlation between g-index and h-index.
Note: (S) stands for standardized values

The four types of scientists described in Table 2 are distinguished in Figure 3, in which top scientists obtain the highest values in both indexes and the low producers appear at the other end of the scale. In-between, big producers and selective scientists are not so clearly separated. Predictive intervals at 95% are shown. As we can see in Figure 3, several scientists – mainly selective and top scientists – lie outside these intervals. Explained variance is 94%. It means that 6% of the cases are not well-explained, besides the ±5% of predictive error. Although these differences between g- and h-index are small, they can be very important for the individual scientists involved. It prevents us from using indistinctly both indicators.

Research performance by type of scientist

The four types of scientists have been compared as to their research performance. As for their absolute number of publications, top and big producers show the highest values, while no differences between low producers and selective scientists are observed (Figure 4a). Concerning total number of citations, top scientists stand out, and there are no differences between big producers and selective scientists (Figure 4b).

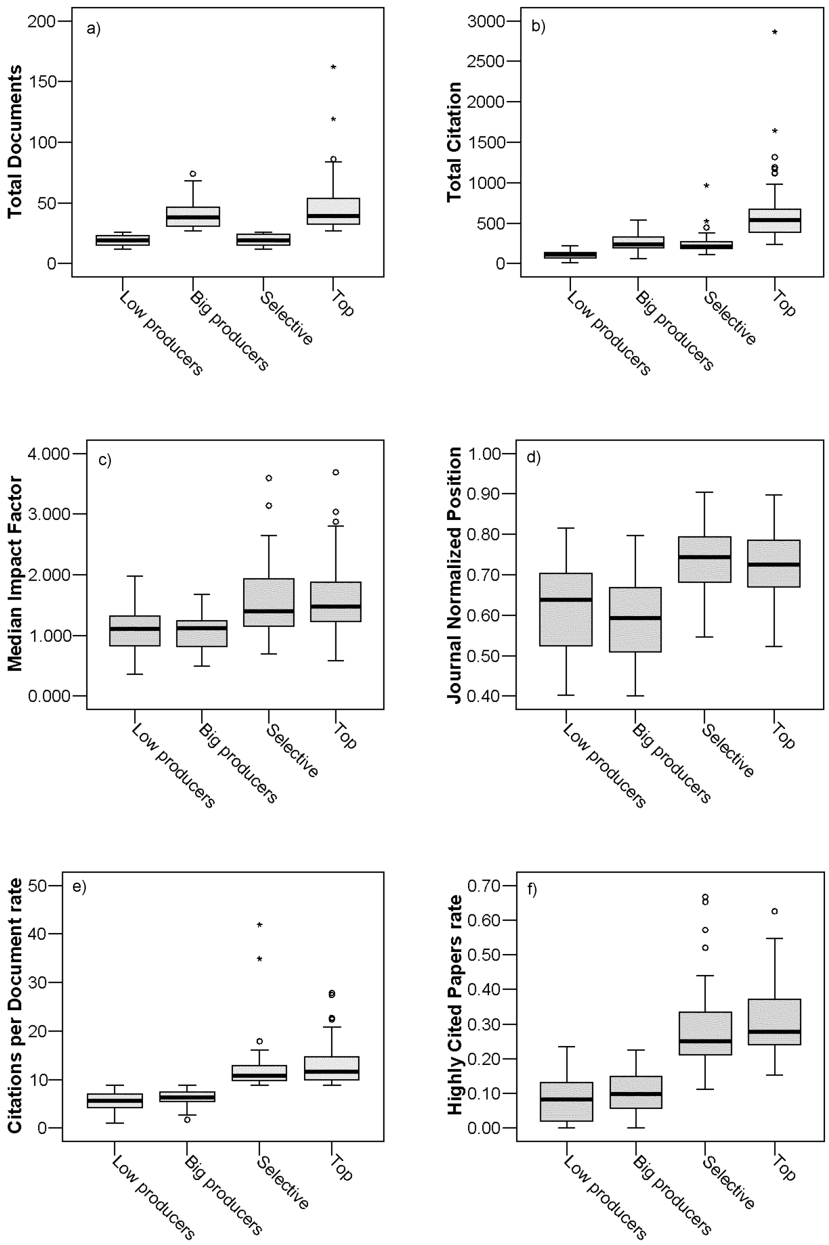

Figure 4a-f. Research performance by type of scientist

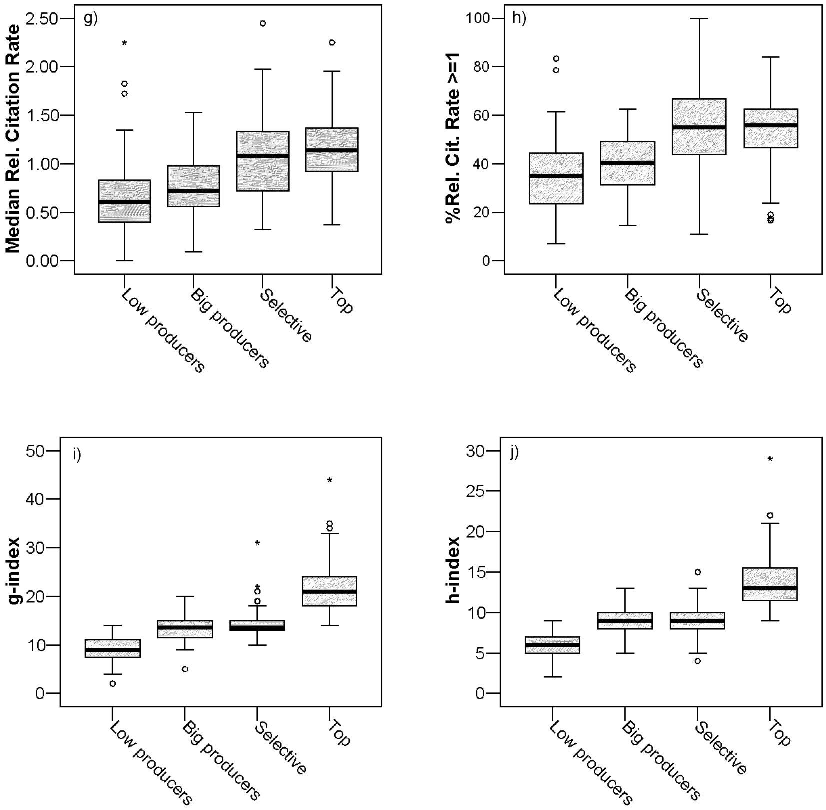

Figure 4g-j. Research performance by type of scientist

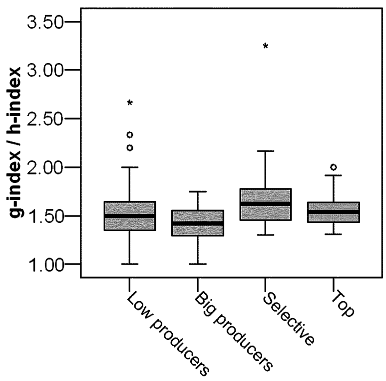

Figure 5. g-index/h-index quotient by type of scientist

A different situation is observed by means of other indicators. As we can see, top scientists and selective scientists obtain the best results in relation to expected impact (Figures 4c and 4d); citations per document and highly cited papers (Figures 4e and 4f), and relative impact (Figures 4g and 4h).

Although selective scientists publish fewer documents than big producers, they frequently obtain the same or even more citations than the latter, and a number of citations per document very similar to that of top researchers. Selective scientists show significantly higher values than low producers and big producers for most impact indicators (Figures 4c–4h) ($p<0.001$), attaining values very close to those of top scientists.

In relation with g- and h-index, in Figures 4i-j we can see that these indexes discriminate very well the group of top scientists, who show the highest indexes, as well as the low producers, who obtain the lowest values. However, no significant differences were found between big producers and selective scientists. Although these two classes of scientists are clearly differentiated by means of several traditional indicators, they are "similar" according to h- and g-index. Detailed values can be analysed in the Appendix 1 and 2.

Is g-index more sensitive to assess selective scientists?

Considering that the g-index was introduced to overcome some of the limitations of h-index, such as taking into account the number of citations received by the most cited documents and reducing the influence of the total number of documents on the final index, we expect g-index to be fairer than h-index with selective scientists. In order to test this hypothesis, two different analyses were conducted.

a) As it has been previously indicated, g-index is around 1.5 times higher than h-index. However, this ratio varies from author to author. If g-index were more sensitive than h-index for the assessment of selective scientists, we would expect a higher g-index/h-index ratio for selective scientists than for the remaining ones. The quotient "g/h", as suggested by EGGHE [2006], was calculated. Values close to 1 indicate no difference at all between the indicators. The higher the quotient, the larger is the difference between h- and g-index.

As it can be seen in Figure 5, the g/h quotient is significantly higher for selective scientists than for the remaining types of scientists, while the lowest quotient corresponds to big producers (significantly lower than that of top and selective scientists, $p<0.000$). So it is clear that selective scientists are the ones who benefit the most from the use of the g-index, which is more sensitive than h-index to detect their good performance. Big producers are especially favoured by h-index whilst selective scientists obtain better scores by means of the g-index.

b) The differences in the position occupied by scientists in the h-index and g-index ranks were analyzed by means of the Wilcoxon signed-rank test. It is interesting to note that no significant differences between g- and h-index (both of them standardized) were found at the global level. However, these results varied when the test was applied separately to the four types of scientists described (Table 6). In fact, no significant differences were found for top scientists and low producers, while there were significant differences for big producers and selective scientists ($p<0.000$). Big producers tend to obtain better positions in the h-index based rankings, while the contrary holds for selective scientists.

Table 6. Wilcoxon signed-rank test. h-index(S) vs g-index(S)

Type of scientists	Negative-positive ranks	N	Mean rank	Sum of ranks	Z	Sig
Low producers	Negative ranks	28(a)	43.00	1204		
	Positive ranks	47(b)	35.02	1646		
	Ties	0(c)				
	Total	75			1.167(d)	0.243
Big producers	Negative ranks	15(a)	20.20	303		
	Positive ranks	37(b)	29.05	1075		
	Ties	0(c)				
	Total	52			–3.516 (d)	0.000
Selective	Negative ranks	35(a)	32.00	1120		
	Positive ranks	19(b)	19.21	365		
	Ties	0(c)				
	Total	54			–3.251(e)	0.001
Top researchers	Negative ranks	39(a)	38.13	1487		
	Positive ranks	32(b)	33.41	1069		
	Ties	1(c)				
	Total	72			–1.198 (e)	0.231

a h-index(S) < g-index(S)
b h-index(S) > g-index(S)
c h-index(S) = g-index(S)
d based on negative ranks
e based on positive ranks
(S) Stands for "Standardized"

To illustrate the fact that g-index is more sensitive than h-index to assess selective scientists, a few cases are shown as an example in Table 7. The research performance of a set of big producers and selective scientists is described by means of several bibliometric indicators. As we can see, selective scientists (B scientists) show a lower h-index than big producers (A scientists) although they show a higher number of citations per document and higher highly cited papers rate (HCP). However, these selective scientists get higher g-indexes than big producers, showing that g-index is more sensitive to their scientific behaviour than h-index.

Table 7. Examples of scientists favoured by h-index (A scientists) or by g-index (B scientists)

Big producers						
Scientist	Number of docs	Tot. citations	Cit/doc rate	HCP rate	g-index	h-index
A1	28	162	5.79	0.04	10	8
A2	33	144	4.36	0.03	9	8
A3	29	136	4.69	0.03	10	8
Selective scientists						
Scientist	Number of docs	Tot. citations	Cit/doc rate	HCP rate	g-index	h-index
B1	13	176	13.54	0.15	13	4
B2	15	188	12.53	0.27	13	6
B3	14	155	11.07	0.21	12	7
B4	13	138	10.62	0.31	11	7
B5	16	168	10.5	0.19	12	6
B6	14	134	9.57	0.21	11	7
B7	19	185	9.74	0.21	13	6
B8	12	124	10.33	0.33	11	6
B9	12	129	10.75	0.42	11	7

Is g-index better than h-index?

Our results show that g-index is more sensitive than h-index to assess selective scientists. However, the g-index also presents limitations, such as the exceedingly high influence that an occasional "big hit" (a highly cited document) can have on the index. This is a problem in those cases in which a scientist presents highly cited papers which are not representative of his/her research performance. A real example is shown in Table 8.

Table 8. Example of the effect of a "big hit" on h- and g-indexes

Researcher A				Researcher B			
R	Citations	Cum. Cit.	R^2	R	Citations	Cum. Cit.	R^2
1	126	126	1	1	25	25	1
2	20	146	4	2	24	49	4
3	9	155	9	3	22	71	9
H 4	**6**	**161**	**16**	4	20	91	16
5	4	165	25	5	20	111	25
6	3	168	36	**H 6**	**8**	**119**	**36**
7	3	171	49	7	4	123	49
8	2	173	64	8	1	124	64
9	1	174	81	*(*)9*	*0*	*124*	*81*
10	1	175	100	*10*	*0*	*124*	*100*
11	1	176	121	*G 11*	*0*	*124*	*121*
12	0	176	144	*12*	*0*	*124*	*144*
G 13	*0*	*176*	*169*				
(*)14	*0*	*176*	*196*				

Notes: (*) *Fictitious documents.* R stands for "ranking".

Researcher A is a low producer, who presents an outstanding number of citations concentrated in one paper (126 citations) which is not representative of his/her average research performance. Researcher B is a selective scientist, whose citation pattern is more homogeneous and holds a higher rate of Highly Cited Papers than A. Although Researcher B obtains a higher h-index than A, researcher A gets a higher g-index due to the influence of the "big hit".

Conclusions

The g-index presents two important improvements as compared to h-index: first, the weighting of the citations received by the documents is considered in the g-index calculation; and secondly, the g-index for a given scientist is not limited by his/her total number of publications. According to these features, g-index might be more adequate than h-index for assessing selective scientists, who are less likely to obtain high values of h-index [COSTAS & BORDONS, 2007].

In this study four different types of scientists have been described: low producers, selective scientists, big producers and top scientists. Low producers present significantly lower h- and g-indexes than top scientists. However, discriminating among intermediate types of scientists – big producers and selective scientists – is more difficult, as previously remarked by other authors [JIN & AL., 2007]. Although the latter two types of scientists can be differentiated by means of traditional bibliometric indicators, relying only on the h- or g-index does not allow us to discriminate between them.

However, our study shows that the g-index is more sensitive than h-index for the assessment of selective scientists, as suggested by the significant differences found in the position occupied by selective scientists in the h-index and g-index ranks, as well as by the higher g-index/h-index ratio observed for selective scientists. Our results suggest that big producers are favoured by h-index whilst selective scientists obtain better positions by means of the g-index. Therefore we consider that the g-index is better suited for the assessment of selective researchers than the h-index.

Considering the whole population of Natural Resources scientists, a strong positive correlation between g- and h-index was observed; moreover both indicators have a good correlation with the total number of citations and the total number of documents. It is interesting to note that g-index shows a better correlation than the h-index with the number of citations per document and with the HCP rate, supporting the idea of the better sensitivity of g-index for the assessment of selective scientists, since the latter tend to present high scores in the two mentioned indicators.

Although the g-index presents some advantages as compared with the h-index, several limitations remain. That is the case of the problems related to the difficult collection of all the citations and documents of scientists; the existence of different types of documents with different impacts; the problem of self-citations or the inability of the indexes to compare researchers from different scientific fields [VINKLER, 2007]. On the other hand, specific limitations are also observed for the g-index, such as the excessive influence of an occasional "big hit" (a highly cited document) which is not probably representative of the average research performance of a scientist.

In spite of our results which indicate that g-index is slightly better than h-index for selective scientists, we still advise against relying on a single indicator for evaluative purposes. The information provided by the ten original bibliometric variables used in this study can be reduced to four different dimensions, but not to just one single variable, such as the h- or g-index. These indexes appear in the first dimension – together with the total number of documents and citations, showing that both indexes are size-dependent indicators –, and it only explains 36% of the total variance. Therefore, the remaining dimensions provide relevant information about other aspects of research performance of scientists, such as the quality of publication journals and the relative impact of documents that are ignored by h- and g-index.

Having in mind all the features and limitations mentioned above, it is clear that h- and g-index need to be used with caution, and should be combined with other indicators. The existence of Highly Cited Papers is heavily valued by the g-index (sometimes in excess), while the h-index values positively a stable profile in the scientific performance of scientists but penalizes selective publication strategies, so in some way they are complementary. We should also take into account that these indicators are still in their infancy, and modifications and improvements are still going on.

The fact that these indexes are easy to calculate makes them especially prone to indiscriminate use. An unreasonable use of these indicators could lead to unintended consequences, as described before for other indicators [WEINGART, 2005]. Consequences such as changes in the publication behaviour of scientists, including an increase in the self-citation rates (to be excluded from these indexes), the creation of citation lobbies, the increase of the Least Publishable Units (LPUs), or the migration of scientists to mainstream topics with high h-indexes, among others.

With the aim of supporting research evaluations at the micro-level, multi-dimensional bibliometric approaches, which consider research performance in their different aspects, are still recommended. On-going research on h-, g- and even A-, R- and AR-indexes (recently introduced, see [JIN & AL., 2007]) is oriented to identify the "best" indicators to assist experts and research managers in research assessment exercises. But adequate study and validation of these indicators before they are implemented in the research assessment practices is needed.

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Appendix 1

Research performance by types of scientists

Types of scientists	Indicators									
	Tot. docs.	Tot. citations	IF	NJP	Cit./doc. rate	HCP rate	RCR	%RCR≥1	g-index	h-index
Top researchers	39 46.56±22.43	535 605.14±379.1	1.47 1.6±0.56	0.72 0.73±0.08	11.59 13.06±4.29	0.28 0.31±0.1	1.13 1.15±0.39	55.78 53.88±14.97	21 21.56±5.24	13 14.01±3.57
Selective researchers	19 19.35±4.54	211.5 238.93±128.39	1.39 1.58±0.59	0.74 0.74±0.08	10.72 12.33±5.61	0.25 0.29±0.12	1.08 1.11±0.44	55 53.81±19.08	13.5 14.35±3.42	9 8.76±1.99
Big producers	38 40.69±12.01	235.5 261.35±110.84	1.11 1.05±0.3	0.59 0.6±0.1	6.33 6.34±1.57	0.1 0.11±0.06	0.72 0.77±0.3	40.19 40.33±11.77	13.5 13.44±2.96	9 9.4±1.85
Low producers	19 18.83±4.38	108 105.36±44.8	1.11 1.09±0.35	0.64 0.62±0.11	5.62 5.51±1.85	0.08 0.09±0.07	0.61 0.67±0.39	35 34.31±16.27	9 8.91±2.52	6 5.92±1.59
Total	26 31.32±18.51	221 308.16±293.18	1.23 1.33±0.53	0.68 0.67±0.11	8.79 9.29±5.04	0.18 0.2±0.14	0.9 0.92±0.44	46.29 45.33±17.95	13 14.6±6.13	9 9.55±3.95

Values shown as: Median
Mean ± Standard deviation

Appendix 2

Statistical significance in the differences between types of scientists (Mann-Whitney U)

Indicators	Type of researchers	Top scientists	Selective scientists	Big producers
Tot. docs.	Selective scientists	*0.000*	–	
	Big producers	NS	*0.000*	–
	Low producers	*0.000*	NS	*0.000*
Tot. citations	Selective scientists	*0.000*	–	
	Big producers	*0.000*	NS	–
	Low producers	*0.000*	*0.000*	*0.000*
IF	Selective scientists	NS	–	
	Big producers	*0.000*	*0.000*	–
	Low producers	*0.000*	*0.000*	NS
NJP	Selective scientists	NS	–	
	Big producers	*0.000*	*0.000*	–
	Low producers	*0.000*	*0.000*	NS
Cit./doc. rate	Selective scientists	NS	–	
	Big producers	*0.000*	*0.000*	–
	Low producers	*0.000*	*0.000*	*0.01*
HCP rate	Selective scientists	NS	–	
	Big producers	*0.000*	*0.000*	–
	Low producers	*0.000*	*0.000*	NS
RCR	Selective scientists	NS	–	
	Big producers	*0.000*	*0.000*	–
	Low producers	*0.000*	*0.000*	*0.05*
%RCR≥1	Selective scientists	NS	–	
	Big producers	*0.000*	*0.000*	–
	Low producers	*0.000*	*0.000*	*0.05*
g-index	Selective scientists	*0.000*	–	
	Big producers	*0.000*	NS	–
	Low producers	*0.000*	*0.000*	*0.000*
h-index	Selective scientists	*0.000*	–	
	Big producers	*0.000*	NS	–
	Low producers	*0.000*	*0.000*	*0.000*

Statistical significance when $p < 0.05$