ARTÍCULOS

PROPOSAL OF USING SCALING FOR CALCULATING FIELD-NORMALIZED CITATION SCORES

Propuesta de utilizar escalado para calcular la citación normalizada por disciplina

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Abstract

Since the end of the 1980s, citation impact values –especially for evaluative purposes– are increasingly presented as field-normalized citation scores than as bare citation counts or citation rates. In rather popular variants of the scores, the average score over a publication year is not exactly one due to multiple *Web of Science* subject categories per paper. We propose a scaling method which introduces slight changes in the field-normalized scores of each paper that ensures that the average value of all scores equals one.

Keywords

Mean normalized citation score; Field normalized citation score; Scaling; Bibliometrics.

Resumen

Desde finales de la década de 1980, los valores de impacto de citación –especialmente para los propósitos de evaluación- se presentan cada vez más como valores de citación normalizada por disciplina más que simplemente como el número de citas o como porcentajes de citación. En las variantes más frecuentes de las puntuaciones, el promedio sobre un año de publicación no es exactamente igual a 1 debido a la posible asignación de un artículo a múltiples categorías temáticas de la *Web of Science*. Proponemos un método de escalado que introduce pequeños cambios en los valores de citación normalizada por disciplina de cada artículo, pero asegura que la media de todas las puntuaciones sea igual a uno.

Palabras clave

Citación media normalizada; Citación normalizada por disciplina; Escalado; Bibliometría.

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1. Introduction

Since the end of the 1980s, citation impact values –especially for evaluative purposes– are increasingly presented as field-normalized citation scores than as bare citation counts or citation rates (**Schubert**; **Braun**, 1986; 1993). For these scores, citation counts of a paper in question are compared with a corresponding reference set: the citation impact of papers published in the same year and subject category. Today, (1) journal sets from *Web of Science* (*WoS*, *Thomson Reuters*) or *Scopus* (**Vinkler**, 2010), (2) fields defined by citation relations between papers (**Waltman**; **Van-Eck**, 2012) and (3) field assignments by experts in a field (**Bornmann**; **Daniel**, 2008; **Bornmann** *et al.*, 2011) are used as subject categories for normalization (journal sets, where many journals are assigned to multiple categories, have been used in most of the bibliometric studies). Only the normalization of the citation impact of a unit's (e.g. a university) publications with reference sets allows cross-field and cross-time comparisons between different units (e.g. universities with different disciplinary profiles and publishing in different time periods).

After a longer debate among bibliometricians on the use of averages of ratios and ratios of averages for the calculation of field-normalized citation scores (**Bornmann**; **Mutz**, 2011; **Larivière**; **Gingras**, 2011; **Lundberg**, 2007; **Opthof**; **Leydesdorff**, 2010; **Van-Raan** *et al.*, 2010), the mean-normalized citation score (*MNCS*) has been proposed by **Waltman**, **Van-Eck**, **Van-Leeuwen**, **Visser**, and **Van-Raan** (2011) as a final solution. The *MNCS* employs averages of ratios (times cited over citations expected) with fractional counting of papers which are in multiple categories. The *SCImago Institutions Ranking*, *InCites*, and the *Times Higher Education Ranking* (*THE Ranking*) use another version of the *MNCS* which is also based on averages of ratios.
http://www.scimagoir.com/methodology.php
http://researchanalytics.thomsonreuters.com/m/pdfs/indicators-handbook.pdf
https://www.timeshighereducation.co.uk/world-university-rankings/2015/world-ranking/#tab-ranking-methodology

The difference is in the handling of papers which are in multiple subject categories. Here, the arithmetic average value of the normalized impact value in each category is used as the average impact for papers which are assigned to multiple categories (**Rehn** *et al.*, 2014). The total impact of a collection of papers is calculated by the average value of the average values.

Today, the *MNCS* (in the different versions) can be seen as one of the most frequently used normalizing indicators in the field of (evaluative) bibliometrics (and thus can be seen as a standard in the field for impact normalization). The indicator is supposed to allow to decide whether a unit (scientist, institution, journal…) has published papers having produced an average citation impact (*MNCS*=1) or an impact below (*MNCS*<1) or above (*MNCS*>1) the average in the field and publication year. These distinctions hold exactly for the *MNCS* if it is calculated via fractional (**Waltman** *et al.*, 2011) or multiplicative (**Herranz**; **Ruiz-Castillo**, 2012) counting for papers which are assigned to multiple categories. In case of fractional counting, a paper's *MNCS* is based on fractionally calculated normalized impact values from different subject categories; in case of multiplicative counting, a paper's *MNCS* is considered multiple times depending on the subject categories the paper is assigned to. However, if the full counting method is used (as in the *SCImago Institutions Ranking*, the *THE Ranking*, and *InCites*), the average value over all *MNCS* values will differ slightly from one. In case of full counting, a paper's *MNCS* is calculated as a mean over the normalized impact values in the subject categories the paper is assigned to. The three counting methods will be illustrated in detail in section 2.

In this study, we would like to propose a small change in the calculation of the *MNCS* using the full counting approach. We will show that the calculation of the average value of all *MNCS* values for a publication year does not lead to exactly *MNCS*=1 in all cases, there are small deviations. Thus, we propose in the following to scale the *MNCS* using the mean *MNCS* over a publication year. Since our proposal can be simply considered in the calculation of *MNCS* values and leads to impact values which allow a better interpretation if the full counting method is used, we would like to bring it up for discussion in the bibliometric community.

2. An example to illustrate the problem

In the following, we consider the same example as in **Waltman** *et al.* (2011): Let us assume that the scientific universe consists of five publications where publications 1 and 2 belong to the scientific field X, publication 3 belongs to the field Y, publication 4 belongs to the field Z, and publication 5 belongs to the fields X and Y, as shown in Table 1. The expected number of citations (*E*) and normalized citation scores (*NCS*) using the fractional, multiplicative, and full counting approach are shown in Table 2.

Table 1. Hypothetical scientific universe with five publications, their assignments to scientific fields, and the citations they received

Publication	Scientific field	Citations
1	X	2
2	X	3
3	Y	8
4	Z	6
5	X & Y	5

Table 2. Expected citations (E) and normalized citations scores (*NCS*)

Publication	E^{frac}	E^{mult}	E^{full}	NCS^{frac}	NCS^{mult}	NCS^{full}
1	3	10/3	10/3	2/3	6/10	6/10
2	3	10/3	10/3	1	9/10	9/10
3	7	13/2	13/2	8/7	16/13	16/13
4	6	6	6	1	1	1
5	21/5	10/3; 13/2	10/3; 13/2	25/21	15/10; 10/13	590/520

It is straightforward to calculate the values of *E* and *NCS* for publications 1-4 according to each counting method, because those four publications belong to a single scientific field. Publications 1 and 2 have the same value of *E* because both belong to the scientific field X:

$$E_1^{frac} = E_2^{frac} = \frac{2+3+5/2}{1+1+1/2} = 3$$

$$E_1^{mult} = E_2^{mult} = E_1^{full} = E_2^{full} = \frac{2+3+5}{1+1+1} = \frac{10}{3}$$

Publication 5 is counted half for the scientific fields X and Y each in the case of fractional counting, while it is counted fully in the cases of multiplicative and full counting. The *NCS* is simply the ratio of the number of observed citations and the number of expected citations: $NCS_1^{frac} = 2/3$, $NCS_2^{frac} = 3/3 = 1$, and:

$$NCS_1^{mult} = NCS_1^{full} = \frac{2/1}{10/3} = \frac{6}{10}$$
$$NCS_2^{mult} = NCS_2^{full} = \frac{3/1}{10/3} = \frac{9}{10}$$

The *NCS* values of multiplicative and full counting agree with each other, but differ from the *NCS* value of fractional counting for publications 1 and 2. This is due to the fact that publication 5 belongs to both fields X and Y which causes different *E* values for fractional counting on one side and multiplicative as well as full counting on the other side.

Calculation of the *E* value for publication 5 using fractional counting is done via the harmonic average of the E values of scientific fields X and Y:

$$E_5^{frac} = \frac{1+1}{1/3+1/7} = \frac{21}{5}$$

In the multiplicative and full counting approaches, we have different *E* values for publication 5 in scientific fields X [$E_5^{mult}(X) = E_5^{full}(X) = 10/3$] and Y [$E_5^{mult}(Y) = E_5^{full}(Y) = 13/2$], as publication 5 counts fully in both approaches. For calculation of the *NCS* value, the arithmetic average of the *NCS* values in scientific fields X (15/10) and Y (10/13) is used in the full counting approach, while publication 5 is counted twice in the multiplicative counting approach. The mean *MNCS* value over all five publications yields 1 for the fractional and multiplicative approaches, but differs slightly from one for the full counting approach:

$$MNCS_{frac} = \frac{\left(\frac{2}{3}+1+\frac{8}{7}+1+\frac{25}{21}\right)}{5} = 1$$
$$MNCS_{mult} = \frac{\left(\frac{6}{10}+\frac{9}{10}+\frac{16}{13}+1+\frac{15}{10}+\frac{10}{13}\right)}{6} = 1$$
$$MNCS_{full} = \frac{\left(\frac{6}{10}+\frac{9}{10}+\frac{16}{13}+1+\frac{590}{520}\right)}{5} = \frac{253}{260} \approx 0.973$$

3. Dataset

The bibliometric data used in the following is from an in-house database developed and maintained by the *Max Planck Digital Library* (*MPDL*, Munich) and derived from the *Science Citation Index Expanded* (*SCI-E*), *Social Sciences Citation Index* (*SSCI*), *Arts and Humanities Citation Index* (*AHCI*) prepared by *Thomson Reuters* (Philadelphia, Pennsylvania, USA), *Web of Science* (*WoS*), as of May 15th 2015.

4. Results

Table 3 shows average *MNCS* values (calculated on the basis of the full counting method) and average number of *WoS* categories for articles and reviews of the publication years 1980-2012. The *MNCS* shown in Table 3 was obtained by normalization with respect to the *WoS* subject categories and averaging over the impact values in each category for each paper. As papers can belong to multiple subject categories, the average *MNCS* on a higher aggregation level can differ from one, while the average *MNCS* over the *WoS* categories is still equal to one. The difference originates from papers which are assigned to multiple *WoS* subject categories because this introduces the average value of average values (see the example in section 2).

In fact, Table 3 shows that the *MNCS* deviates from one by 1%-4.2% in 24 of the 33 years shown in Table 3. Therefore, the *MNCS* deviates by 1% or more in 73% of the years.

The average of all *MNCS* values per year is greater than one (negative deviation) only in 1993 and smaller than one (positive deviation) in the other years (cf. Table 3). The average number of *WoS* categories per paper has been increasing since 1980 as shown in Table 3. The relative increase of *WoS* categories per paper amounts to 22.5% (0.7% per year on average). The maximum number of *WoS* subject categories per paper was 5 until 1985 and has increased to 6 in 1987. Also, the percentage of papers which are assigned to more than one subject category has increased from 25.8% in 1980 to 42.3% in 2012. This is an increase of 63.9% (1.9% per year). Both, increase of the average number of *WoS* categories per paper and the increase of the percentage of multiply categorized papers, increase the potential of a deviation of the *MNCS* from one over all *MNCS* values of a publication year.

The *NCS* for each paper averaged over the *WoS* categories (NCS_i), where it has been assigned to, could be divided by the average value of all *NCS* values ($\overline{MNCS}$) of a publication year:

$$\overline{MNCS} = \frac{1}{N}\sum_{i=1}^{N} NCS_i$$

$$NCI_i = \frac{NCS_i}{\overline{MNCS}}$$

Here, *N* is the number of papers in the publication year where this scaling is applied to, and *i* indexes the papers. This scaling results in a slightly different impact value for each paper (NCI_i) than before (NCS_i) with the advantage that the average value of all NCI_i values equals one in each publication year and overall. This scaling approach will not alter the *MNCS* values of the fractional and multiplicative counting methods.

Returning to the example in Section 2, we have obtained $MNCS_{frac} = MNCS_{mult} = 1$ and $MNCS_{full} = 253/260 \neq 1$. The scaling approach proposed here would mean in this example that each NCS_i^{full} value is multiplied with 260/253 in order to obtain the NCI_i^{full} values while the NCS_i^{frac} and NCI_i^{frac} values as well as the NCS_i^{mult} and NCI_i^{mult} values are equal:

$$NCI_i^{frac} = NCS_i^{frac}$$
$$NCI_i^{mult} = NCS_i^{mult}$$
$$NCI_i^{full} = NCS_i^{full}\frac{260}{253}$$

This results in an average impact over all publications in this example of 1:

$$MNCI_{full} = \frac{1}{5}\left(\frac{6}{10}+\frac{9}{10}+\frac{16}{13}+1+\frac{590}{520}\right)\frac{260}{253} = 1$$

Table 3. Average *MNCS* values, their deviation from one in percentages, average number of *WoS* categories, and percentage of multiply categorized papers for articles and reviews of the publication years 1980-2012

Publication year	Average MNCS	Deviation in percent	Average number of *WoS* categories	Percentage of multiply categorized papers
1980	0.987	1.29	1.31	25.8
1981	0.988	1.22	1.31	25.8
1982	0.987	1.35	1.31	25.5
1983	0.980	2.00	1.32	26.3
1984	0.986	1.44	1.32	26.1
1985	0.988	1.19	1.34	27.5
1986	0.989	1.08	1.35	28.0
1987	0.992	0.84	1.35	28.3
1988	0.995	0.46	1.36	28.8
1989	0.996	0.43	1.38	29.8
1990	0.997	0.32	1.39	30.5
1991	0.991	0.92	1.40	31.3
1992	0.996	0.45	1.42	32.5
1993	1.001	-0.08	1.44	33.5
1994	0.994	0.58	1.45	34.3
1995	0.991	0.89	1.47	35.6
1996	0.987	1.35	1.48	36.1
1997	0.986	1.46	1.51	37.6
1998	0.982	1.86	1.53	38.0
1999	0.982	1.87	1.53	38.3
2000	0.978	2.25	1.53	38.3
2001	0.981	1.94	1.54	38.9
2002	0.976	2.44	1.55	39.2
2003	0.972	2.89	1.55	39.2
2004	0.972	2.88	1.56	40.0
2005	0.969	3.24	1.57	40.1
2006	0.970	3.06	1.58	41.0
2007	0.966	3.51	1.60	42.0
2008	0.966	3.50	1.60	41.9
2009	0.962	3.96	1.60	42.4
2010	0.960	4.15	1.60	42.4
2011	0.960	4.20	1.61	42.6
2012	0.961	4.04	1.60	42.3

5. Discussion

After demonstrating in this study that the *MNCS* does not lead to exactly *MNCS*=1 on the level of all papers within a publication year, we have proposed to scale each *NCS* value obtaining a slightly different NCI value for each individual paper to reach exactly an average MNCI value of 1 for each publication year. In the example presented in Section 2, this leads to an unusual situation: publication 4 is the only paper in its category, thereby having an *NCS* value of exactly 1, but after our scaling the impact value of publication 4 is slightly larger than one: 260/253 ≈ 1.03. This can be considered as a disadvantage of the scaling approach, but this hypothetical example does not occur in practical bibliometrics. Since subject categories are based on journal sets or other large publication sets reflecting fields, reference sets generally contain more than one paper with different citation counts. Average citation counts over these subject categories usually do not lead to integers while citation counts of individual papers are always integer numbers. Therefore, the example of publication 4 is hypothetical and should not occur in bibliometric practice.

The *NCS* values of the full and multiplicative counting methods are the same for papers which belong to a single subject category. Differences in *NCS* values between both approaches are observed when papers are assigned to multiple subject categories. The scaling of *NCS* values using full counting affects all *NCS* values for each paper independent of the number of subject categories where the paper was assigned to. Therefore, the NCI values of the multiplicative and full counting approaches differ after scaling of the full counting *NCS* values.

Although percentile-based approaches – especially the proportion of the 10% most frequently cited papers within a subject category and publication year – have been proposed as a more robust field normalizing method than *MNCS* (**Hicks** *et al.*, 2015; **Waltman** *et al.*, 2012), the *MNCS* is (still) widely used in evaluative bibliometrics. Thus, we would like to recommend scaling in the calculation of the *MNCS*. Also, a discussion might be necessary for other indicators when a paper is assigned to multiple subject categories (by using a full counting method). Other indicators might have the same problem as the MNCS

The proposal of scaling for the *MNCS* solves the same problem as the proposal of using the fractional counting method for calculating the *MNCS*. This method is similar to the proposal of using the fractional counting method for calculating the proportion of the 10% most frequently cited papers within a subject category and publication year. Starting from the observations that one does not receive exactly 10% for the 10% most frequently cited papers within a subject category and publication year (but deviations of around 1% within certain disciplines), **Waltman** and **Schreiber** (2013) proposed a fractional counting method. Here, publications at the threshold of 10% are fractionally counted as top 10% papers or below 90% papers. This approach ensures (similar to scaling for the *MNCS*) that one has exactly 10% top 10% papers. The fractional counting approach is used for the Leiden Ranking (**Waltman** *et al.*, 2012).

Although *MNCS* (and *NCS*) values should not be interpreted to the precision provided in tables (**Hicks** *et al.*, 2015), it is very useful if the average of all *NCS* values (*MNCS*) of a publication year equals exactly one.

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