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Citation analysis of scientific categories

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Abstract

Databases catalogue the corpus of research literature into scientific categories and report classes of bibliometric data such as the number of citations to articles, the number of authors, journals, funding agencies, institutes, references, etc. The number of articles and citations in a category are gauges of productivity and scientific impact but a quantitative basis to compare researchers between categories is limited. Here, we compile a list of bibliometric indicators for 236 science categories and citation rates of the 500 most cited articles of each category. The number of citations per paper vary by several orders of magnitude and are highest in multidisciplinary sciences, general internal medicine, and biochemistry and lowest in literature, poetry, and dance. A regression model demonstrates that citation rates to the top articles in each category increase with the square root of the number of articles in a category and decrease proportionately with the age of the references: articles in categories that cite recent research are also cited more frequently. The citation rate correlates positively with the number of funding agencies that finance the research. The category h-index correlates with the average number of cites to the top 500 ranked articles of each category ($R^2 = 0.997$). Furthermore, only a few journals publish the top 500 cited articles in each category: four journals publish 60% ($\sigma = \pm 20\%$) of these and ten publish 81% ($\sigma = \pm 15\%$).

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1. Introduction

Bibliometric indicators contribute to ranking universities (Kinney, 2007, Moed, 2017), researchers (Hirsch, 2005, Verma, 2015), and journals (Garfield, 2006), and funding decisions for institutes and governments (Bornmann et al., 2008, Bornmann and Daniel, 2008). An individual's citation count and h-index, and the impact factor of the journal's that publishes their work provide input to awards and promotion committees. However, when these committees examine diverse dossiers and compare prestige and productivity between categories, they have little quantitative metrics to substantiate their decisions. Ranking criteria include alumni, awards, highly cited individuals, the number of articles in the Science Citation Index-Expanded and Social Science Index, and articles published in *Science* and *Nature* (ARWU, 2016). Citation counts are the basis of several bibliometric indicators—h-index, impact factor (N_{IF}), eigen factor, and g-index. The h-index equals the rank of an article (ordered from the most cited article to the least cited), h, for which it has been cited at least that often (Hirsch, 2005). But these indicators are unhelpful when comparing an engineer versus a scientist or a poet and a cinematographer. Furthermore, because of the disproportionate weighting of the N_{IF} as a means to measure the quality of an article, the San Francisco Declaration on Research Assessment recommended that it not be used for hiring, promotions or funding decisions (Cagan, 2013). Many journals accept their recommendations and now report the (SNIP), SCImago Journal Rank (*SJR*) and a five-year impact factor ($N_{\mathrm{IF},5}$) together with N_{IF}. The SNIP considers a three-year window and corrects for a fields average number of references in papers (Moed, 2010, Leydesdorff and Opthof, 2010).

Google Scholar groups journals into scientific categories and then ranks them according to an h_5-index: the number of articles in the previous five years with that number of citations (Braun et al., 2006). The most common ranking system is the Journal Impact Factor (N_{IF}) that represents the ratio of the number of citations in years $x-1$ and $x-2$ to the number of articles the journal publishes in year x. The number of citations is a proxy to an article's quality (Ebadi and Schiffauerova, 2016); however, since citations practices differ widely across scientific categories, many researchers question their validity as an evaluation metric (Bornmann and Daniel, 2008, Adler et al., 2009, MacRoberts and MacRoberts, 1996). Indeed, comparing productivity and prestige across scientific fields is dubious without criteria that represent substantial contribution. Still, national research evaluation agencies base their judgment criteria on the number of citations (Radicchi and Castellano, 2012, Abbott, 2009, Gilbert, 2009). Normalizing citations corrects for differences in citation rates between categories (Radicchi and Castellano, 2012, Colliander and Ahlgren, 2011, Waltman and van Eck, 2013, Kaur et al., 2013). Fractional citation counting apportions credit based on the number of authors of

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an article and is one method to account for differences in researchers citation counts between scientific categories (Garfield, 1979, Moed, 2010). Combining fractional counting with percentile ranks (Leydesdorff and Opthof, 2010) may be a superior indicator of a researchers. Relative impact indicators for mean citations compare journal papers between fields (Schubert and Braun, 1986, Vinkler, 2003, 2013).

Here we compare the citation practices of the scientific categories in Web of Science™ Core Collection (2015)™ (WoS). First we describe the database, then demonstrate how the number of citations, N_{cit}, varies as a function of bibliometric factors—number of articles per category, number of authors per article (for the 500 most cited), age of the references in these articles, number of institutions financing the research and factors related to journals that publish the research. We demonstrate that the number of articles and the age of the references explain more variance in the citation rates of the 500 most cited articles in each category than do the number of references and the number of authors. This premise compares elite articles from each of the categories and implies that the 500 most cited articles of each have the same quality, which exaggerates the differences between a category that has 300 000 articles and one that has 5000. It attributes scientific advances to research that is cited most. Rather than the top 500, future work will compare 500 articles from each category starting from the 10% or the 25%.

2. Methods

From 2010 to 2014, *Web of Science Core Collection*^{TM} (WoS) (Web of Science™ Core Collection, 2015) indexed 11.9 million documents into 251 scientific categories. Researchers in the pure sciences, engineering and medicine publish more work indexed by WoS compared with the humanities, social sciences and fine arts. Within these broad scientific fields and subfields, publication and citation rates vary widely, which complicates comparing the researchers, category, journal or institutes, productivity and impact (Waltman and van Eck, 2013). Since the citation patterns vary with document type (Radicchi and Castellano, 2012), we only consider the 6.5 million publications that WoS classifies as articles and ignore all other types (reviews, papers in proceedings, meeting abstracts, etc.).

In the beginning of January, 2016, we downloaded the WoS 500 most cited articles from each of the 251 categories. Following Crespo et al. (2010), we consider that citations represent intrinsic scientific value and the culture of the scientific field. Since the database has the top 500 articles in each category, we consider that differences in citation rates within these categories are due entirely to bibliometric factors and not quality or scientific impact.

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We restricted the work to the *Web of Science Core Collection*. In the *Basic Search* category of the WoS, we entered *":"* as the criteria and highlighted the field category *Topic*. We added a second field category *Year Published* and set the years to 2010–2014. In the following *Search* page, we restricted the study to *Articles* (under the *Document Types* tab). For each of the 251 *Web of Science Categories*, we sorted the articles from most cited to least cited, then saved the first 500 articles from the *Save to Other File Format* tab, included the *Full Record and Cited References*, and set the *File Format* to *Tab-Delimited*.

Each category file contains more than 40 columns of data including: article category, author's full name, title, journal, abstract, date, scientific field, affiliations, funding agencies, etc. Some errors remain in the database particularly related to the formatting of the references. We checked all references that were older than 500 years and corrected erroneous entries.

The WoS citation index compiles data from 12 000 journals. It assigns many of these articles to more than one category such that the sum of the total number of articles is 11.3 million (although the overall total number of articles is only 6.5 million): 304 journals have articles that are duplicated in two categories, 68 are assigned to 3 categories, 16 to 4 categories and 4 journals to 5 categories. Articles from *Advanced Materials* and *Nano Letters* appear in 6 categories. Nine of the top 10 articles in mathematical computational biology, computer science interdisciplinary applications, and probability and statistics are identical. Equally, biochemical research methods, biophysics and crystallography share all of the top 6 articles except for one. The article with the most cites (18103) is listed in three categories: biochemistry molecular biology, genetics heredity, and evolutionary biology.

WoS assigns 337 000 articles to multidisciplinary materials and only 800 to poetry and African, Australian, and Canadian literature. Because of this large disparity in the number of articles per category, we combined similar categories to ensure that each had at least 4000 papers. For example, we added medical ethics to the ethics category and put folklore, and 6 literature categories to literary theory criticism. The mean number of papers in each category of the truncated dataset (236 categories) was $\bar{N}_{\mathrm{art}} = 43000$ papers.

The following list describes the bibliometric field indicators. We correlated the number of times papers are cited with bibliometric indicators. For each indicator, we developed a power law expression and calculated the R^2. We then developed power law correlations with multiple factors and retained the expression that gave the highest R^2.

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R_{cat} We rank the categories from 1 to 236 based on the number of articles that WoS assigns to each. Multidisciplinary materials science, multidisciplinary chemistry, applied physics and chemical physics have the most articles (> 240000) while demography, industrial labor relations and logic have the least (< 4500).

$\bar{N}_{cit}$ The first several dozen articles in as many as 20 categories have uncharacteristically high citations. The paper with 18103 citations inflates the mean category average of biochemistry molecular biology, genetics heredity, and evolutionary biology by 36. To reduce the variability introduced by these highly cited articles, we set $\bar{N}_{cit}$ equal (Redner, 1998) to the average number of citations to papers ranked from 31 to 500.

h_{cat} The category h-index considers a five-year period (2010 to 2014) and equals the number of articles in a category, h, that have been cited at least h times: Multidisciplinary materials science, multidisciplinary chemistry, multidisciplinary sciences and general internal medicine all have at least 300 articles that have been cited more than 300 times ($h_{cat} > 300$); literary reviews, romance literature and classics have less than 10 papers that have been cited 10 times ($h_{cat} < 10$).

$\bar{N}_{IF}$ The mean weighted average of the N_{IF} (2014) of the 10 journals that publish the most cited papers in each category:

$$\bar{N}_{IF} = \frac{\sum n_i N_{IF,i}}{\sum n_i} \tag{1}$$

where n_i is the number of articles the ith journal publishes ($i = 1, 10$).

N_{art} Total number of articles that WoS assigns to each category.

$\bar{N}_{fund}$ Mean number of agencies that funded the research as reported in WoS funding agencies listed in the WoS.

N_{ref} The total number of references in the bibliography of all 500 articles in a category.

β The Weibull distribution characterizes the relationship between the cumulative number of references, $n(t)$, and their age, t, the difference between the year the journal published the article and when the reference was published (Patience et al., 2015):

$$n(t) = N_{ref}\left(1 - \exp\left(-\frac{t}{\beta}\right)\right) \tag{2}$$

where β is the scale parameter: 63% of the references are younger than β. As many as 85 categories cite at least one article older than 300 y and 8 categories cite more than 100 articles older than that (the number of reference articles older than 300 y are in parentheses): classics (687), romance literature (414), literary theory criticism (397), history (344), theatre (283), multidisciplinary humanities (141), philosophy of science

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history (102) and art (101). We excluded all references older than 100 y in calculating β and only consider references written after 1916.

$\bar{N}_{\mathrm{au}}$ Astronomy astrophysics averages 116 co-authors per article, while particles fields physics averages 169 and nuclear physics average 290. The number of co-authors per article exceeds 15 in 15 categories. To avoid these anomalously high values, in our model, we fit the number of authors per article (in each category) to a Weibull function then assign the number of authors per paper, N_{au} equal to β_{au}.

η The fraction of 500 articles that the top 4 journals publish. In agricultural engineering, *Bioresource Technology* published 422 of the top 500 articles; *Neuroimage* published 80% of the top 500 of the neuroimaging category; and, *Science* and *Nature* published 454 of the 500 most cited in multidisciplinary sciences. Although 10% of the journals indexed by WoS have at least one paper among the 500 most cited, only 10 journals account for 60% of the 118000 articles of this study. (Supplementary file:Top 10 journals per category.xlsx)

3. Results

The *h*-index links productivity of individuals with the citation history of their published articles. It prejudices young researchers and individuals who publish in categories with low citation rates. Modifications to improve the *h*-index include fractional counting (Leydesdorff and Opthof, 2010), normalizing citations, correcting for the dimensionality of the *h*-index with a conversion factor (Dienes, 2015). An h_{cat} minimizes the pitfalls associated with the individual *h*-index; it is an aggregate value that applies to all researchers for the same 5-year period. It is a measure of productivity and correlates with the number of researchers in a field, which reflects the priority that society attributes to specific scientific categories. For instance, the h_{cat} (2010–2014) of multidisciplinary sciences is 367: 367 articles between 2010 and 2014 were cited at least 367 times as of January 2016. It was only 3 for Slavic Literature.

The average of the number of citations to the top 500 papers per categories, $\bar{N}_{\mathrm{cit}}$, correlates with h_{cat} (Figure 1):

$$h_{\mathrm{cat}} = 4.5\bar{N}_{\mathrm{cit}}^{0.71}, R^2 = 0.997 \tag{3}$$

Iglesias and Pecharromán (2007) derived a theoretical relationship that they apply to individuals that takes into account both the category productivity and an individual's productivity based on

$$h = \sqrt[3]{\frac{N_{\mathrm{art}}}{4}}\bar{N}_{\mathrm{cit}}^{2/3} \tag{4}$$

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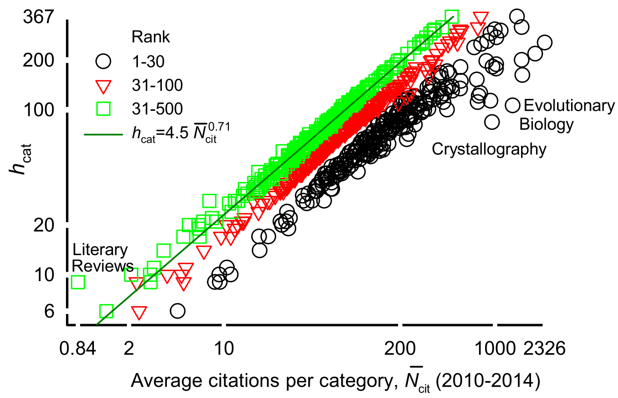

Figure 1. The h_{cat} correlates with the average number of citations of the most highly ranked articles. A power law model fits the average citation rates of articles ranked from 31–100 better than those ranked from 1–30. The correlation coefficient is $R^2 = 0.997$ for the articles ranked from 31–500.

Eq. (3) specifically applies to the article rank from 31 to 500. For the articles ranked from 31 to 100, the data are displaced to the right slightly (the coefficient increases) but the slope of the line is the same and slightly higher than the Eq. (4). In fact, considering any series of articles with the same rank—100 to 200, 200 to 300, 300 to 500—only the coefficient changes but the exponent is essentially constant and $R^2 > 0.99$. However, for the most highly cited papers, ranked 1 to 30, for example, many categories deviate substantially from the regression line (circles to the right). Such articles in these categories represent the substantial fluctuations (Redner, 1998) characteristic of the extremes of the bibliometric citation data. Coincidentally, they share the most highly cited papers.

Whereas the h_{cat} increases to the power 0.71 with respect to $\bar{N}_{cit}$, how does the category average impact factor, $\bar{N}_{IF}$, vary with $\bar{N}_{cit}$? The impact factor for a given year, i is:

$$N_{IF,i} = \frac{N_{cit,i-1} + N_{cit,i-2}}{N_{art,i-1} + N_{art,i-2}} \tag{5}$$

Recall that the category impact factor is the weighted average N_{IF} of the top 10 journals that publish the 500 most cited articles. Finardi (2013) reported that N_{IF} are poorly correlated with N_{cit} but differences among scientific areas exist. By restricting our analysis to the most highly cited papers, we evaluate the differences between areas and find that $\bar{N}_{IF}$ increases linearly with citations, but more precisely $\bar{N}_{cit}$ (Figure 2):

$$\bar{N}_{IF} = 0.075\bar{N}_{cit}, R^2 = 0.81 \tag{6}$$

$\bar{N}_{IF}$ is greater than 25 for general internal medicine (50), multidisciplinary sciences (36), and cell biology (26) (Appendix). It is below 0.5 for literary theory criticism, romance literature, classics, theater, and Asian studies. The categories that deviate

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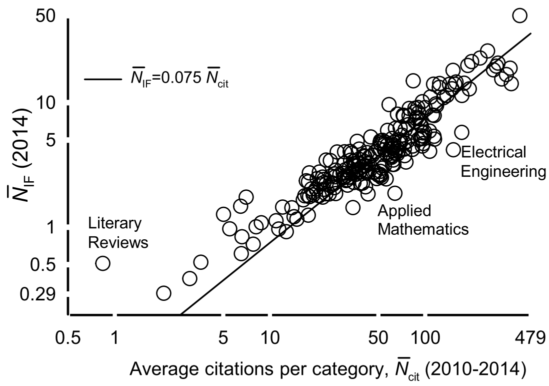

Figure 2. The weighted $\bar{N}_{IF}$ of the journals that publish the top 500 articles for each category is proportional to the average of the number of citations per category.

substantially from the regression line include electrical engineering, applied mathematics, astronomy/astrophysics and nuclear science technology.

4. Discussion

Both the h_{cat} and $\bar{N}_{IF}$ correlate with citation rates and are useful metrics to compare categories quantitatively. But what factors contribute to the citation frequency of an article? Tahamtan et al. (2016) categorize the factors that contribute to how often an article is cited: (1) paper related—research quality, novelty, how well the authors present their results, accessibility, the number of references, N_{ref} and age, β. (Vieira and Gomes, 2010); (2) journal related—N_{IF}, language; and, (3) author related—N_{au}, authors reputation, collaborations, race, gender, age etc. Yu and Yu (2014) included research field as an addition factor that contributes to citation frequency, which would include N_{art} and N_{fund}. Here we examine all four factors but assume that since we populate the database solely with the most cited articles, the research quality is equivalent across all categories. The article related aspects we consider are N_{ref}, β and the number of articles WoS assigns to a category, N_{art}. The only journal related factor we consider is N_{IF}, as expressed by the parameter η. We compared the percentage of women graduating from 141 scientific disciplines with the average number of citations in those disciplines and found no positive correlation, which agrees with other work (National Science Foundation, 2014, Rørstad and Aksnes, 2015).

Other author related factors we examined include N_{au} and N_{fund}.

The number of articles in a category, N_{art}, is the single most important factor that correlates with $\bar{N}_{cit}$ (SCImago Journal Rank, Zitt and Small, 2010). It decays exponentially with respect to the rank (Figure 3). Articles in categories that cite proportionately more often than the number of articles that WoS assigns to

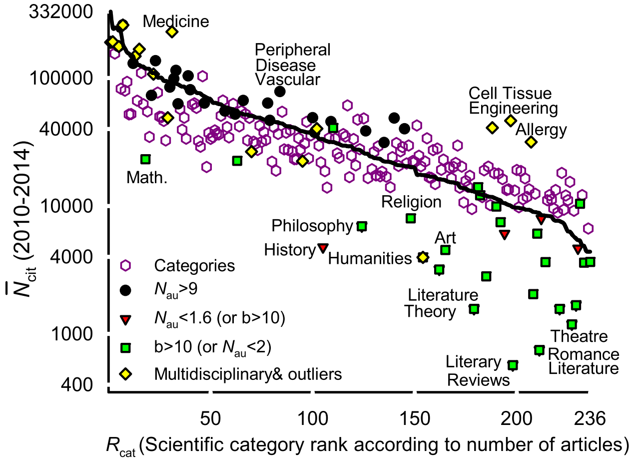

Figure 3. The total citation count to the top papers in a category ($30 < R \leq 500$), $\bar{N}_{cit}$, versus the rank of the number of papers assigned to this category (black line). The number of citations to the most cited papers for each category follows a similar trend (magenta hexagons). Several categories related to biology/medicine cite more frequently than the number of papers in these categories whereas the social sciences, the arts and some categories related to mathematics cite less frequently.

the category lie above the black line in Figure 3 (biological sciences—general internal medicine, peripheral vascular disease, cell tissue engineering, allergy and evolutionary biology). Cell tissue engineering, andrology and mathematical psychology are cited 3 times more than there are papers ($N_{cit} > 3\ N_{art}$). Mathematics, nursing, religion, history, humanities and literature are among the categories that cite proportionately less often than the number of papers that they publish and fall below the line: History and literature reviews have 10 times more papers than citations ($N_{cit} < 10\ N_{art}$). Assuming that the number of citations is directly proportional to the number of papers explains 64% of the variance: $N_{cit} = 0.73\ N_{art}$ ($R^2 = 0.64$).

The deviation between the highest number of citations and the lowest for a given N_{art} is about 3. Biological sciences and medicine related categories lie near the upper bound while humanities lie below the lower bound.

Equally important as N_{art} to explain the variance in the category $\bar{N}_{cit}$ data is the average age of the references in the articles' bibliography, β. The Weibull distribution accounts for more than 99.5% of the variance in the age distribution. It varies from 4 y (nanoscience nanotechnology and multidisciplinary materials science) to more than 20 y (classics, history of social sciences and romance literature), and averages 9 y over all categories. Categories with a lower β will necessarily have journals with a higher N_{IF} since researchers cite recent articles. As many as 44% of the papers that researchers publish in multidisciplinary materials science are two years old or less while it is only 5% in classics. An inverse cubed relation accounts for 66% of the variance in the data:

$$\bar{N}_{cit} = 35000/\beta^3,\ R^2 = 0.66 \tag{7}$$

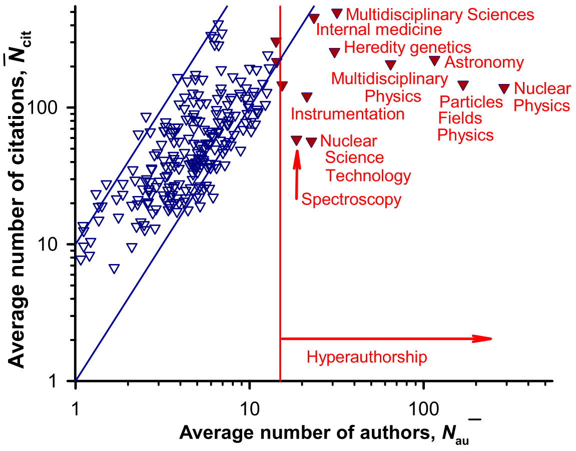

Figure 4. The average number of citations to the top ranked articles in a category $30 < R \leq 500$, $\bar{N}_{\text{cit}}$, increases proportionately with the square of the number of authors and are bounded by two extremes $\bar{N}_{\text{cit}} = \bar{N}_{\text{au}}^2$ and $\bar{N}_{\text{cit}} = 10\bar{N}_{\text{au}}^2$. Ten categories average more than 15 authors per category, which corresponds to hyperauthorship (red filled triangles) (Boffito et al., 2016).

Besides the number of papers in a category and β, the number of citations increases with the number of authors, N_{au} (Figure 4) (Abramo and D'Angelo, 2015, Glänzel and Thijs, 2004). Authorship attributes credit to those that contribute to research. Through authorship, people accrue a reputation (Cronin, 2001). Researchers in biosciences cite more often than architects and these varying citation practices render comparisons across scientific fields problematic (Crespo et al., 2010). Articles in multidisciplinary physics, astronomy/astrophysics, particles fields physics and nuclear physics can have several hundred and even more than three thousand authors—hyperauthorship (Birnholtz, 2006, Li et al., 2013)—whereas literature, poetry, and history tend to have a single author. Ten categories exceed 15 authors per paper, which is indicative of hyperauthorship (Boffito et al., 2016). Excluding hyperauthorship, papers average less than 5 authors per paper. Citations increase with the square of the number of authors per paper, with a 10-fold spread:

$$\bar{N}_{\text{au}}^2 < \bar{N}_{\text{cit}} < 10N_{au}^2 \tag{8}$$

5. Model

Principal component analysis shows that no linear combination of all possible parameters accounts for the majority of the variance. However, a power law model including the prime factors accounts for 86% of the variance: $\bar{N}_{\text{cit}} = \alpha_0 N_{\text{art}}^{\alpha_1} \bar{N}_{\text{au}}^{\alpha_2} / \beta^{\alpha_3}$. Excluding 12 categories related to psychology, business and management (Iglesias and Pecharromán, 2007), the following expression accounts for 95% of the variance:

$$\bar{N}_{\text{cit}} = \left(1.5 + 0.33\eta\left(1 + N_{\text{fund}}\right)^{5/4}\right)\frac{N_{\text{art}}^{0.5}}{\beta} \tag{9}$$

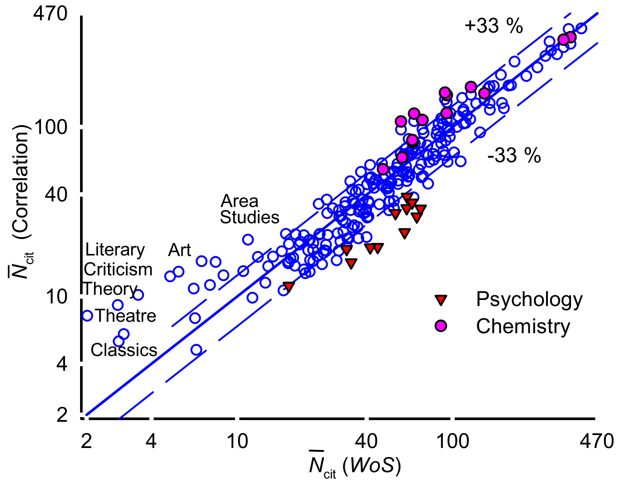

Figure 5. The equation $\bar{N}_{cit} = \left(1.6 + 0.37\eta\left(1 + N_{fund}\right)^{1.3}\right) N_{art}^{0.5}/\beta$ accounts for 95% of the variance in the average number of citations per category.

The number of papers in a category and the age of the references in these papers account for most of the variance in $\bar{N}_{cit}$. The first term variable in the parenthesis, η, represents the fraction of articles of the 500 most cited articles that the top 4 journals publish (Tables 1–8). This factor exceeds 0.97 for agricultural engineering, multidisciplinary sciences, neuroimaging and material sciences coatings, and is lower than 0.26 for literary criticism, classics, and management.

The second term variable, N_{fund}, accounts for the number of funding agencies that finance the research, which correlates with the number of authors—the correlation coefficient was lower with $\bar{N}_{au}$ versus N_{fund}. Considering that the SNIP (Source Normalized Impact per Paper) journal metric accounts for the average length of reference lists, it is surprising that this factor is insignificant for this data set (Leydesdorff and Opthof, 2010). Presumably, funding agencies weigh their selection criteria heavily on the established publishing record of researchers, which reinforces the Matthew effect (Ebadi and Schiffauerova, 2016).

Most categories lie within 33% of the regression line but the regression model consistently underestimates the citations to the psychology categories and it overestimates many of the fine arts categories and some of the chemistry categories (Figure 5).

Table 1. Bibliometric indicators (2010–2014): Category rank from 1 to 30.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
1	Multidisciplinary mat. sci.	381	301	18.8	331865	6.6	4.5	0.63	3.4
2	Multidisciplinary chemistry	385	306	14.2	248702	6.2	4.7	0.68	3.2
3	Applied physics	311	260	19.5	246995	6.8	5	0.79	3.3
4	Physical chemistry	358	290	16.7	245840	6.4	5	0.71	3.3
5	Biochemistry mol. biology	354	255	20.7	235487	12.5	5.4	0.58	4.4
6	Electrical engineering	165	166	4.2	227823	3.4	6.4	0.29	1.9
7	Multidisciplinary sciences	519	367	35.9	184404	16.2	5.2	0.98	5.9
8	Environmental sciences	159	160	12.9	170599	5.9	6.2	0.6	2.7
9	Neurosciences	187	181	11.4	159033	8.2	7.7	0.5	3.9
10	Surgery	104	121	5.7	155221	8.6	7	0.3	1.4
11	Pharmacology, pharmacy	105	117	10.1	149609	6.8	7.1	0.32	2.7
12	Oncology	260	218	22.7	147570	15.4	5.5	0.53	4
13	Condensed matter physics	296	250	18.2	131802	6.8	4.8	0.87	3.4
14	Chemical eng.	133	141	14.2	127297	4.8	6	0.74	2.3
15	Nanoscience nanotechnology	337	274	15.4	126462	6.4	4.4	0.81	3.3
16	Biotechnology, microbiology	220	188	19.8	123573	7.7	5.6	0.66	3.1
17	Optics	125	136	14.0	122955	6.1	6.4	0.78	2.5
18	Mathematics	46	68	1.8	119243	2.1	12.3	0.39	1.6
19	Public occupational health	110	124	5.8	118333	6.5	7.3	0.29	2
20	Applied mathematics	70	86	1.9	117549	2.4	9	0.37	1.6
21	Clinical neurology	146	149	10.9	111086	11.7	7.6	0.45	5.8
22	Multidisciplinary physics	215	197	12.8	109406	6.4	8.6	0.93	5.4
23	Cell biology	272	238	25.9	108662	12.8	5.3	0.67	4.8
24	Energy, fuels	154	157	14.0	101404	5.2	5.6	0.69	2.3
25	Organic chemistry	100	113	5.4	101007	4.4	5.8	0.67	2.4
26	Analytical chemistry	99	113	5.2	100161	4.7	5.5	0.69	2.3
27	Plant sciences	93	106	7.4	95409	7.8	7.7	0.63	2.9
28	Food science technology	65	81	3.2	95236	4.6	8.1	0.52	1.4
29	Multidisciplinary geosciences	98	115	6.6	93070	6.4	9.5	0.47	2.4
30	Immunology	170	171	14.6	92018	10.8	5.9	0.63	4.7

Table 2. Bibliometric indicators (2010–2014): Category rank from 31 to 60.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
31	General internal medicine	460	316	49.7	91063	19.0	5.8	0.97	8.8
32	Astronomy, astrophysics	197	177	5.7	90901	20.8	7.1	0.61	8.1
33	Heredity genetics	229	200	21.3	90283	17.7	5.1	0.55	7
34	Microbiology	125	133	7.9	89376	9.3	6.1	0.47	3.6
35	Radiology, nuclear medicine	115	128	5.9	87358	7.6	6.8	0.57	2.3
36	Economics	79	97	4.2	85808	2.3	9.1	0.29	0.3
37	Polymer science	98	109	5.0	85683	4.7	6.3	0.68	2.1
38	Mechanics	67	86	3.2	82732	2.9	9.3	0.34	1.4
39	Cardiac cardiovascular systems	208	182	14.3	82181	14.5	7.5	0.81	3.8
40	Experimental medicine	162	167	18.1	80830	13.4	6.4	0.84	4.5
41	Ecology	124	130	7.9	79713	5.7	8.6	0.28	2.6
42	Physics–atomic mol. chem.	127	138	5.1	79699	3.9	7.3	0.77	2.5
43	Psychiatry	117	129	11.1	77000	7.8	7.5	0.52	5
44	Metallurgy, metallurgical eng.	65	82	3.6	76348	4.3	9.4	0.8	1.7
45	Mechanical engineering	58	76	3.1	75736	3.3	9.4	0.43	1.5
46	Biochemical research methods	207	162	14.0	73352	6.0	5.8	0.6	3.1
47	Endocrinology, metabolism	127	134	9.7	71958	9.4	6.9	0.54	3.6
48	Veterinary sciences	40	56	2.2	70466	5.7	8.8	0.37	1.3
49	Pediatrics	74	91	5.0	69246	7.1	7.8	0.62	2.3
50	Civil engineering	67	85	3.9	68200	4.0	7.3	0.79	1.7
51	Applied chemistry	69	85	3.9	64375	4.7	7.4	0.59	1.7
52	Inorganic, nuclear chemistry	78	95	4.7	64157	5.0	7.4	0.89	2.4
53	Instruments, instrumentation	74	90	4.8	63594	4.3	6.2	0.75	2.3
54	Medicinal chemistry	73	89	4.3	62651	6.5	7.6	0.65	1.8
55	Electrochemistry	101	117	5.1	62286	5.0	5.6	0.73	2
56	Interdisciplinary computer sci.	134	126	4.1	60469	3.8	7.7	0.61	1.8
57	Infectious diseases	110	121	9.1	59151	10.3	6.1	0.59	4.1
58	Telecommunications	83	105	3.3	58937	3.7	5.3	0.47	1.4
59	Water resources	69	88	4.2	57784	4.7	8.2	0.7	1.9
60	Biophysics	107	113	8.3	57391	6.3	6.8	0.4	3.1

Table 3. Bibliometric indicators (2010–2014): Category rank from 61 to 90.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
61	Particles fields physics	126	134	5.4	57041	4.5	10.8	0.8	8.1
62	Meteorology, atmospheric sci.	104	119	6.5	55871	9.5	7	0.52	2.9
63	Zoology	45	62	3.1	55437	4.4	15.6	0.38	2.6
64	Computer sci. info. systems	84	101	3.7	53146	3.2	7.5	0.45	1.5
65	Computer sci. AI	111	125	4.7	53076	3.1	7.6	0.41	2.1
66	Gastroenterology, hepatology	133	142	13.2	52101	10.5	6.5	0.73	3.6
67	Environmental engineering	105	119	5.3	51862	4.8	6.2	0.79	2
68	Obstetrics, gynecology	65	84	4.5	51756	6.7	7.3	0.54	1.9
69	Biomedical engineering	98	111	7.4	50719	6.6	6.3	0.84	2.6
70	Multidisc. engineering	53	74	2.6	50580	3.3	8.8	0.54	1.6
71	Orthopedics	64	83	3.8	50246	5.7	8.1	0.51	1.4
72	Mathematical physics	61	78	2.4	49314	2.8	9.2	0.7	2.2
73	Marine, freshwater biology	55	73	2.8	49131	5.2	10.1	0.31	2.3
74	Biology	85	100	6.6	49057	6.7	7.7	0.63	3.1
75	Thermodynamics	64	84	3.6	48245	3.4	7.9	0.61	1.1
76	Toxicology	76	94	5.5	47447	6.6	7.9	0.43	2
77	Physiology	66	79	4.3	47206	6.4	8.3	0.36	2.5
78	Hematology	127	136	9.4	46673	12.9	6.4	0.78	3.9
79	Urology, nephrology	93	109	8.4	46350	9.2	6.1	0.69	2.3
80	Educational research	44	66	2.7	46203	2.7	9.6	0.37	0.1
81	Nutrition, dietetics	83	101	4.9	45511	6.7	7.2	0.56	2.3
82	Nuclear sci. technology	38	57	1.4	45307	6.8	9.9	0.62	1.9
83	Geochemistry, geophysics	73	90	4.1	45091	4.7	11	0.45	2
84	Peripheral vascular disease	157	152	11.4	44332	12.1	7.9	0.83	3.9
85	Statistics, probability	109	111	4.2	44155	3.2	8.3	0.78	1.9
86	Fluids, plasmas physics	55	72	2.5	43118	3.6	8.7	0.7	1.7
87	Management	75	94	4.9	42111	2.5	11.9	0.25	0.2
88	Interdisciplinary math appl.	55	73	2.6	42083	2.8	9	0.46	1.6
89	Crystallography	78	84	4.2	41570	5.7	6.4	0.94	2.5
90	Spectroscopy	53	72	2.5	41260	5.3	8.4	0.39	2.5

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Table 4. Bibliometric indicators (2010–2014): Category rank from 91 to 120.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
91	Dentistry, oral surgery	46	64	3.7	41075	5.6	8.4	0.45	1
92	Agronomy	47	66	3.2	40309	5.5	9.1	0.53	1.9
93	Ophthalmology	68	85	4.6	39500	6.5	8.8	0.66	2.8
94	Operations res. management	55	72	2.6	38668	2.6	9.9	0.47	1.2
95	Multidisciplinary agriculture	45	62	2.8	38386	5.3	7.8	0.83	1.6
96	Sport science	61	78	3.8	38073	5.5	8.4	0.57	1.3
97	Automation control systems	91	108	4.5	37607	3.1	6.7	0.67	2.1
98	Computer sci. software eng.	47	66	2.1	37596	3.4	7.5	0.28	1.4
99	Health care science services	71	89	3.9	37155	6.0	7.2	0.44	1.3
100	Respiratory system	98	115	9.1	36915	10.5	7.2	0.7	4.1
101	Pathology	75	95	6.3	36251	9.4	6.6	0.54	2.7
102	Multidisciplinary psychology	81	99	7.8	35326	2.8	10.8	0.5	0.4
103	Computer science theory	59	81	3.0	33601	3.2	7.6	0.33	2
104	Rehabilitation	44	63	2.8	33403	5.1	8.7	0.34	1.1
105	History	10	21	1.1	33312	1.4	19.6	0.28	0
106	Dairy, animal science	37	58	2.3	32548	5.5	9.6	0.7	1.8
107	Nursing	28	43	1.9	32082	3.9	8.1	0.26	0.9
108	Clinical psychology	68	86	4.8	31743	5.1	9.3	0.33	1.6
109	Virology	91	109	7.0	31649	10.1	6.2	0.85	3.4
110	Nuclear Physics	82	100	4.7	31571	4.7	12.2	0.85	10.9
111	Experimental psychology	67	85	3.5	31321	3.3	10.1	0.34	0.9
112	Coatings, films	52	69	2.8	30783	4.8	7.4	0.98	1.7
113	Dermatology	48	65	5.3	30474	7.2	8.3	0.62	2.1
114	Political science	39	57	3.1	29881	1.7	10.1	0.3	0
115	Psychology	73	92	8.1	29628	4.1	10.3	0.4	1.7
116	Environmental studies	70	90	6.2	29625	3.3	7.2	0.63	1.5
117	Computational biology	122	121	4.5	29329	4.2	6.5	0.81	2.3
118	Entomology	34	49	2.4	29266	4.6	10.9	0.3	1.9
119	Oceanography	50	68	2.8	29259	4.8	10	0.4	2.4
120	Business	67	87	5.1	27946	2.5	11.9	0.29	0

Table 5. Bibliometric indicators (2010–2014): Category rank from 121 to 150.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
121	Building technology	42	59	3.0	27665	3.3	9.2	0.68	1.3
122	Biomaterials	95	109	7.6	27583	6.7	6	0.93	2.7
123	Behavioral science	56	72	4.9	27401	4.3	9.9	0.4	1.8
124	Philosophy	14	28	0.9	26731	1.3	14.3	0.29	0.1
125	Evolutionary biology	97	106	7.8	25971	4.7	8.8	0.68	2.5
126	Parasitology	77	95	7.9	25569	9.5	6.9	0.91	3.4
127	Otorhinolaryngology	33	49	2.4	25521	5.4	9.7	0.49	0.9
128	Sociology	42	62	2.7	24444	1.8	10.9	0.31	0
129	Manufacturing eng.	39	56	2.7	24273	3.2	8.7	0.6	1.1
130	Health policy services	53	74	4.0	23758	5.2	6.8	0.53	1.3
131	Ceramics materials sci.	35	52	2.5	23612	4.6	10.1	0.88	1.6
132	Physical geography	59	77	4.2	23489	5.0	9.7	0.45	2.3
133	Fisheries	34	49	2.5	23335	5.1	9.5	0.5	2.1
134	Forestry	37	52	3.1	22706	4.6	9.8	0.67	2.2
135	Transplantation	62	80	4.5	22288	10.3	6.5	0.67	2.6
136	Interdisciplinary social sci.	34	51	2.2	22216	2.8	10.1	0.5	0.2
137	Law	25	41	3.5	22148	1.9	10.9	0.23	0
138	Linguistics	28	44	2.7	22057	2.5	11.9	0.38	0.5
139	Computer science hardware	48	71	3.3	21756	3.4	6.4	0.5	1.9
140	Critical care medicine	97	111	9.0	21483	10.4	8	0.8	4.4
141	Biodiversity, conservation	62	84	6.0	20992	5.3	8.1	0.68	2.9
142	Acoustics	41	59	2.8	20857	4.2	8.7	0.49	1.4
143	Reproductive biology	54	73	4.3	20769	6.4	7.8	0.7	1.8
144	Geriatrics, gerontology	58	77	5.0	20695	7.6	7.8	0.57	3
145	Rheumatology	80	96	7.9	20565	10.0	7.4	0.84	5.1
146	Industrial engineering	43	62	2.3	20473	2.9	8.9	0.58	1
147	Developmental psychology	59	76	4.8	20417	4.5	9.7	0.45	1.3
148	Language, linguistics	16	31	1.2	20102	1.9	12.6	0.34	0
149	Soil science	45	66	3.1	20077	4.9	9.6	0.64	1.9
150	Business finance	44	66	3.4	19688	2.4	10.2	0.54	0

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Table 6. Bibliometric indicators (2010–2014): Category rank from 151 to 180.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
151	Developmental biology	85	102	8.9	17669	7.6	6.7	0.86	3.5
152	Social psychology	50	68	3.8	17553	3.1	12	0.47	0
153	Information, library sci.	41	62	2.9	17488	2.8	9.1	0.51	0.7
154	Multidisciplinary humanities	8	21	1.7	17455	1.7	12.9	0.51	0
155	Geography	45	67	3.7	17381	2.3	7.9	0.46	0.6
156	Agricultural engineering	68	85	4.3	17177	4.6	7.3	0.99	1.8
157	Education scientific disc.	34	53	2.5	17068	3.6	8.3	0.61	0.7
158	Anthropology	33	50	2.9	16922	3.2	11.8	0.5	1.5
159	Anesthesiology	55	72	4.8	16889	6.5	7.5	0.75	2.1
160	Horticulture	30	45	2.6	16857	6.3	9.3	0.73	1.9
161	Remote sensing	56	77	4.6	16306	4.3	8.4	0.8	1.7
162	Literature	6	20	1.0	16235	1.4	14.1	0.48	0
163	Transportation sci.	38	54	2.6	16111	3.0	7.7	0.64	1.5
164	Applied psychology	46	68	4.0	16034	2.9	11.5	0.4	0.1
165	Religion	9	22	1.0	15876	1.9	12.4	0.47	0
166	International relations	27	47	2.6	15566	1.7	8.6	0.42	0
167	Composites materials sci.	40	56	3.2	15411	3.7	8.1	0.86	1.3
168	Emergency medicine	33	53	3.3	15289	6.8	8.2	0.81	1.1
169	Tropical medicine	40	58	3.5	15286	8.9	8.3	0.91	2.4
170	Substance abuse	43	64	3.7	15071	4.8	8.5	0.56	1.9
171	Photographic technology	59	81	4.6	15007	4.3	8.4	0.85	1.8
172	Integrative medicine	28	41	2.9	14095	6.2	8.9	0.84	1.5
173	Medical laboratory technol.	41	63	4.9	13860	7.2	7.1	0.76	2
174	Ethics	21	37	2.0	13768	2.2	10.2	0.64	0.4
175	Transportation	31	47	2.5	13688	2.8	9.1	0.61	0.7
176	Communication	28	47	2.1	13327	2.1	9.8	0.36	0
177	Biomedical social science	34	52	3.0	13187	4.9	8.2	0.71	0.7
178	Aaerospace engineering	19	34	1.2	13077	3.0	11.3	0.71	1.1
179	Literary theory criticism	3	10	0.0	12970	1.1	18.5	0.25	0
180	Planning development	36	57	2.7	12802	2.0	9.3	0.49	0

Table 7. Bibliometric indicators (2010–2014): Category rank from 181 to 210.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
181	Paleontology	28	44	2.5	12463	4.7	13.9	0.61	2.5
182	Geological engineering	24	38	1.9	12317	3.2	12.6	0.4	1.6
183	Mining, mineral processing	24	39	1.7	12260	4.8	11.9	0.89	1.4
184	Medical informatics	38	58	2.7	12051	4.7	7.3	0.6	1.6
185	Art	6	17	1.3	12001	2.6	14.5	0.66	0.5
186	Gerontology	41	60	4.2	11865	6.4	9	0.77	2.3
187	Characterization, testing	20	35	1.8	11782	3.8	9.8	0.7	1.3
188	Neuroimaging	82	98	6.0	11759	6.8	7.1	0.97	3
189	Geology	36	55	3.9	11542	4.9	11.8	0.71	2.2
190	Archaeology	20	34	2.0	11383	3.9	13.5	0.73	1.5
191	Mineralogy	36	53	3.4	11194	4.6	11.5	0.71	2.1
192	History philosophy of sci.	15	30	1.4	11047	1.8	14.3	0.42	0.6
193	Social sci. math. methods	32	53	2.7	10603	2.3	11.3	0.49	0.9
194	Area studies	12	24	1.0	10533	1.5	7.6	0.3	0
195	Family studies	27	46	1.8	10331	3.3	9.5	0.44	0
196	Audiology speech pathology	27	41	2.2	10179	3.8	11.6	0.68	1.4
197	Cell tissue engineering	93	111	14.9	10045	9.4	5.7	0.83	3.9
198	Literary reviews	1	9	0.5	9790	1.1	15.4	0.65	0
199	Textiles materials sci.	26	46	3.4	9736	4.9	7.6	0.95	2
200	Educational psychology	38	59	3.4	9692	3.2	11.2	0.57	0
201	Social work	20	33	1.8	9670	2.9	9.6	0.51	0
202	Limnology	38	56	3.2	9578	4.3	10.4	0.86	2.3
203	Criminology, penology	23	38	2.2	9572	2.7	11.1	0.34	0
204	Mycology	33	52	4.0	9402	5.6	10.9	0.5	2.1
205	Anatomy morphology	24	41	2.5	9343	5.1	11.1	0.54	2
206	Hospitality, leisure, sport	27	44	2.3	9328	2.4	10.4	0.61	0.1
207	Allergy	63	86	9.6	9201	9.5	7.1	0.91	6
208	Architecture	4	14	0.5	8993	2.0	15	0.48	0.3
209	Urban studies	25	42	2.2	8965	2.4	9	0.55	0.5
210	Petroleum engineering	12	27	1.1	8874	3.5	13.7	0.77	1.2

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Table 8. Bibliometric indicators (2010–2014): Category rank from 211 to 236.

Rank	Category	$\bar{N}_{cit}$	h_{cat}	$\bar{N}_{IF}$	N_{art}	$\bar{N}_{au}$	β	η	$\bar{N}_{fund}$
211	Romance literature	2	6	0.1	8795	1.1	19.9	0.33	0
212	Cultural studies	16	33	1.2	8481	1.6	10.1	0.54	0.1
213	Public administration	21	38	1.9	8453	1.8	9.6	0.35	0
214	Music	7	20	1.5	8387	2.0	13.5	0.58	0.2
215	Paper, wood material sci.	22	40	2.5	8359	4.1	10.2	0.85	1.6
216	Legal medicine	24	42	2.4	8334	5.1	8.7	0.78	0.9
217	Primary health care	23	38	2.8	8239	5.5	7.8	0.48	1.4
218	Social issues	19	35	2.3	7834	2.1	9.2	0.44	0.3
219	Robotics	27	46	2.2	7672	3.4	8.1	0.62	1.5
220	Ocean engineering	18	32	1.7	7660	3.4	11.1	0.77	1.8
221	Classics	3	9	0.0	7618	1.1	22.8	0.24	0
222	Biological psychology	36	56	4.0	7480	3.7	10.6	0.6	1.5
223	Women's studies	19	32	1.8	7312	3.0	9.6	0.6	0.4
224	Special education	24	42	2.0	6813	4.2	9.9	0.63	0
225	Ergonomics	22	38	1.8	6340	3.1	10	0.69	0.4
226	Cybernetics computer sci.	31	56	4.0	6295	3.3	8.3	0.7	2.1
227	Theater	2	10	0.3	6009	1.2	15.2	0.35	0
228	Ornithology	18	34	2.4	5757	4.9	7	0.59	1.5
229	Asian studies	3	11	0.4	5561	1.2	18.5	0.35	0
230	Film, radio, television	9	28	0.7	5400	1.4	10.3	0.52	0
231	Mathematical psychology	21	42	2.7	5340	2.5	12.3	0.77	0.2
232	Microscopy	24	43	2.3	4904	5.1	9.8	0.71	1.8
233	History of social sci.	7	17	0.8	4867	1.7	21.4	0.42	0
234	Demography	19	36	1.8	4447	2.0	10.1	0.52	0
235	Industrial relations labor	13	28	1.5	4403	2.1	10.8	0.44	0
236	Logic	7	19	0.6	4381	1.8	15.1	0.38	1

6. Conclusions

Publishing a highly cited paper is gratifying and confirms that the work has an impact on the scientific community. However, the number of citations the top articles accrue depends on factors other than quality and originality. We tabulate bibliometric indicators for the top 500 cited articles of 236 scientific categories and include the average impact factors of the journals that publish the articles, the category h-index and the total number of articles in each category. With this data, researchers, institutions and funding agencies can gauge their productivity and impact quantitatively.

Citation rates, $\bar{N}_{cit}$ vary across research categories by several orders of magnitude as do the number of articles per category and the number of authors per article. Categories with more articles and more funding are cited more. Other factors that correlate with citations include the age of the references, journal impact factor and

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funding agencies. We assume that $\bar{N}_{cit}$ is related to bibliometric indicators and that 500 articles from categories with 100 000 articles (0.5%) are comparable to those with 5000 (10%). This comparison may exaggerate the differences between fields, but science endeavours that have orders of magnitude more researchers will have that much more impact.

Most categories are within 33% of the $\bar{N}_{cit}$ regression equation. Other factors that may account for the difference may be related to the scope of the category. For instance, many researchers outside of the psychology field may be citing psychology papers, which would increase the number of citations beyond what we expect based on the bibliometric indicators. The correlation overestimates the number of citations for nursing and many engineering categories: here, the citation patterns might be narrower as only the people in these fields cite one another. A further limitation to the analysis relates to the limitations of WoS: coverage of the humanities, social sciences, business, and even mathematics are poorer than they are for natural sciences and health sciences. However, the number of funding agencies, which correlates with the number of authors (and the number of international collaborations), helps increase the visibility of research and its scientific impact.

Declarations

Author contribution statement

Gregory S. Patience: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Christian A. Patience: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Bruno Blais, Francois Bertrand: Contributed reagents, materials, analysis tools or data.

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