UNIVERSIDAD CARLOS III DE MADRID working papers

Working Paper

Economic Series 13-08

April 2013

Departamento de Economía

Universidad Carlos III de Madrid

Calle Madrid, 126, 28903 Getafe (Spain)

"THE IMPACT OF EXTREME OBSERVATIONS IN CITATION DISTRIBUTIONS"

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Abstract

This paper studies the role of extremely highly cited articles in two instances: the measurement of citation inequality, and mean citation rates. Using a dataset, acquired from Thomson Scientific, consisting of 4.4 million articles published in 1998-2003 in 22 broad fields with a five-year citation window, the main results are the following. Firstly, both within each of 22 broad fields and in the all-sciences case, citation inequality is strongly affected by the presence of a handful of extreme observations, particularly when it is measured by citation inequality indices that are very sensitive to citation differences in the upper tail of citation distributions. Secondly, the impact of extreme observations on citation averages is generally much smaller. The concluding Section includes some practical lessons for students of citation inequality and/or users of high-impact indicators.

Acknowledgements

The authors acknowledge financial support by Santander Universities Global Division of *Banco Santander*. Ruiz-Castillo also acknowledges financial help from the Spanish MEC through grant ECO2011-29762.

INTRODUCTION

Given the skewness of citation distributions (see *inter alia* Seglen, 1992, Shubert *et al.*, 1987, Glänzel, 2007, Albarrán and Ruiz-Castillo, 2011, and Albarrán *et al.*, 2011a), citation inequality –however measured– is expected to be very high. By itself, this need not constitute a problem. However, it is also well known that, occasionally, a handful of truly highly cited articles may entirely dominate the citation distributions of relatively small research units. This situation causes two problems. Firstly, many measures of citation inequality may be unduly influenced by these few observations. Apart from the difficulties that this situation might create for the study of citation inequality itself, it may cause serious problems for the evaluation of research using citation impact indicators that respond positively to increases in citation inequality. In particular, one of us has proposed a high-impact indicator that is increasing in citation inequality measured by the coefficient of variation (Albarrán *et al.*, 2011b).[1] Secondly, by construction, widely used average-based indicators of citation impact (see Waltman *et al.*, 2011, for a recent discussion) are insensitive to distributive aspects of citation behavior. However, even average-based indicators may be dramatically influenced by extreme observations. This problem is best illustrated with the place of the University of Göttingen in the 2010/2011 Leiden Ranking.[2] This paper is an empirical investigation of these issues.

Using a dataset, acquired from Thomson Scientific, consisting of 4.4 million articles published in 1998-2003 in 22 broad fields with a five-year citation window, we perform two exercises. Firstly, we study the sensitivity of certain citation inequality indices to the presence of extreme observations, namely, extremely highly cited articles in a particular field. We focus on the Generalized Entropy (GE hereafter) family of citation inequality indices that have been characterized in the income inequality literature in terms of a number of

[1] Other recent contributions in citation analysis highlight the potential influence that distributional considerations might have in the assessment of citation profiles. At the opposite extreme from Albarrán *et al.* (2011b), see Ravallion and Wagstaff (2011); see also Bouyssou and Marchant (2010), Marchant (2009), and Abatemarco and Dell'Anno (2012).

[2] The *Leiden Ranking 2011/2012* (http://www.leidenranking.com/methodology.aspx) is based on publications in the sciences and the social sciences in Thomson Reuters' Web of Science database in the period 2005-2009. The University of Göttingen is ranked second with the Mean Normalized Citation Score (MNCS) indicator, but it is rated 238th based on its share of publications within the world top 10% of most highly cited documents. The MNCS indicator is strongly influenced by a single publication in January 2008 that has been cited 16,000 times by the end of 2010 (see Waltman *et al.*, 2012).

interesting properties (Bourguignon, 1979, Cowell and Kuga, 1981, and Shorrocks, 1980, 1984). This family is well suited to illustrate the potential problem created by extreme observations because several of its members are particularly sensitive to citation differences at different segments of citation distributions. Secondly, we investigate the influence of extreme observation on field mean citation rates.

The remaining part of this paper is organized into three Sections. Section II studies the sensitivity of three members of the GE family of citation inequality indices to the presence of extreme observations, while Section III does the same for the mean citation indicator. The concluding Section IV includes some practical recommendations for the evaluation of the citation impact in the light of our results.

II. THE SENSITIVITY OF CITATION INEQUALITY INDICES TO EXTREME OBSERVATIONS

II.1. The GE Family of Citation Inequality Indices

Assume that there are N articles, indexed by $l = 1,\dots, N$, and let c_l be the number of citations received by the i-th one. Let $\boldsymbol{C} = (c_1,\dots, c_l,\dots, c_N)$ be the ordered citation distribution where $c_1 \leq c_2 \leq \dots \leq c_N$. For any population partition, we are often interested in expressing the overall citation inequality as the sum of two terms: a weighted sum of within-group inequalities, plus a between-group inequality component. An inequality index is said to be decomposable by population subgroup, if the decomposition procedure of overall inequality into a within-group and a between-group term is valid for any arbitrary population partition. In the relative, or scale-invariant inequality case it is customary to calculate the between-group component by applying the inequality index to a citation vector in which each article in a given subgroup is assigned the subgroup's citation mean. Under this convention, it is well known that the GE family of inequality indices are the only measures of relative inequality that satisfy the usual properties[3] required from any inequality index and, in addition, are decomposable by population subgroup (Bourguignon, 1978, and Shorrocks, 1980, 1984).

[3] Namely, continuity; scale invariance; invariance to population replications, or size-invariance, and S-convexity that ensures that transfers from an article with more citations to another with fewer citations without altering their ranking reduce citation inequality.

If we denote by μ the mean of distribution C, then the GE family can be described by means of the following convenient cardinalization:

$$I_\alpha(C) = (1/N)\,(1/\alpha^2 - \alpha)\,\Sigma_l\,(c_l/\mu^\alpha - 1),\ \alpha \neq 0,1; \qquad (1)$$

$$I_0(C) = (1/N)\,\Sigma_l \log(\mu/c_l);$$

$$I_1(C) = (1/N)\,\Sigma_l\,(c_l/\mu)\log(c_l/\mu).$$

Parameter α summarizes the sensitivity of I_α in different parts of the citation distribution: the more positive (negative) α is, the more sensitive I_α is to citation differences at the top (bottom) of the distribution (Cowell and Kuga, 1981). I_1 is the original Theil index, while I_0 is the mean logarithmic deviation.

Consider any partition of C into, say, F scientific fields, indexed by $f = 1,\ldots, F$. Let $c^f = (c^f_1,\ldots, c^f_i,\ldots, c^f_{Nf})$ be field f citation distribution, where c^f_i is the number of citations received by the i-th article in field f, and N_f is the number of articles in field f, so that $\Sigma_f N_f = N$. Denote the ratio N_f/N by p^f, and let v^f be the share of total citations held by articles in field f. The formula for the GE index when written in decomposable form is the following:

$$I_\alpha(C) = \Sigma_f w_\alpha^f I_\alpha(c^f) + I_\alpha(\mu^1,..., \mu^F), \qquad (2)$$

where $w_\alpha^f = [(v^f)^\alpha (p^f)^{1-\alpha}]$, and $I_\alpha(\mu^1,..., \mu^F)$ is the between-group inequality calculated as if each article in field f receives the field's mean citation μ^f. Note that $\Sigma_f w_\alpha^f = 1$ only when $\alpha = 0, 1$, in which cases we have $w_0^f = p^f$, and $w_1^f = v^f$.

In the analysis of the all-fields case, it is customary to take into account the differences in publication and citation practices across fields by taking the field mean citations as normalization factors. Thus, in the normalized citation distribution, denoted by C^*, article i in field f is assigned the normalized citations $c^{f*}_i =$

c^f_i/μ^f.[4] When we do this, the mean citation of the normalized citation distribution in every field becomes $\mu^{f*} = 1$ for all *f*. Therefore, the between-group term in decomposition (2) becomes zero. Furthermore, since the normalized citation distribution in any field, c^{f*}, is simply a re-scaling of the original distribution c^f, we have $I_\alpha(c^{f*}) = I_\alpha(c^f)$ for all α. Therefore, for every α we have

$$I_\alpha(C^*) = \Sigma_f w^f_\alpha I_\alpha(c^f). \tag{3}$$

Thus, the overall citation inequality of the normalized distribution C^* is equal to the within-group term in the decomposition of the overall citation inequality in the un-normalized case (see Eq. 2).

In order to study the sensitivity of citation inequality indices to extreme observations, we choose the members of the GE family I_0, I_1, and I_2, which are particularly sensitive to citation differences at, approximately, the bottom, the middle, and the very top of citation distributions.

II.2. The Impact of Extreme Observations

In this paper only research articles or, simply, articles, are studied. The dataset consists of 4.4 million articles published in 1998-2003, and the 35 million citations they receive after a common five-year citation window for every year. We identify the set of fields with the 20 broad fields for the natural sciences and two for the social sciences distinguished by Thomson Scientific. In practice, by extreme observations we mean the six articles with the maximum number of citations in each field. Table 1 presents the number of articles per field, the field mean citations, and the number of citations of the six most cited articles in each field. Field sizes range from 20,672 in the Multidisciplinary case, to 947,261 in Clinical Medicine. Average citations also vary widely, from 2.4 in Mathematics to 20.4 in Molecular Biology. Finally, it is interesting to see that the number of citations of the smallest of the six extreme observations is from almost 20 times the average citation in

[4] For an analysis of the consequences of this and other classification-system-based normalization procedures of the target or cited-side type, see Radicchi and Castellano (2012), Crespo *et al.* (2013a, b), Li *et al.* (2013), and Waltman and Van Eck (2013).

Microbiology, or 25/26 times in Agricultural Sciences and Neuroscience and Behavioral Sciences, to more than 100 times in Chemistry, Physics, Computer Science, and Clinical Medicine. The smallest of the six extreme observations in the all-sciences case is more than 300 times greater than the average citation both before and after normalization.

Table 1 around here

Table 2 presents the impact on I_2 of consecutively eliminating the six most cited articles in each field. The two rows in the all-fields case refer to the raw and the normalized citation distributions $\boldsymbol{C}$, and $\boldsymbol{C}^*$ (see Eqs. 2 and 3). Since there are 22 fields, in this case we measure the impact on I_2 of consecutively eliminating 22, 44,…, up to 132 articles from the 4,472,332 in the entire dataset. Tables 3, and 4 contain the same information for indices I_1 and I_0. The problem posed by articles with zero citations in expression (1) is solved as follows. For I_1 in Table 3, we apply the convention 0 log(0) = 0, while for I_0 we experiment by assigning small values to uncited articles. The results in Table 4 are for ε_1 = 0.01. Since the coefficient of variation (CV hereafter) –that is, the ratio of the standard deviation over the mean– is the citation inequality index that appears in the high-impact indicator introduced in Albarrán *et al.* (2011b), we have recorded the results of the same experiment in Table 5. It should be noted that, for any citation distribution $\boldsymbol{C}$, there exists the following relationship between the CV($\boldsymbol{C}$) and $I_2(\boldsymbol{C})$:

$$\mathrm{CV}(\boldsymbol{C}) = [2I_2(\boldsymbol{C})]^{1/2}.$$

Tables 2, 3, 4, and 5 around here

The results are very eloquent. When citation inequality is measured by I_2, which is particularly sensitive to citation differences in the upper tail of citation distributions, the impact of extreme values is truly large. In four scientific fields, eliminating a single observation reduces citation inequality by 34.6% (Computer Science), 23.6% (Mathematics), 17.7% (Chemistry), and 9.9% (Space Science). In five other fields, the reduction of citation inequality ranges from 5.3% (Multidisciplinary) to 7.5% (Geosciences), while in the next five fields the reduction ranges from 1.5% (Agricultural Science) to 4.0% (Immunology). When we eliminate six observations, the reduction in citation inequality ranges from 18% (Space Science) to 66.7% (Computer Science) in the first four fields, from 10.2% (Multidisciplinary) to 16.6% (Biology and Biochemistry) in the next five, and from 4.9% (Plant and Animal Science) to 9.3% (Immunology). Interestingly enough, the successive elimination of the most cited articles in each field causes the between-group term according to I_2 (see Eq. 2) to increase at each juncture. Consequently, the elimination of one or six observations in the all-fields case results in a reduction of citation inequality according to this index from 4.8% to 11.8% for the raw citation distribution, and from 9.2% to 19.3% for the normalized citation distribution.

When we use citation inequality indices that are more sensitive to citation differences in lower segments of citation distributions, although a few qualitative results are maintained the order of magnitude of the problem considerably decreases. Firstly, the identity of the fields that are more affected by extreme observations in our dataset always includes Computer Science and Mathematics in the first two positions, as well as Space Science, Multidisciplinary, and Immunology in the next places. However, the field rank according to the size of the reduction in citation inequality after the elimination of six observations using the different indicators is rather different: the correlation coefficient between the rankings according to I_2 and I_1, I_2 and I_0, and I_1 and I_0 are - 0.19, 0.09, and 0.34, respectively. Secondly, not surprisingly in view of the sensitivity of the citation indicators to differences in lower parts of citation distributions, the impact of the elimination of extreme observations using I_1 and I_0 is much smaller than what we saw before using I_2. For example, the more important reductions in citation inequality after the elimination of six observations range from 2.7% (Mathematics) to 8.1% (Computer Science) according to I_1, and from 0.4% (Mathematics) to 1.1% (Computer Science) according to I_0. Similarly, in the all-sciences case, the elimination of six observations results in a reduction in citation inequality in the raw and normalized citation distributions of 1.0% and 1.3% according to I_1, and 0.2% in both cases according to I_0.

Finally, we may ask under which standard the previously recorded reductions in citation inequality can be convincingly considered to be very large. A reasonable reference is the random elimination of observations in each field, and hence in the all-sciences case, rather than the systematic elimination of the most cited articles. We have computed the average reduction (and the standard deviation) in citation inequality according to I_2, I_1, I_0, and CV over 1,000 trials, in each of which six observations from each field, or 132 in the all-sciences case, were randomly eliminated. The results are in Table 6. Given the relationship between the CV and I_2, only the results for I_2, I_1, I_0 need to be studied.

Table 6 around here

The average effect over 1,000 trials of randomly eliminating six observations per field indicates that only on six out of (22 x 6) = 72 occasions does this operation lead to an increase in citation inequality. More importantly, only in five cases does the random elimination of observations lead to a result that is statistically different from zero. The exceptions are Agricultural Science according to the three indices, and the all-sciences case when citation inequality is measured by I_0. On average, the reduction of citation inequality in Agricultural Science is equal to 0.0070%, 0.0061%, and 0.0081% according to I_2, I_1, I_0, while the systematic reduction of the six most cited articles led to a reduction in citation inequality according to the three indices equal to 3.7%, 0.7%, and 0.1% (see Tables 2, 3, and 4). In the all-sciences case, the reduction in citation inequality according to I_0 caused by the random (and systematic) elimination of observations in the raw and the normalized citation distributions amounts to 0.0006% (0.2%), and 0.0005% (0.2%). The conclusion is that, as expected, the reductions in citation inequality recorded in Tables 2 to 5 are –in all cases– very large indeed.

III. THE SENSITIVITY OF FIELD CITATION AVERAGES TO EXTREME OBSERVATIONS

The effect of extreme observations on field average values, as well as in the all-fields case, is in Table 7. This information indicates that, except in some cases, the sensitivity of field mean citations to extreme observations is generally small.

Table 7 around here

For example, eliminating the six most highly cited observations in eleven fields reduces mean citation by 0.2% or less. For seven other fields, the reduction is in the 0.3-0.4% range. On the other hand, in the remaining four cases the impact of extreme observations begins to be non-negligible, in the 0.6-0.7% range (Space Sciences, and Mathematics), or above 1% in the last two cases: 1.1% in the Multidisciplinary field, and 2.5% in Computer Science. Of course, these four fields are among those whose citation inequality is dramatically affected by extreme observations. Finally, in the all-sciences case with raw or normalized data the elimination of 132 observations has a negligible impact.

IV. CONCLUSIONS

This paper has studied the role of extreme observations in two instances. Firstly, when citation inequality is measured by three members of the GE family of citation inequality indices –denoted by I_2, I_1, I_0– that are sensitive to citation differences in different parts of citation distributions and, secondly, when citation distributions are summarized by their averages. In both cases, we use a dataset of almost 4.5 million articles published in 1998-2003 with a five-year citation window, partitioned into 22 broad fields that vary in size from 20,672 (Multidisciplinary) to 947,261 (Clinical Medicine). The results can be summarized as follows.

1. We find that citation inequality is strongly affected by the presence of extreme observations, particularly when it is measured by citation inequality indices –such as I_2– that are very sensitive to citation differences in the upper tail of citation distributions. For example, we find that removing the single most cited

article from each field reduces citation inequality according to I_2 by less than 1% in seven cases, between 1% and 5% in six cases, between 5% and 10% in six cases, and by 17.7%, 23.6%, and 34.7% in the three remaining cases (Chemistry, Mathematics, and Computer Science).

The systematic elimination of highly cited articles has very large effects even when citation inequality is measured by indices that are more sensitive to citation differences in other parts of citation distributions. For example, the removal of the six most cited articles in each field, that is, 132 observations out of a total of 4,472,332, generates a reduction in citation inequality in the raw and normalized citation distributions in the all-sciences case of 1% and 1.2% according to I_1, and 0.2% according to I_0. These effects should be considered to be large when we take into account that the random removal of such a small set of observations within a dataset of almost 4.5 million items causes essentially no change at all in citation inequality however measured.

2. The impact on citation averages of eliminating extreme observations is generally much smaller. However, the removal of the six highest cited articles in four instances (Space Science, Mathematics, Multidisciplinary, and Computer Science) reduces field average citations in the range 0.6%-2.9% –a non-negligible amount.

Beyond the analysis of citation inequality itself, what are the practical implications of these results for the evaluation of the citation impact achieved by research units in specific fields, or even in the all-sciences case? Generally, the effect of extreme observations may depend on the context, namely, on the size of the extreme observations and the size of the citation distributions involved.

Consider first the use of average-based indicators of citation impact. We have seen that in our dataset the two fields whose mean citations are most affected are Computer Science and the Multidisciplinary discipline. In the first one, the smallest extreme observation is about 175 times the average citation, and the size is almost 100,000 articles. In the second one, these two figures are 33 and about 20,000 articles. As we have seen, the removal of the six extreme observations leads to a reduction of 2.9% and 1.1% of the two field averages. Although we have qualified these magnitudes as non-negligible, it is likely that these same extreme observations would have a much greater influence in smaller research units, such as University Departments, Research Institutes, entire Universities, or even small-sized countries in these (or other) two fields. This is the reason why we must celebrate the recent decision by the CWTS (Center for Science and Technological Studies) to compute confidence intervals in the Leiden Ranking for their estimates of an average-based indicator –the MNCS indicator– for the best 500 universities in the world in the all-sciences case. As a matter of fact, this is a practical and rigorous way to identify cases like the University of Göttingen described in footnote 2.

Of course, an alternative way of addressing the problem raised by extreme observations is to substitute an average-based indicator such as the MNCS by another robust indicator of centrality, such as the median. In the Leiden Ranking case, the CWTS uses an indicator from a completely different family, the *Proportion top 10%*, defined as the percentage of an institution's scientific output included into the set formed by the 10% of the most cited papers in their respective scientific fields. The *Proportion top 10%* is a percentile rank indicator that is also robust to extreme observations.[5]

Similar comments are relevant for high-impact citation indicators that increase with citation inequality among the high-impact articles defined as those articles with citations above a certain threshold. A good example is provided by the member of the family of high-impact indicators introduced in Albarrán *et al.* (2011a) –denoted by H_2– that varies directly with the coefficient of variation among high-impact articles. When H_2 was applied to a partition of the world into three large geographical areas –the U.S. the European Union, and the Rest of the World– using essentially the same dataset analyzed in this paper and a citation threshold

[5] This indicator is also known as the *Excellence Rate* in the *SCImago Institutions Rankings* (SIR) 2011 World Report (http://www.scimagoir.com/pdf/sir_2011_world_report.pdf), based on the Scopus® database (Elsevier B.V.).

fixed at the 80th percentile of the world citation distribution, there seems to be no problem caused by extreme observations (see Albarrán *et al.*, 2011c, d, and Herranz and Ruiz-Castillo, 2012a, b, 2013).

The situation is rather different when we consider research units of a relatively small size, as in the partition of the world into 39 countries and eight residual geographical areas when the citation threshold is fixed in the 90th percentile of world citation distributions in each of the fields studied in this paper (see Albarrán and Ruiz-Castillo, 2012). In 18 out of 22 fields a handful of extreme observations drastically affect the CV of the high-impact articles of a number of small countries, and hence their world ranking in terms of the high-impact indicator H_2. In many occasions these drastic changes are not caused by any of the field extreme observations described in columns 4 to 8 in Table 1. What we face is a local phenomenon where a few observations are extreme only in the context of the citation distribution of a relatively small country. The case of Ireland with only 87 articles above the world top 10% in Biology and Biochemistry illustrates the problem. The ratio of the Irish H_2 indicator to the world's one falls from the original extraordinary value of 13.93 to 3.83, 1.40, and 0.72 when we eliminate successively the top one, two, or three articles in the Irish distribution. These three articles are highly cited but not among the most cited in the field in question (for an analysis of other cases, see pages 12-13, and Table 1 in Albarrán and Ruiz-Castillo, 2012).

The conclusion is that for high-impact indicators that go beyond a mere percentage of top cited papers, it is essential to estimate confidence intervals that would allow us to detect the existence of extreme observations that drastically influence the ranking of research units. Likewise, it would be interesting to substitute citation inequality indexes such as the CV in the H_2 case for alternative citation inequality measures, such as the inter-quantile range, robust to extreme observations.

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Table 1. Number of articles, and extreme observations by filed

	Number of Articles	%	Mean citati	Six most cited articles						(10) =
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(9)/(3)
Fields										
1. Agricultural Sciences	82,837	1.9	4.9	258	215	159	141	132	125	25.5
2. Biology & Biochemistry	275,568	6.2	12.5	2,591	2,198	1,914	1,422	1,077	958	76.6
3. Chemistry	550,147	12.3	7.6	4,461	2,921	2,469	947	921	858	112.9
4. Clinical Medicine	947,261	21.2	9.7	3,438	3,308	2,695	2,092	1,941	1,904	196.3
5. Computer Science	98,727	2.2	3.0	2,598	1,591	1,479	829	688	526	175.3
6. Economics & Business	63,380	1.4	3.9	372	221	202	192	154	149	38.2
7. Engineering	356,269	8.0	3.2	325	277	267	244	237	228	71.3
8. Environment & Ecology	109,826	2.5	7.1	949	669	315	295	289	251	35.4
9. Geosciences	120,059	2.7	6.7	973	488	378	307	291	284	42.4
10. Immunology	60,875	1.4	16.0	1,156	772	685	639	601	477	29.8
11. Materials Science	199,364	4.5	4.5	509	471	433	388	355	350	77.8
12. Mathematics	117,496	2.6	2.4	872	284	276	261	253	215	89.6
13. Microbiology	73,039	1.6	11.4	325	322	276	241	235	223	19.6
14. Molecular Biology & Genetics	122,233	2.7	20.4	970	881	834	800	788	766	37.5
15. Multidisciplinary	20,672	0.5	3.2	249	135	121	114	109	106	33.1
16. Neuroscience & Behavior	140,686	3.2	13.7	607	552	437	376	353	351	25.6
17. Pharmacology & Toxicology	76,728	1.7	8.0	317	297	283	247	235	223	27.9
18. Physics	456,144	10.2	6.9	2,345	1,793	1,307	1,279	1,239	1,136	164.6
19. Plant & Animal Science	261,401	5.8	5.1	669	414	281	258	244	241	47.3
20. Psychiatry & Psychology	110,008	2.5	7.0	327	315	293	288	284	242	34.6
21. Social Sciences, General	169,207	3.8	3.3	189	185	179	170	169	165	50.0
22. Space Science	60,405	1.4	11.0	1,630	1,100	562	556	505	478	43.5
ALL FIELDS										
Raw Data	4,472,332	100	7.9	4,461	3,438	3,308	2,921	2,695	2,598	328.9
Normalized data*			1.0	878.5	583.6	538.0	500.1	382.1	356.6	356.6

* In every field, the citations received by any article are normalized by the field mean citation

Table 2. Sensitivity of the index I_2 to the elimination of a handful of most cited articles

Fields	Initial Citation Inequality	% reduction in citation inequality after the elimination of the following number of most cited articles: 1	2	3	4	5	6
1. Agricultural Sciences	1.112	-1.4	-2.3	-2.7	-3.1	-3.4	-3.7
2. Biology & Biochemistry	1.284	-5.8	-10.0	-13.2	-14.9	-15.8	-16.6
3. Chemistry	1.730	-17.7	-25.2	-30.6	-31.3	-32.1	-32.7
4. Clinical Medicine	2.474	-2.6	-5.0	-6.6	-7.5	-8.3	-9.1
5. Computer Science	10.888	-34.7	-47.7	-59.2	-62.8	-65.3	-66.7
6. Economics & Business	1.609	-4.0	-5.3	-6.4	-7.4	-8.0	-8.5
7. Engineering	1.587	-0.8	-1.4	-2.0	-2.4	-2.8	-3.2
8. Environment & Ecology	1.039	-7.4	-11.1	-11.8	-12.5	-13.1	-13.6
9. Geosciences	1.108	-7.5	-9.3	-10.4	-11.1	-11.7	-12.3
10. Immunology	1.034	-3.8	-5.4	-6.7	-7.8	-8.7	-9.3
11. Materials Science	1.946	-1.5	-2.8	-3.8	-4.7	-5.4	-6.1
12. Mathematics	2.235	-23.6	-26.0	-28.3	-30.3	-32.2	-33.6
13. Microbiology	0.736	-0.6	-1.2	-1.7	-2.0	-2.3	-2.6
14. Molecular Biology & Genetics	1.288	-0.6	-1.1	-1.6	-2.0	-2.3	-2.7
15. Multidisciplinary	2.388	-5.3	-6.6	-7.7	-8.6	-9.4	-10.2
16. Neuroscience & Behavior	0.878	-0.7	-1.3	-1.6	-1.8	-2.1	-2.3
17. Pharmacology & Toxicology	0.944	-0.9	-1.7	-2.5	-3.0	-3.5	-3.9
18. Physics	2.334	-5.3	-8.4	-10.0	-11.5	-13.0	-14.2
19. Plant & Animal Science	1.205	-2.6	-3.5	-3.9	-4.3	-4.6	-4.9
20. Psychiatry & Psychology	1.290	-0.6	-1.2	-1.7	-2.2	-2.7	-3.1
21. Social Sciences, General	1.439	-0.6	-1.1	-1.6	-2.1	-2.5	-3.0
22. Space Science	1.732	-9.9	-14.3	-15.3	-16.4	-17.2	-18.0
ALL FIELDS							
Raw Data	2.183	-4.8	-7.6	-9.4	-10.3	-11.1	-11.8
Normalized data*	1.961	-9.2	-13.2	-16.2	-17.5	-18.5	-19.3

* In every field, the citations received by any article are normalized by the field mean citation

Table 3. Sensitivity of the index I_1 to the elimination of a handful of most cited articles

Fields	Initial Citation Inequality	% reduction in citation inequality after the elimination of the following number of most cited articles:					
		1	2	3	4	5	6
1. Agricultural Sciences	0.734	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7
2. Biology & Biochemistry	0.630	-0.4	-0.8	-1.1	-1.3	-1.4	-1.6
3. Chemistry	0.716	-0.7	-1.1	-1.4	-1.5	-1.6	-1.7
4. Clinical Medicine	0.868	-0.2	-0.3	-0.5	-0.6	-0.6	-0.7
5. Computer Science	1.315	-3.1	-4.7	-6.3	-7.1	-7.7	-8.1
6. Economics & Business	0.884	-0.5	-0.7	-0.9	-1.0	-1.2	-1.3
7. Engineering	0.897	-0.1	-0.2	-0.2	-0.3	-0.3	-0.4
8. Environment & Ecology	0.615	-0.6	-1.1	-1.2	-1.3	-1.5	-1.6
9. Geosciences	0.668	-0.6	-0.8	-1.0	-1.1	-1.2	-1.4
10. Immunology	0.574	-0.6	-0.9	-1.2	-1.4	-1.6	-1.8
11. Materials Science	0.918	-0.2	-0.3	-0.5	-0.6	-0.7	-0.8
12. Mathematics	0.913	-1.3	-1.6	-1.9	-2.2	-2.5	-2.7
13. Microbiology	0.518	-0.1	-0.3	-0.4	-0.5	-0.6	-0.6
14. Molecular Biology & Genetics	0.707	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6
15. Multidisciplinary	1.154	-0.7	-1.0	-1.3	-1.5	-1.7	-1.9
16. Neuroscience & Behavior	0.566	-0.1	-0.2	-0.3	-0.4	-0.4	-0.5
17. Pharmacology & Toxicology	0.606	-0.2	-0.3	-0.5	-0.6	-0.7	-0.8
18. Physics	0.909	-0.3	-0.6	-0.7	-0.9	-1.0	-1.1
19. Plant & Animal Science	0.722	-0.2	-0.3	-0.4	-0.5	-0.5	-0.6
20. Psychiatry & Psychology	0.752	-0.1	-0.2	-0.3	-0.4	-0.5	-0.6
21. Social Sciences, General	0.851	-0.1	-0.2	-0.3	-0.3	-0.4	-0.5
22. Space Science	0.800	-1.0	-1.6	-1.8	-2.0	-2.2	-2.4
ALL FIELDS							
Raw Data	0.875	-0.3	-0.5	-0.7	-0.8	-0.9	-1.0
Normalized data*	0.801	-0.4	-0.7	-0.9	-1.1	-1.2	-1.3

* In every field, the citations received by any article are normalized by the field mean citation

Table 4. Sensitivity of the index I_0 to the elimination of a handful of most cited articles, epsilon=0.01

Fields	**Initial Citation Inequality**	**% reduction in citation inequality after the elimination of the following number of most cited articles:**					
		1	**2**	**3**	**4**	**5**	**6**
1. Agricultural Sciences	1.605	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
2. Biology & Biochemistry	1.058	-0.1	-0.1	-0.2	-0.2	-0.2	-0.3
3. Chemistry	1.394	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
4. Clinical Medicine	1.453	0.0	0.0	-0.1	0.1	-0.1	-0.1
5. Computer Science	2.398	-0.4	-0.6	-0.8	-0.9	-1.0	-1.1
6. Economics & Business	1.825	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
7. Engineering	1.955	0.0	0.0	0.0	0.0	-0.1	-0.1
8. Environment & Ecology	1.180	-0.1	-0.2	-0.2	-0.2	-0.2	-0.3
9. Geosciences	1.395	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2
10. Immunology	0.801	-0.1	-0.2	-0.3	-0.4	-0.4	-0.5
11. Materials Science	1.886	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
12. Mathematics	1.966	-0.2	-0.2	-0.2	-0.3	-0.3	-0.4
13. Microbiology	0.881	0.0	-0.1	-0.1	-0.1	-0.2	-0.2
14. Molecular Biology & Genetics	1.045	0.0	-0.1	-0.1	-0.1	-0.1	-0.2
15. Multidisciplinary	2.389	-0.1	-0.2	-0.3	-0.3	-0.4	-0.4
16. Neuroscience & Behavior	0.906	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
17. Pharmacology & Toxicology	1.087	0.0	-0.1	-0.1	-0.1	-0.2	-0.2
18. Physics	1.701	0.0	-0.1	-0.1	-0.1	-0.1	-0.2
19. Plant & Animal Science	1.491	0.0	-0.1	-0.1	-0.1	-0.1	-0.1
20. Psychiatry & Psychology	1.440	0.0	0.0	-0.1	-0.1	-0.1	-0.1
21. Social Sciences, General	1.847	0.0	0.0	0.0	-0.1	-0.1	-0.1
22. Space Science	1.579	-0.1	-0.2	-0.3	-0.3	-0.4	-0.4
ALL FIELDS							
Raw Data	1.626	0.0	-0.1	-0.1	-0.1	-0.1	-0.2
Normalized data*	1.510	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2

***** In every field, the citations received by any article are normalized by the field mean citation

Table 5. Sensitivity of the coefficient of variation to the elimination of a handful of most cited articles

Fields	Coefficient of Variation	% reduction in coefficient of variation after the elimination of the following number of most cited articles:					
		1	2	3	4	5	6
1. Agricultural Sciences	1.491	-0.7	-1.1	-1.4	-1.6	-1.7	-1.9
2. Biology & Biochemistry	1.603	-3.0	-5.1	-6.8	-7.7	-8.3	-8.7
3. Chemistry	1.860	-9.3	-13.5	-16.7	-17.1	-17.6	-18.0
4. Clinical Medicine	2.224	-1.3	-2.5	-3.3	-3.8	-4.2	-4.7
5. Computer Science	4.666	-19.2	-27.7	-36.2	-39.0	-41.1	-42.3
6. Economics & Business	1.794	-2.0	-2.7	-3.2	-3.7	-4.1	-4.4
7. Engineering	1.781	-0.4	-0.7	-1.0	-1.2	-1.4	-1.6
8. Environment & Ecology	1.441	-3.8	-5.7	-6.1	-6.4	-6.8	-7.0
9. Geosciences	1.489	-3.8	-4.8	-5.3	-5.7	-6.0	-6.3
10. Immunology	1.438	-1.9	-2.8	-3.4	-4.0	-4.5	-4.8
11. Materials Science	1.973	-0.7	-1.4	-1.9	-2.4	-2.7	-3.1
12. Mathematics	2.114	-12.6	-14.0	-15.3	-16.5	-17.7	-18.5
13. Microbiology	1.213	-0.3	-0.6	-0.8	-1.0	-1.2	-1.3
14. Molecular Biology & Genetics	1.605	-0.3	-0.6	-0.8	-1.0	-1.2	-1.4
15. Multidisciplinary	2.186	-2.7	-3.4	-3.9	-4.4	-4.8	-5.3
16. Neuroscience & Behavior	1.325	-0.3	-0.6	-0.8	-0.9	-1.0	-1.1
17. Pharmacology & Toxicology	1.374	-0.5	-0.9	-1.2	-1.5	-1.8	-2.0
18. Physics	2.160	-2.7	-4.3	-5.1	-5.9	-6.7	-7.4
19. Plant & Animal Science	1.552	-1.3	-1.8	-2.0	-2.2	-2.3	-2.5
20. Psychiatry & Psychology	1.607	-0.3	-0.6	-0.9	-1.1	-1.4	-1.5
21. Social Sciences, General	1.696	-0.3	-0.6	-0.8	-1.0	-1.3	-1.5
22. Space Science	1.861	-5.1	-7.4	-8.0	-8.6	-9.0	-9.4
ALL FIELDS							
Raw Data	2.089	-2.4	-3.9	-4.8	-5.3	-5.7	-6.1
Normalized data*	1.980	-4.7	-6.8	-8.5	-9.2	-9.7	-10.2

* In every field, the citations received by any article are normalized by the field mean citation

Table 6. Sensitivity of different citation inequality indices to the random elimination of six articles per field

Average impact in % (and standard deviation) after 1,000 trials

Fields	I_0	I_1	I_2	**Coefficient of Variation**
1. Agricultural Sciences	-0.0081	-0.0060	-0.0070	-0.0035
	(0.0040)	(0.0025)	(0.0025)	(0.0013)
2. Biology & Biochemistry	-0.0012	-0.0008	-0.0008	-0.0004
	(0.0018)	(0.0009)	(0.0013)	(0.0006)
3. Chemistry	-0.0004	-0.0003	-0.0003	-0.0002
	(0.0008)	(0.0009)	(0.0027)	(0.0013)
4. Clinical Medicine	-0.0002	-0.0001	0.0000	0.0000
	(0.0004)	(0.0004)	(0.0004)	(0.0002)
5. Computer Science	-0.0008	-0.0004	0.0010	0.0005
	(0.0024)	(0.0037)	(0.0070)	(0.0035)
6. Economics & Business	-0.0015	-0.0009	-0.0007	-0.0003
	(0.0049)	(0.0054)	(0.0142)	(0.0071)
7. Engineering	-0.0002	-0.0002	-0.0001	0.0000
	(0.0008)	(0.0011)	(0.0017)	(0.0008)
8. Environment & Ecology	-0.0008	-0.0004	0.0000	0.0000
	(0.0039)	(0.0030)	(0.0075)	(0.0038)
9. Geosciences	-0.0005	-0.0002	-0.0006	-0.0003
	(0.0032)	(0.0041)	(0.0146)	(0.0073)
10. Immunology	-0.0012	-0.0006	-0.0004	-0.0002
	(0.0084)	(0.0071)	(0.0180)	(0.0090)
11. Materials Science	-0.0002	0.0001	-0.0021	-0.0011
	(0.0016)	(0.0015)	(0.0371)	(0.0186)
12. Mathematics	-0.0004	-0.0001	0.0012	0.0006
	(0.0023)	(0.0026)	(0.0051)	(0.0025)
13. Microbiology	-0.0011	-0.0003	-0.0002	-0.0001
	(0.0067)	(0.0052)	(0.0083)	(0.0041)
14. Molecular Biology & Genetics	-0.0004	0.0001	-0.0013	-0.0007
	(0.0036)	(0.0024)	(0.0150)	(0.0075)
15. Multidisciplinary	-0.0022	-0.0018	-0.0075	-0.0037
	(0.0125)	(0.0187)	(0.0810)	(0.0406)
16. Neuroscience & Behavior	-0.0006	-0.0004	0.0002	0.0001
	(0.0036)	(0.0062)	(0.0047)	(0.0024)
17. Pharmacology & Toxicology	-0.0007	-0.0003	-0.0007	-0.0004
	(0.0059)	(0.0063)	(0.0179)	(0.0090)
18. Physics	-0.0001	0.0000	-0.0007	-0.0003
	(0.0008)	(0.0010)	(0.0181)	(0.0090)
19. Plant & Animal Science	-0.0002	-0.0001	-0.0002	-0.0001
	(0.0014)	(0.0017)	(0.0052)	(0.0026)
20. Psychiatry & Psychology	-0.0005	-0.0002	-0.0009	-0.0004
	(0.0036)	(0.0041)	(0.0276)	(0.0138)
21. Social Sciences, General	-0.0003	-0.0001	-0.0003	-0.0001
	(0.0019)	(0.0028)	(0.0078)	(0.0039)

22. Space Science	-0.0005	-0.0007	0.0018	0.0009
	(0.0061)	(0.0091)	(0.0202)	(0.0101)
ALL FIELDS				
Raw Data	-0.0006	-0.0004	-0.0001	-0.0001
	(0.0004)	(0.0008)	(0.0023)	(0.0011)
Normalized data*	-0.0005	-0.0002	-0.0001	-0.0001
	(0.0004)	(0.0004)	(0.0016)	(0.0008)

***** In every field, the citations received by any article are normalized by the field mean citation

Table 7. Sensitivity of average citations to the elimination of a handful of most cited articles

Fields	Average citation	% reduction in average citations after the elimination of the following number of most cited articles:					
		1	**2**	**3**	**4**	**5**	**6**
1. Agricultural Sciences	4.9	-0.06	-0.12	-0.15	-0.19	-0.22	-0.25
2. Biology & Biochemistry	12.5	-0.07	-0.14	-0.19	-0.23	-0.26	-0.29
3. Chemistry	7.6	-0.11	-0.18	-0.23	-0.26	-0.28	-0.30
4. Clinical Medicine	9.7	-0.04	-0.07	-0.10	-0.12	-0.15	-0.17
5. Computer Science	3.0	-0.89	-1.43	-1.94	-2.22	-2.46	-2.64
6. Economics & Business	3.9	-0.15	-0.23	-0.31	-0.39	-0.45	-0.51
7. Engineering	3.2	-0.03	-0.05	-0.07	-0.10	-0.12	-0.14
8. Environment & Ecology	7.1	-0.12	-0.20	-0.24	-0.28	-0.32	-0.35
9. Geosciences	6.7	-0.12	0.18	-0.23	-0.26	-0.30	-0.33
10. Immunology	16.0	-0.12	-0.19	-0.26	-0.33	-0.39	-0.43
11. Materials Science	4.5	-0.06	-0.11	-0.16	-0.20	-0.24	-0.28
12. Mathematics	2.4	-0.30	-0.40	-0.50	-0.59	-0.67	-0.75
13. Microbiology	11.4	-0.04	-0.07	-0.11	-0.13	0.16	-0.19
14. Molecular Biology &	20.4	-0.04	-0.07	-0.11	-0.14	-0.17	-0.20
15. Multidisciplinary	3.2	-0.37	-0.57	-0.75	-0.92	-1.08	-1.23
16. Neuroscience & Behavior	13.7	-0.03	-0.06	-0.08	-0.10	-0.12	-0.13
17. Pharmacology & Toxicology	8.0	-0.05	-0.10	-0.14	-0.18	-0.22	-0.25
18. Physics	6.9	-0.07	-0.13	-0.17	-0.21	-0.25	-0.29
19. Plant & Animal Science	5.1	-0.05	-0.08	-0.10	-0.12	-0.14	-0.15
20. Psychiatry & Psychology	7.0	-0.04	-0.08	-0.12	-0.15	-0.19	-0.22
21. Social Sciences, General	3.3	-0.03	-0.07	-0.10	-0.13	-0.16	-0.18
22. Space Science	11.0	-0.24	-0.41	-0.49	-0.57	-0.65	-0.72
ALL FIELDS							
Raw Data	**7.9**	**-0.01**	**-0.02**	**-0.03**	**-0.04**	**-0.05**	**-0.06**
Normalized data*	**1.0**	**-0.02**	**-0.03**	**-0.04**	**-0.06**	**-0.06**	**-0.07**

***** In every field, the citations received by any article are normalized by the field mean citation