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Almost Always Unequal: Co-Authors' Contributions to Scientific Publications

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Abstract

Scientific work has become increasingly organized as teamwork and most research publications are now joint work of several co-authors. While of utmost importance for fair and valid research evaluation, the quantitative patterns of relative work contribution by team members to co-authored publications have remained opaque. Here we present an empirical study of contribution patterns. We analyze a large data set of author-provided percent contribution claims for co-authored scientific publications submitted as part of applications to scholarship programs. We find that the distribution of work input in co-authored publications is overwhelmingly unequal. This is in direct contrast to extant assumptions in research evaluation practice and professional science studies which presuppose equal contributions and do not adjust or weight publication and citation counts differentially by contribution. Such flawed methodology should be discontinued, as it unfairly disadvantages major contributors.

Introduction

A major open question in the science of science is how much, on average, do co-authors contribute to multi-author publications? And how are the number of co-authors of a paper and the position of an author's name in the author list related to the size of their contribution? The answers have far-reaching consequences for bibliometric research and the practice of research assessments of individuals, working groups, departments, organizations, and countries. A validated method for the allocation of relative credit for joint work to the involved contributors that reflects as closely as possible their relative contributions is indispensable for fair assessments and valid basic research. But we do not presently know enough about the typical contribution patterns in scientific teamwork. Are co-authors' relative inputs mostly equal or so close to equal as to be indistinguishable from equality? Or are they unequal, and if so, how much?

Many different co-author credit attribution schemes (or counting methods) have been proposed (Gauffriau, 2021) but it is not well known which of them are used in research and practice. The only study to investigate counting method use in scientometric research is that of Larsen (2008). Larsen analyzed the 85 accepted contributions to two conferences of the International Society for Scientometrics and Informetrics which used some method of publication counting. His summary of the findings is:

It is obvious that in more than half of the cases the information given on counting methods is insufficient. Whole counting is probably the dominating method but in more than half of the cases there is insufficient information to establish that whole counting was used. There is a nearly complete lack of arguments for the use of this method. (Larsen, 2008, p. 238)

Only 31 % of the papers reported the applied method and a mere 6 % gave any justification for their choice. Several papers had problems with non-additive results. Non-additive results occur because, with whole counting, each contributing author is allocated one whole publication unit such that a paper with two authors is counted as two publications in total. Consequently, counts of all authors' publications are always greater than the true number of papers. Besides whole counting, the only other frequently used method at the time of Larsen's study was equal fractional counting, which is somewhat of an unofficial standard method in professional bibliometrics (Waltman, 2016). Equal fractional counting means that each author of a paper by *n* co-authors receives an equal share of credit of 1/*n*. Equal fractional counting is preferred by professionals over whole counting (also called full counting) as it does not lead to inflated counts due to non-additivity when sums of participating units, such as authors and countries, are calculated to obtain total values.
Some researchers have noted a lack of empirical data to substantiate a decision to use a particular counting or credit attribution method (e.g., Petersen, Wang, & Stanley, 2010, p. 3). Korytkowski & Kulczycki (2019), after comparing several counting methods, conclude:

We have shown how different variants of publication counting methods influence the rankings. We could construct other variants, but it will not make our task, i.e. selecting the proper way of counting, any easier, because there is no external and objective reference point. (p. 815)

However, there is at least some informative evidence on co-author contribution patterns. Evidence from qualitative studies in the sciences has accumulated, indicating that contribution-based name ordering is common (Knorr Cetina, 1999, p. 167; Laudel, 2001, p. 776; 2002, p. 11; Müller, 2012, pp. 301–303).
The most directly relevant and valid evidence comes from empirical studies of quantitative contribution estimation of authors themselves. Research on authors' own claims and statements of their relative contributions to co-authored work showed that contribution-based author name ordering is common and contributions are mostly unequal (Ali, 2021; Donner, 2020; Slone, 1996). But work in this approach has used quite small and unrepresentative samples. These scattered results are corroborated by a survey of active researchers from the UK, which found that:

The listing of authors in order of contribution (with first author providing the greatest contribution) is the most frequent practice in most disciplines except for the humanities where alphabetical order is the norm. But it is notable that in physical sciences, mathematics and social sciences alphabetical ordering *and ordering by contribution are almost equally common. (Research Information Network, 2009, p. 26).*

Possible answer choices were, however, not mutually exclusive and several practices per discipline were commonly indicated.

Various co-author credit allocation methods, or bibliometric counting methods, have been proposed and the choice of method is important because the methods lead to very different results (Abramo, D'Angelo, & Rosati, 2013b, 2013a; Chudlarský, Dvořák, & Souček, 2014; Egghe, Rousseau, & Van Hooydonk, 2000; Gauffriau & Larsen, 2005; Korytkowski & Kulczycki, 2019; Moed, 2000). At higher levels of aggregation, such as countries, the differences between methods manifest primarily in citation impact indicator values rather than publication sums (Huang, Lin, & Chen, 2011; Lin, Huang, & Chen, 2013).

Despite their validity deficits, full counting and equal fractional counting still remain bibliometric standard methods, as no consensus has emerged on which of various more sophisticated credit allocation methods is most appropriate (Gauffriau, 2021; Ioannidis et al., 2007; Põder, 2022). In fact, much of the professional literature has confined itself to comparisons between only full counting and equal fractional counting (Gauffriau & Larsen, 2005; Korytkowski & Kulczycki, 2019; Põder, 2022; Stock, Dorsch, Reichmann, & Schlögl, 2023; Thelwall et al., 2023), which both assume and imply equal contribution of all co-authors. It is thus crucial to investigate the measurement validity of counting methods with respect to co-author contributions, that is, to study which of the methods is in closest agreement with actual co-author contributions, insofar as these can be quantified and collected.

Here we address the persistent problem of a lack of knowledge on empirical patterns of contributions to joint publications by co-authors (Korytkowski & Kulczycki, 2019; Moed, 2000; Narin et al., 1976; Price, 1981) by an analysis of patterns of quantified contribution with respect to papers' co-author counts and the position of co-authors' names in the author list in a large-scale data set of author-provided percentage contribution claims.

Methods and data

In this study we analyze a large dataset of author contribution statements for co-authored scientific and scholarly publications. These data were collected in the application process for two funding programs of the Tri-Council, three Canadian government research funding agencies. These are the Vanier Canada Graduate Scholarships, for prospective doctoral students, and the Banting Postdoctoral Fellowships. Both programs offer attractive conditions of fully financed three year (Vanier) and two year (Banting) research positions and are correspondingly highly selective. The two programs are administered by three funding agencies, each responsible for one broad area of research: CIHR/IRSC is responsible for health research, NSERC/CRSNG for the natural sciences and engineering, and SSHRC/CRSH covers the social sciences and humanities. For both programs, applicants submit a comprehensive application dossier which is the basis for the decisions of selection committees at the three funding organizations, which rank applications according to the criteria of academic excellence, research potential, and leadership in the case of Vanier and the criteria of research excellence and leadership, quality of proposed research program, and institutional commitment and demonstrated synergy in the case of Banting. Each agency awards a similar number of scholarships and fellowships for a total of 166 Vanier and 70 Banting recipients annually.

When applying to either program, applicants are required to submit a publication list and to state their own contribution to all publications. This is done by filling a "Contribution Percentage" field that provides a dropdown menu from which applicants have to select a contribution range starting from "0-10" in increments of 10 %. Next to that field is a help tab that can be toggled when clicked which provides the following text: *"Based on your contribution role, indicate the approximate percentage (%) of work you contributed towards this publication, as a proportion of the total work contributed to this publication by all authors/contributors"*.

These publication contribution claims are the primary data for this study. Additionally we use metadata of the applicants' publications and socio-demographic and process variables from the application and administration system. Applicants submitted their contribution claims privately and under confidentiality. They only estimated their own, not all co-authors', contributions. The other co-authors' assessments of their own or the applicants' contributions were not collected. Thus, applicants made submissions with a presumably very low expectation that any co-author would see their claims. While co-authors might occasionally be reviewer panel members, in such cases they would not rate an applicant because of conflict of interest regulations. Because of these specific conditions and because of the well-established cognitive bias of overestimation of one's own contributions to teamwork relative to that of others (Broad, 1981; Caruso, Epley, & Bazerman, 2006; Herz, Dan, Censor, & Bar-Haim, 2020; Ilakovac, Fister, Marusic, & Marusic, 2007) we anticipate that applicants on the whole overstate their contributions. We make the assumption that this overestimation is independent of the number of co-authors of a paper and the applicant's author position on a paper, such that in effect their claimed overestimated contribution is proportional to their unobserved true contribution.

Contribution claims in Vanier and Banting applications have to be submitted by choosing a value range for one's own contribution from the ten ordered category ranges '1-10 %', '11-20 %', …, '91-100 %'. Researchers who apply are not told how and if their declared percent contributions will be used to evaluate their applications. We use these ordinal categorical data directly in rank-correlational analysis but transform them to their mid-range values (5, 15, ..., 95) for other analyses which require numerical data. Authors are often able to make a quantitative estimate of their own and co-authors' relative contributions to a common publication (Ali, 2021; Donner, 2020), although the uncertainty of such estimates is presumably substantial – how large remains an open issue for further research. As the data entry categories in this case are relatively fine-grained, inaccuracies of the mid-range point estimates with respect to the unknown true values necessarily have to be small.

The publication co-author contribution data include all applications for the years 2016 to 2021 independent of funding success: those which were not funded, those offered funding, and withdrawn ones. This time range was selected because this is the competition years for which the percent contributions were available, at the time of the study. This is not a random representative sample of the global community of researchers. It is restricted to early career researchers with ambitions to start or continue a research career.

This data set consists of 46,910 percentage contribution claims in 6,219 applications submitted by 5,547 unique applicants to one of the funding programs. Table 1 shows the sample sizes by agency. Additional information on the relevant publications was retrieved from CrossRef. For this, the CrossRef API was queried with the free text reference (including authors, date of publication, title, venue, volume, issue, publisher and page range). We retrieved the top 5 candidates, and used a python script (adapted from this repository: https://github.com/CrossRef/reference-matching-evaluation) to provide custom weights, and picked the candidate publication record with the highest score to get the DOI of each reference. In order to get the exact position of each applicant's name in the author list, we used a fuzzy matching approach based on the author list entered for each publication by the applicant.

Table 1. Sample overview.

Agency	Program	Number of applications	Number of unique applicants	Number of contribution claims
CIHR	Banting	1,183	1,048	12,841
NSERC	Banting	1,248	1,154	13,621
SSHRC	Banting	1,032	925	6,991
CIHR	Vanier	1,028	929	5,807
NSERC	Vanier	890	849	3,336
SSHRC	Vanier	800	745	2,511

We compare the empirically observed values of claimed percent contribution to the predictions that a selection of bibliometric counting methods make. We chose methods which divide one unit of publication credit such that the parts sum to 1.0, modified here to match the empirical data by multiplying by 100 to get percent values. We only chose methods which do not depend on choosing free parameters. We included equal fractional counting as the current standard method of professional bibliometrics and competing methods which divide the publication unit unequally according to different principles. Some propose monotonically decreasing credits as the author position increases, others propose different higher values for the last or later authors in the byline. In general, all the alternative methods were proposed with the intention to better reflect actual relative author contributions while avoiding inflating publication counts by yielding credit shares for one publication which sum to more than unity. Despite this intention, they were not validated with empirical criterion data so far. The following methods are compared:

- Equal fractional counting. First suggested by Price & Beaver (1966).
- Harmonic counting. Proposed originally by Hodge & Greenberg (1981), re-introduced and empirically studied by Hagen (2008).
- Harmonic parabolic counting. Proposed in Aziz & Rozing (2013).
- Arithmetic counting. Proposed by Kalyane & Vidyasagar Rao (1995) and van Hooydonk (1997).
- 'Proportional' method of Howard, Cole & Maxwell (1987).
- Geometric count. Proposed by Egghe, Rousseau & van Hooydonk (2000).
- DFG (2004) 'rule of thirds'. Proposed to weight JIF points in performance based funding systems of German medical faculties and still used frequently for this purpose (Aman & van den Besselaar, 2024). The two-author case was not specified in the document but we split the credit evenly between both authors.

Further information and calculation formulas can be found in the respective cited references.

Results

Descriptive analysis

Figure 1 presents the average values of the claimed percent contributions for publications with two to five and ten co-authors (converted mid-range numerical values) and the values that the studied bibliometric counting methods give for the same input combinations. The error bars in panel *a* indicate 95 % confidence intervals for the means. Several notable observations can be made from the empirical contributions claims in panel *a*.

First, the average size of the claimed contribution in multi-author papers depends strongly on the author position. For instance the first author in a two-author papers on average claims 79 % while the second author claims 49 %. Second, these average claims do not add up to 100 %, thus, overestimation is confirmed. Third, size of claims only weakly depends on author count. The claims for first author, for instance, are all close to each other, although the claims decrease slightly with increasing author count. Fourth, the decrease in claimed contributions with increasing author position is not linear and flattens out while for papers of four and more authors we can discern a clear last-author effect such that this position's claims are higher than that of the preceding position. Fifth, confidence intervals for the means are small, indicating that there is close agreement on the typical claims across applicants contingent on author count and position. Comparing this pattern with those for the seven chosen bibliometric counting methods for the same author count and position data in panels *b* to *h*, none of the methods seems to be a very good approximation – with the pattern of equal fractional counting being obviously inconsistent with the empirical results. This comparison is continued in the following correlational analysis.

Correlation analysis

Table 2 shows the results of the correlational analysis of selected bibliometric counting methods for the empirical data. This excludes the data for single-author publications, as all methods credit them with a value of 100 %. The table contains Pearson correlation coefficients for data transformed to numerical figures using the range midpoint values, Spearman rank correlation coefficients for the untransformed original data (both with 95 % confidence intervals), and average absolute deviations between counting method values and transformed empirical data. Note that the empirical data is affected by overestimation which puts some unknown upper limit on possible correlations and a lower limit on average absolute deviation. We find it makes little difference whether we use original data and rank correlation or numeric estimates and Pearson correlation. For the whole dataset, geometric counting, harmonic counting, and the method of Howard, Cole, & Maxwell (1987) show the highest correlations with rank correlations of $\rho \approx 0.75$ each. Among these three, geometric counting has the smallest average absolute error with a misestimation of 20 percentage points (pp). Arithmetic counting, harmonic parabolic counting, and the method of DFG (2004) show rank correlations between 0.63 and 0.66. Equal fractional counting is aligned worst with the empirical data: $\rho=0.40$, average absolute deviation: 32.5 pp. These results are consistent across major domains of research as the results disaggregated by agency show. Notably, equal fractional counting also does poorly in the social sciences and humanities, a domain with lower co-author numbers. Switching from equal fractional counting to, say, geometric counting, bibliometricians and research evaluators can reduce the average error in co-authored publication contribution estimation from 32.5 to 20.2 pp, which is a 38 percent relative improvement.

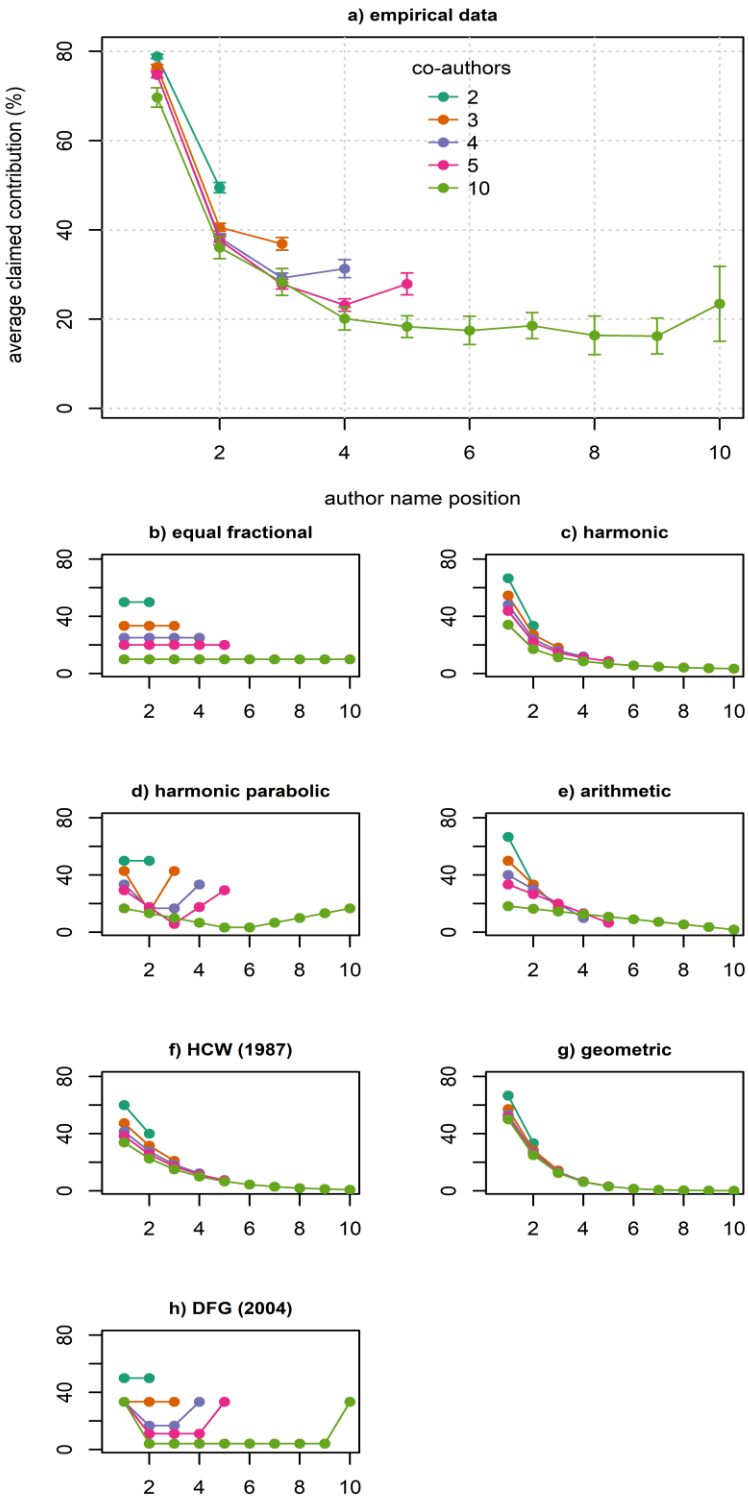

Figure 1. Average percent contribution to co-authored publications by author count and author position for empirical data and various bibliometric counting methods.

Table 2. Correlations of bibliometric counting methods with empirical contribution claims data.

Data set	bibliometric counting method	Pearson r	Spearman ρ	avg. abs. deviation
all science domains, N=37,157	equal fractional	0.40 (0.39, 0.40)	0.40 (0.39, 0.41)	32.5
	harmonic	0.76 (0.75, 0.76)	0.75 (0.75, 0.75)	22.7
	arithmetic	0.61 (0.60, 0.62)	0.64 (0.63, 0.65)	25.8
	Howard, Cole, Maxwell (1987)	0.74 (0.73, 0.74)	0.74 (0.74, 0.74)	24.3
	geometric	0.79 (0.79, 0.80)	0.75 (0.75, 0.76)	20.2
	DFG (2004)	0.68 (0.67, 0.68)	0.66 (0.66, 0.67)	29.6
	harmonic parabolic	0.61 (0.60, 0.62)	0.63 (0.62, 0.64)	30.6
CIHR - health research, N=16,379	equal fractional	0.39 (0.37, 0.40)	0.39 (0.38, 0.41)	33.1
	harmonic	0.77 (0.76, 0.77)	0.77 (0.76, 0.78)	23.1
	arithmetic	0.59 (0.58, 0.60)	0.63 (0.62, 0.64)	26.8
	Howard, Cole, Maxwell (1987)	0.75 (0.75, 0.76)	0.76 (0.76, 0.77)	24.3
	geometric	0.81 (0.80, 0.81)	0.77 (0.77, 0.78)	20.1
	DFG (2004)	0.73 (0.72, 0.73)	0.72 (0.71, 0.72)	29.4
	harmonic parabolic	0.63 (0.62, 0.64)	0.67 (0.66, 0.68)	31.0
NSERC - natural sciences and engineering research, N=15,440	equal fractional	0.44 (0.42, 0.45)	0.43 (0.42, 0.44)	33.8
	harmonic	0.78 (0.77, 0.78)	0.75 (0.74, 0.76)	23.3
	arithmetic	0.64 (0.63, 0.65)	0.66 (0.65, 0.67)	26.3
	Howard, Cole, Maxwell (1987)	0.76 (0.75, 0.77)	0.74 (0.74, 0.75)	25.3
	geometric	0.81 (0.80, 0.81)	0.75 (0.74, 0.76)	20.9
	DFG (2004)	0.70 (0.69, 0.71)	0.68 (0.67, 0.68)	31.2
	harmonic parabolic	0.65 (0.64, 0.66)	0.65 (0.64, 0.66)	31.7
SSHRC - social sciences and humanities research, N=5,338	equal fractional	0.32 (0.30, 0.35)	0.33 (0.30, 0.35)	26.6
	harmonic	0.68 (0.67, 0.70)	0.68 (0.66, 0.69)	20.0
	arithmetic	0.58 (0.57, 0.60)	0.61 (0.60, 0.63)	21.4
	Howard, Cole, Maxwell (1987)	0.66 (0.64, 0.67)	0.66 (0.64, 0.67)	21.0
	geometric	0.72 (0.71, 0.73)	0.68 (0.67, 0.70)	19.0
	DFG (2004)	0.49 (0.47, 0.51)	0.47 (0.44, 0.49)	25.7
	harmonic parabolic	0.48 (0.46, 0.50)	0.46 (0.44, 0.48)	26.1

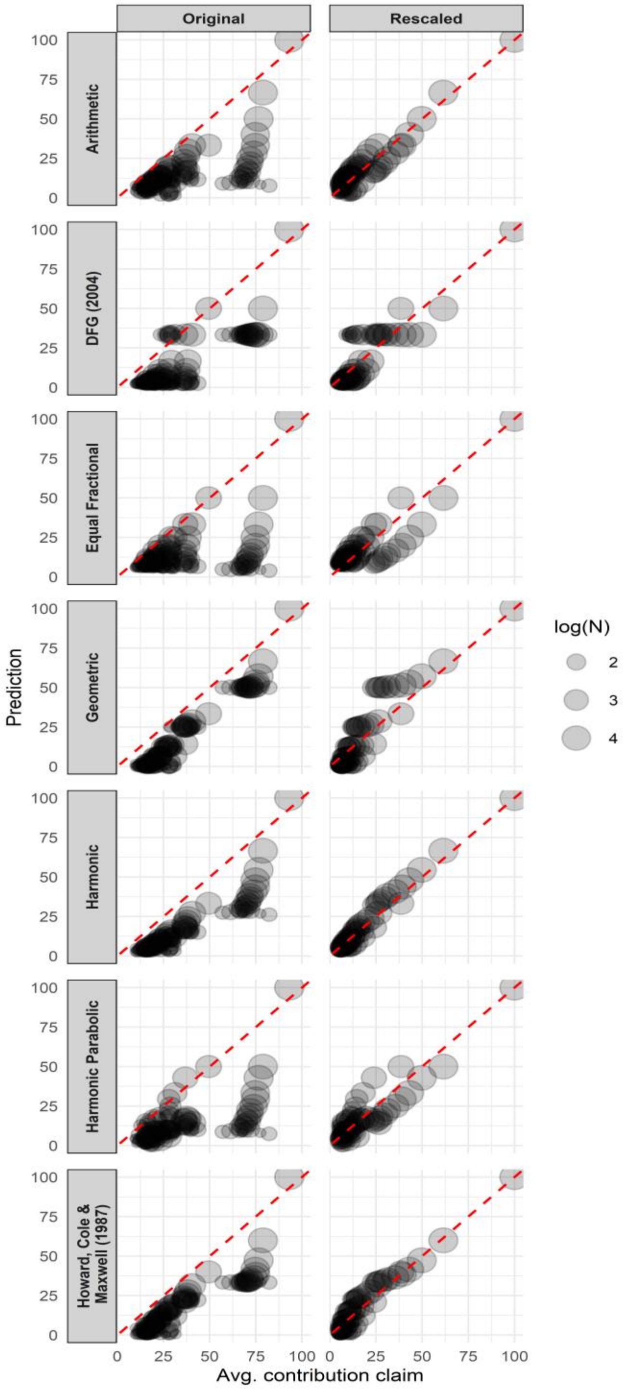

Figure 2. Comparison of empirical contribution data with bibiometric method predictions.

Note: Average values across combinations of author number and position displayed and scaled by log(N). Left, mid-range numerical values. Right, mid-range numerical values rescaled to sum to 100 % for each author count.

Figure 2 visualizes the comparisons of empirical data and counting method values for the calculated average values of contribution claims for each combination of author count and author position. On the left are the full data as transformed to numerical values, which include the overestimations. On the right we have removed the overestimations by rescaling such that the total sum for each author count data subset equals 100 %. For example, the contribution claim averages for first to third authors of three-author papers are 77, 41, 37 %. These were rescaled by the same factor to values of 50, 26, 24 %. This is only possible for subsets of the data for which enough observations for each author position are available, thus the right side plots only show the data for up to 12-author papers while the left side plots show more data. The figure indicates that some counting methods exhibit biased estimates in specific ranges. For example, the DFG (2004) method gives values which sum to 33 % to all first and last authors, these are mostly higher or lower according to the empirical data. The predicted values of equal fractional counting and harmonic parabolic counting are either too low or too high across most of the range. The method of Howard et al. (1987) and harmonic counting show very little bias.

Discussion

We have studied a large-scale dataset of percentage contribution claims by authors of co-authored scientific papers. The primary pattern that characterizes this data is profound inequality of contributions within one paper. As a first approximation, the author order tracks contribution order from most to least. An initial steep descent from first to middle authors is followed by a tapering off into a flat stretch, and, depending on author count, a final upturn for the last-author position. This empirical pattern of contributions resembles a ski jumping ramp, rather than the level plains which the equal contribution assumption of fractional counting implies.

Our findings indicate a misalignment between prevailing bibliometric methodology and real contribution patterns. Appropriate credit allocation is just as important for bibliometric research and research evaluation of higher aggregate units such as working groups, departments, and organizations as it is for individual co-authors. This is because the lower level units are mostly naturally nested within the higher level ones, such that credits for authors directly cascade up and can be aggregated to their affiliations by summation. The notable exception are multiple affiliations of a single author, which requires special handling. This not only goes for publication credit but is also relevant for citation analysis where co-author contribution shares are natural weights for fairly apportioning citation impact to co-authors and their affiliations.

In order to more closely reflect the actual contributions of co-authors, users of bibliometrics should phase out full and equal fractional counting and use counting methods that have been shown to agree much more closely with empirical contribution data in this study as these have higher validity. These may be the harmonic counting (Hagen, 2008; Hodge & Greenberg, 1981), geometric counting (Egghe et al., 2000), or the “proportional” method of Howard et al. (1987) or newly devised methods which align with actual contributions even better.

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