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Contributory inequality alters assessment of academic output gap between comparable countries

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A B S T R A C T

An elite segment of the academic output gap between Denmark and Norway was examined using harmonic estimates of publication credit for contributions to *Science* and *Nature* in 2012 and 2013. Denmark still leads but the gap narrowed in 2013 as Norway's credit increased 58%, while Denmark's credit increased only 5.4%, even though Norway had 36% fewer, and Denmark 40% more, coauthor contributions than in 2012. Concurrently, the credit produced by the least productive half of the contributions rose tenfold from 0.9% to 10.1% for Norway, but dropped from 7.2% to 5.7% for Denmark. Overall, contributory inequality as measured by the Gini coefficient, fell from 0.78 to 0.51 for Norway, but rose from 0.63 to 0.68 for Denmark. Neither gap narrowing nor the positive association between reduced contributory inequality and increased credit were detected by conventional metrics. Conventional metrics are confounded by equalizing bias (EqB) which favours small contributors at the expense of large contributors, and which carries an element of reverse meritocracy and systemic injustice into bibliometric performance assessment. EqB was corrected by using all relevant byline information from every coauthored publication in the source data. This approach demonstrates the feasibility of using EqB-corrected publication credit in gap assessment at the national level.

1. Introduction

The main objective of this work is to use recent advances in bibliometric credit allocation to gain new insights into the academic output gap between two comparable countries, in this case Denmark and Norway. Previous studies invariably rated the academic output of Denmark above Norway (e.g. Glänzel, 2000; Research Council of Norway, 2014; Schneider, 2010; van Leeuwen, 2012), but all gap size estimates based on conventional bibliometric methods are inaccurate because they do not adequately account for the size of each country's contribution to internationally coauthored publications.

Almost 200 countries contribute to the global production of academic publications and the output of many is changing rapidly (National Science Board, 2014). Everyone, therefore, wants to know how well they are doing in relation to others and their shared concern is to avoid being misguided by inaccurate information. Such concern over perceived academic output gaps between countries has fuelled research policy debate for nearly two centuries, and the concept of academic productivity as an input/output ratio has evolved in a context of international comparison (Godin, 2006, 2009; Nowotny, 2007). An early example is Charles Babbage's concern about the decline of science in England relative to Germany (Babbage, 1830; Foreigner, 1931); a concern quantified by Edward Frankland in 1871 (Devonshire, 1872, p. 371:5866) (cf. Braun, 1993;

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Cardwell, 1972; Nye, 1984), and echoed in the modern debate about the same topic 150 years later (Martin, 1994). On a broader scale, the dynamic nature of international science today is reflected in current trends suggesting that the academic pre-eminence of the US may be surpassed by China in the foreseeable future (Leydesdorff, 2012).

The global growth in academic output has been accompanied by an unabating increase in international collaboration (Aksnes, Frølich, & Slipersæter, 2008; Leydesdorff & Wagner, 2008). More than a quarter of all publications in the world are produced by multi-national teams, and several smaller countries produce more than half of their research papers in collaboration with international partners (Royal Society UK, 2011). Collaboration has many benefits, is often encouraged by policy makers and funding agencies, and is considered essential for groundbreaking research where the required effort is beyond the capacity of a single nation (Bidault & Hildebrand, 2014; Sonnenwald, 2007). Participation in international top-level research is therefore regarded as an indication of national competitive ability and academic achievement.

But in conventional measures of academic output, collaboration is a major source of inaccuracy. The routine approach is to inflate publication counts by issuing full publication credit to every country included in the list of author affiliations. The other conventional approach is to divide one unit of credit equally among a paper's coauthors, and then tally the fractions for each country. Such fractional publication counting corrects for inflationary bias, but not for the equalizing bias (EqB) which is the inevitable consequence whenever the coauthors of a paper have not contributed equally.

EqB skews bibliometric assessments and accounts for a massive shift of credit from primary to secondary authors. As a result, biased equal credit scores produce distorted publication performance rankings that are fundamentally different from rankings obtained from estimates of actual coauthor credit (Hagen, 2014a). Furthermore, the powerful distortional effect of EqB is inevitably compounded in derived bibliometric indices and indicators. EqB may also provide an incentive for unethical behaviour, including unwarranted claims for honorary authorship or gift authorship.

The key to more reliable publication counting is to ensure accurate accreditation of coauthors by including all relevant byline information. This bottom-up approach is facilitated by the harmonic formula, which provides equitable distribution of coauthor credit for scientific papers with a hierarchical byline structure (Hagen, 2008, 2013). It also accommodates additional byline information which, for instance, may indicate the equality of some or all coauthors, or the presence of a senior author. Recent studies of field specific publication patterns have used the harmonic formula to partially eliminate EqB (Fernandes, 2014; Walters & Wilder, 2015), but future studies must also include additional byline information about equality or seniority in an effort to completely eliminate EqB.

Here, I use an evidence-based informetric approach to estimate the effect of international academic collaboration on measurements of publication output for two comparable nations, Denmark and Norway. First, I address the need for improved accuracy by portraying how the combination of increased output and increased international collaboration over the past four decades has generated a widening zone of overlap between the upper and lower boundaries of the two countries' total publication output. Second, I provide a close-up of the academic output gap between Denmark and Norway, by analyzing in detail their scientific contributions to the two top-tier journals *Science* and *Nature* for the years 2012 and 2013. Third, I quantify the inequality profile of each country's contributions, and provide new information about the relationship between contributory inequality and cumulative top-level output. And finally, I conclude by demonstrating how EqB altered the perceived direction of annual change in the top-level academic output gap.

2. Background: accounting for coauthorship in publication counting

The use of publication counts as a quantitative base for research policy was pioneered by Frankland's testimony to the British Royal Commission in 1871, when he used publication counts for the year 1866 to provide a quantitative assessment of the alledged academic performance gap which showed Britain lagging behind Germany (Cardwell, 1972; Devonshire, 1872, p. 371:5866). At the time coauthorship was not a confounding issue but inaccuracy due to international collaboration had already entered the picture. It was Frankland who pointed out that the count for Britain underestimated the gap because it included publications from German scientists residing in Britain who had received their training in Germany.

2.1. *Inflated publication counting*

Inflated publication counting was initiated in 1917, when S.I. Franz (Franz, 1917, p. 202, footnote 1) decided to assign full value publication credit to both individuals of a joint publication (cf. Godin, 2006). This approach provided a strong incentive for joint authorship which expanded seamlessly to multiple authorship. Inflated counting has dominated quantitative research output analysis ever since.

But inflated publication counting is confounded by two separate sources of bias. Inflationary bias, generated by issuing one full unit of credit repeatedly to each coauthor or participating country; and equalizing bias (EqB), generated by ignoring differential contribution (Hagen, 2008).

2.2. *Fractional publication counting*

Nearly 50 years ago, as multiple authorship became increasingly common, Price and Beaver (1966) introduced the practice of fractional counting in an influential paper which set a longstanding, unintended precedent for using fractional counting in conjunction and comparison with inflated counting (e.g. Gauffriau, Larsen, Maye, Roulin-Perriard, & von Ins, 2008; Martin, 1994; Nature Index, 2014a).

> *We define fractional productivity as the score of an author when he is assigned 1/n of a point for the occurrence of his name among n authors on the by-line of a single paper. Thus a man with one paper of which he is the sole author, a second of which he is one of two authors, and a third in which he is one of five, will have a fractional productivity of 1.7 and a full productivity of three papers.* (Price & Beaver, 1966, p. 1014–1015)

Despite some support (Lindsey, 1980; Narin, 1976), fractional counting was not an immediate success, and 15 years later Price lamented that:

> *... publications or citations must be divided among all the authors listed on the byline, and in the absence of evidence to the contrary it must be divided equally among them. Thus each author of a three-author paper gets credit for one-third of a publication and one-third of the ensuing citations. ... Any time you take a collaborator you must give up a share of the outcome, and you diminish your own share. That is as it should be; to do otherwise is a very cheap way of increasing apparent productivity.* (Price, 1981)

Lately fractional counting has found practical application as a proxy measure for coauthor credit in metrics-based national research funding systems in Norway, Denmark, and elsewhere (Hicks, 2012). This is cause for concern as less than 4% of all coauthored research papers intentionally choose to indicate equal contribution by listing the coauthors' names in alphabetical order (Waltman, 2012). The implication is that over 96% of all contemporary papers are susceptible to confounding by equalizing bias (EqB) when publication credit is counted fractionally.

The immediate effect of EqB is to overestimate the credit of small contributions and underestimate the credit of large contributions (Hagen, 2008). EqB also precludes assessment of the effect of contributory inequality on cumulative publication output. Fractional counting may therefore misrepresent the publication performance of comparable nations by exaggerating or concealing the gap between them. Either way, there is a risk that inaccurate estimates of publication performance may inspire misguided and counterproductive initiatives with unanticipated undesirable outcomes for the scientific community.

2.3. Harmonic estimates of actual publication credit

The harmonic formula, although not named as such at the time, was first proposed by Hodge and Greenberg (1981) as a response to Price's (1981) plea for division of publication credit among all the authors listed on the byline. Unfortunately forgotten until 2008 (Hagen, 2008, 2009), it has since been validated against empirical data and has outperformed other credit allocation schemes from the bibliometric literature (Hagen, 2010, 2013).

The harmonic formula owes its transparency to three simple ethical criteria (Hagen, 2008, 2010):

1. One publication credit is shared among all coauthors
2. The first author gets the most credit, and in general the *i*th author receives more credit than the (*i*th + 1)th author
3. The greater the number of authors, the less credit per author.

One recent study found that the harmonic formula explained nearly 97% of the variation in a composite empirical dataset composed of 3 independent sets of data from the scientific subfields of chemistry, medicine and psychology (Hagen, 2013); that is, a coefficient of determination $R^2 = 0.9676$ was obtained for the linear regression between values predicted by the harmonic formula and the empirical data points. In contrast, fractional credit explained less than 40% of the variation, with EqB accounting for the roughly 60% discrepancy between the two figures. A follow-up theoretical analysis showed that the amount of EqB increases as the number of coauthors increases, and suggested that fractional credit scores are likely to be dominated by EqB when the number of coauthors exceeds 12 (Hagen, 2014b).

In short, the harmonic formula makes it possible to assess the relative contribution of collaborators by providing accurate, parsimonious and verifiable quantification of hierarchical bylines. The prospect of improved accuracy has implications for applications currently afflicted by EqB, including assessment of the effect of international coauthorship on the publication gaps between nation states. It also makes it feasible to study previously unexplored aspects of publication data in unprecedented detail, for example, by documenting the relationship between contributory inequality and cumulative publication output.

2.4. Top-down versus bottom-up allocation of publication credit

Proxy indicators, such as inflated and fractional counting, quantify publication credit according to a top down approach which allocates the same amount of credit to all coauthors irrespective of their actual contribution. The advantage is that automated credit allocation is unproblematic. But the disadvantage is that the credit of all coauthors who have not contributed equally is severely biased by EqB (Hagen, 2014a).

In contrast, a bottom-up approach uses all relevant evidence in the source data to provide an accurate informetric estimate of actual publication credit for all coauthors. Credit, therefore, is not allocated equally unless there is evidence indicating equal contribution. When there is no evidence of equal contribution, credit must be allocated according to the available information. Such information usually consists of a hierarchical byline structure but may also include additional information indicating specific departures from the hierarchy, such as two or more equal coauthors, or the presence of a senior author. Allocation of hierarchical information is easily automated using the harmonic formula (e.g. Walters & Wilder, 2015).

Advantages of the bottom-up approach include increased accuracy, transparency, reproducibility and credibility. However, a full implementation of automated bottom-up allocation is still hampered by non-standardised coding of relevant additional information, by the persistence of incomplete, inaccurate or ambiguous byline information, and by the ongoing evolution of larger and more complex author collaborations. To resolve these challenges completely will require a concerted multidisciplinary effort by all involved stakeholders. Meanwhile, the preferred remedy is to encourage authors to state their contributions more explicitly, by making every effort to respect the information they do provide.

3. Material and methods

3.1. Conventional publication counts and the prevalence of international collaboration 1973–2013

Publication counts were obtained by searching the Web of Science (WoS) database for articles and reviews including either Denmark or Norway in the authors address field during the timespan 1973–2013. Domestic only publication counts for each country were obtained by excluding all foreign “Countries/Territories” from the result. The prevalence of international collaboration was calculated as the proportion of non-domestic papers.

3.1.1. Doubling time

Constant doubling time is a defining feature of exponential growth (e.g. Price, 1951). I assumed that the growth in publication output, measured as the number of papers including a Danish or Norwegian author affiliation, was nearly exponential between 1973 and 2013 (cf. Fig. 2A), and calculated the doubling time D as:

$$D = (t_1 - t_0)/d, \quad t : \text{time interval}, \; d : \text{number of doublings}. \tag{1}$$

Here the time interval is $(t_1 - t_0) = 2013 - 1973 = 40$ years. The denominator d is the number of doublings between the first (P_0) and the last (P_1) publication count. An estimate for d was derived as follows:

$$2^d P_0 = P_1 \tag{2}$$

$$2^d = P_1/P_0 \tag{3}$$

$$\log_2(2^d) = \log_2(P_1/P_0) \tag{4}$$

$$d = \log_2(P_1) - \log_2(P_0) \tag{5}$$

3.2. Top-level publications 2012–2013

Top-level publications were identified by restricting the publication names to *Science* or *Nature*, and by limiting the timespan to include only 2012 and 2013. All top-level publications thus identified were downloaded from the publishers, and all relevant byline information was verified directly from the pdf-files of the original papers. This resulted in 125 Danish papers and 44 Norwegian papers (Table 2). However, 9 of these papers included affiliations from both countries, so the total count was 125 + 44 – 9 = 160 papers. Two Danish papers included a coauthor with a “Present address” in Norway. This was interpreted as an indication that the Norwegian affiliation had not been involved in the production of the paper, and hence these papers were not included in the Norwegian count.

For 4 papers, where the byline included both a group author and named coauthors, one individual was listed twice; once as part of the group and once as a named individual coauthor. In these cases the group as a whole was accredited according to its byline position, and then the person’s portion of the group contribution along with credit for the named contribution were added together and recognized as that individual’s contribution.

The end result was a list of 476 Danish and 123 Norwegian individual coauthor contributions (Table 2). For two papers with alphabetical bylines, authorship credit was divided equally among the coauthors. Authorship credit for all other contributions was calculated using the harmonic formula.

3.2.1. Harmonic credit

Harmonic authorship credit for the ith author of a publication with N coauthors was calculated according to the following formula (Hagen, 2008; Hodge & Greenberg, 1981):

$$\text{Harmonic } ith \text{ author credit} = \frac{1/i}{1 + (1/2) + \cdots + (1/N)} \tag{6}$$

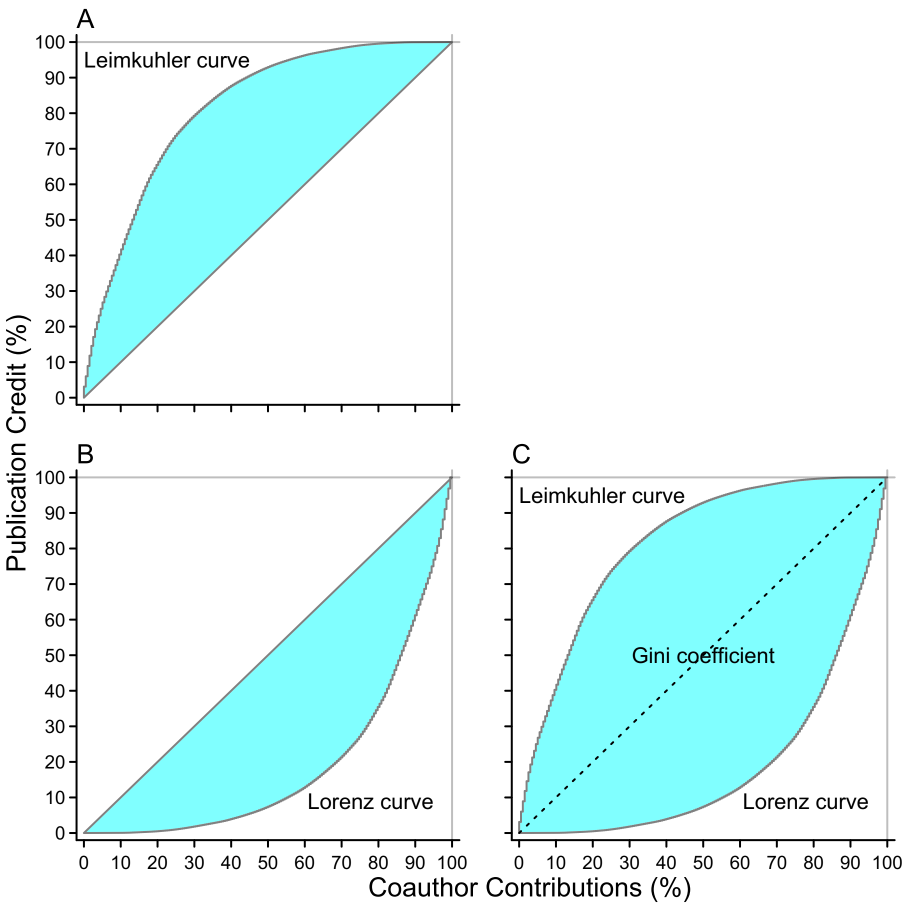

Fig. 1. Schematic diagram of inequality measures. (A) Coauthor contributions are sorted in decreasing order in a Leimkuhler curve. (B) Coauthor contributions are sorted in increasing order in a Lorenz curve. (C) The Gini coefficient G is depicted as the area between the Leimkuhler and Lorenz curves. The diagonal line represents $G = 0$, a hypothetical state of no inequality.

3.2.2. Additional byline information

Corresponding last author. The presence of a corresponding last author, or in some cases 2, 3 or 4 adjacent corresponding last authors, was interpreted as an indication of senior authorship, and the senior(s) contribution was regarded as equivalent to the contribution of the first author. Consequently the rank of intermediate coauthors was demoted by the number of senior authors (Hagen, 2008, Fig. 5 therein).

Senior authorship, thus defined, was detected in 55.6% ($n = 81$) of the 160 papers in the dataset. The majority (90.1%, $n = 64$) of the 79 papers without a senior author had a corresponding first author; and of these, one paper had 2, and another had 3, equally contributing corresponding first authors. The second author was the corresponding author on 4 papers (2.5% of the total); and of these, one paper had 2, and another had 3, equally contributing first authors. That leaves only 3 papers (1.9% of the total) where the corresponding author was neither the last, the first, nor the second author.

Non-corresponding last author. Historically, there is some ambiguity as to whether a non-corresponding last author is an *honorary* author who does not meet recognized authorship criteria, or simply the coauthor who has made the smallest contribution to the manuscript. Assuming the latter, has the advantage of discouraging honorary authorship by minimizing its gain. However, a third possibility occurs if the last author is in fact an authentic senior author, but one who is still following the *noblesse oblige* convention of relinquishing the first position to a junior colleague. In such a case the contribution of

Table 1
Conventional publication performance comparison.

Country	Doubling time	Publication count		International collaboration	
	d (Years)	1973 (P_0)	2013 (P_1)	1973 (%)	2013 (%)
Denmark	13.70	2106	15 929	16.1	63.0
Norway	13.77	1586	11 882	11.3	60.2

Publication (article and review) counts retrieved from WoS, mid 2014.

the senior author goes undetected, his or her credit is underestimated, and the credit of the coauthors is correspondingly overestimated (Hagen, 2014a).

Footnotes. Footnoted indications of equal contribution were respected by dividing credit equally among the specified coauthors. A subset of 79 contributions had footnotes indicating shared first authorship.

Partially alphabetical bylines. Partial alphabetical listings involving a portion of the byline, or the members of a group author, were detected in 28 papers and ranged in size from 5 to 132 individual coauthors. For example, a paper with 46 coauthors listed the last 43 alphabetically (*Science* 337(6094):556–559), and a paper with 85 coauthors listed coauthors 19–71 alphabetically (*Nature* 489(7414):101–108). Coauthors in these partially alphabetical listings were treated as equal contributors. Alphabetical sequences of ≤4 coauthors were not detected. In general, however, such short alphabetical sequences are ambiguous (Waltman, 2012, Section 2 therein), and equality should therefore be explicitly indicated in order to avoid misinterpretation.

Author affiliations. Credit was subdivided equally among an author's affiliations when the author had indicated both domestic and foreign addresses. The end result was a verified list of harmonic credit estimates for 599 individual coauthor contributions (Table 2).

3.2.3. Fractional and inflated credit

Fractional credit was calculated by dividing credit equally among all coauthors of a paper, and then summing the credit for the coauthor affiliations from each country (Aksnes, Schneider, & Gunnarson, 2012; Gauffriau et al., 2008; Gauffriau & Larsen, 2005). Inflated credit was calculated by allocating one full unit of credit to each country for every paper to which it had contributed.

3.2.4. Lorenz/Leimkuhler curves and Gini coefficients

Lorenz (1905) curves, and Gini (2005) coefficients (Ceriani & Verme, 2012), are standard measures of distributional inequality. Lorenz curves were constructed by sorting each country's contributions to *Science* and *Nature* in increasing order, and plotting the cumulative proportion of publication credit as a function of the percentage of coauthor contributions during 2012 and 2013.

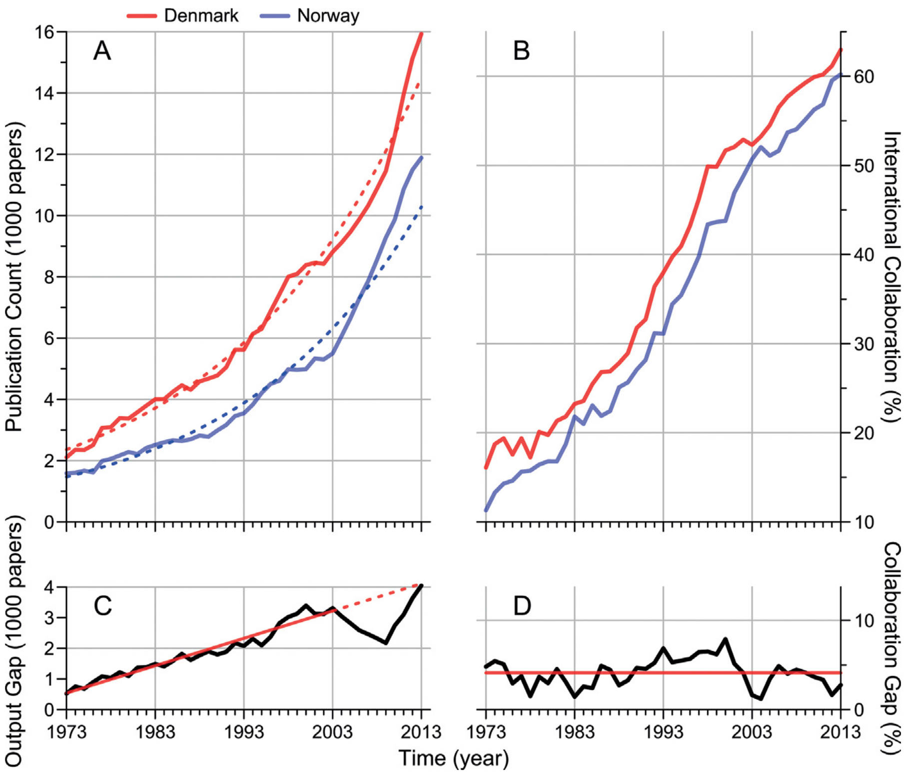

Fig. 2. Four decades of concomitant rise in research output and international collaboration. (A) Publication output measured as the number of all scientific papers including a Danish or Norwegian author affiliation. The dashed curves represent fitted exponential growth curves. (B) Prevalence of international collaboration measured as the percentage of Danish or Norwegian papers including a foreign author affiliation. (C) Publication output gap depicted as the difference between the two curves in panel A. The trend line is fitted to data from 1973 until 2003, and extended until 2013 as a dashed line. (D) International collaboration gap depicted as the difference between the two curves in panel C. The horizontal line represents a mean difference of 4.12%.

Leimkuhler (1967) curves (Fig. 1A) and Lorenz curves (Fig. 1B) are similar. The only difference is that the contributions are sorted in decreasing order in a Leimkuhler curve (Burrell, 1991, 2005a, 2005b). Lorenz and Leimkuhler curves tell the same story, but with different emphasis – a Lorenz curve will, for example, tell you that 50% of the contributions produced 10% of the publication credit, while a Leimkuhler curve will tell you that 50% of the contributions produced 90% of the publication credit.

Here, the Gini coefficient is depicted as the area between the Lorenz curve and the Leimkuhler curve (Fig. 1C). It varies between 0 (a hypothetical state of no inequality, represented by the diagonal line) and 1 (a hypothetical state of maximum inequality represented by the entire plotting area). This novel depiction of the Gini coefficient differs from the commonly encountered depiction which only includes half of the coefficient, as portrayed in Fig. 1B.

Gini coefficients were calculated using the *reldist* package of *R* version 3.1.1 (http://www.R-project.org).

4. Results and discussion

4.1. Delineating the publication gap

4.1.1. Conventional inflated publication count

The academic output of both Denmark and Norway has risen rapidly during the past four decades (Fig. 2A). Both countries have contributed to an increasing number of publications at a nearly exponential rate, with an estimated doubling period of 13.70 years for Denmark and 13.77 years for Norway (Table 1). Note that although the pattern of increase appears to be faster than exponential for both countries during the last decade (Fig. 2A), this may be an artefact of expanded coverage by the WoS database (cf. Larsen & von Ins, 2010).

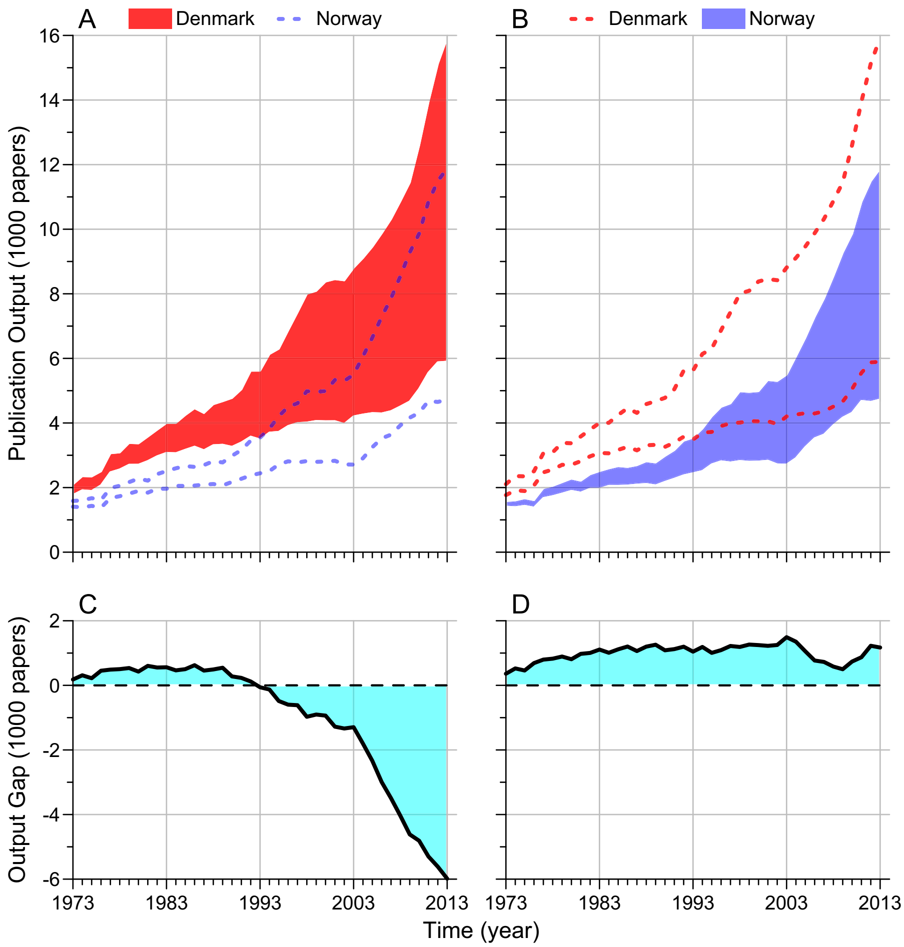

Fig. 3. From gap to overlap. (A) Research output of Denmark delimited as the region between the number of all scientific papers including a Danish author affiliation, and the number of papers with Danish only affiliations. The corresponding region for Norway is indicated with dotted lines. (B) Research output of Norway delimited as the region between the number of all scientific papers including a Norwegian author affiliation, and the number of papers with Norwegian only affiliations. The corresponding region for Denmark is indicated with dotted lines. (C) Output gap depicted as the difference between Danish only papers, and all Norwegian papers. (D) Output gap depicted as the difference between Danish only papers, and Norwegian only papers.

Denmark has consistently contributed to more scientific papers than Norway (Fig. 2A), and in absolute terms the output gap between the countries increased from <1000 papers per annum in 1973 to approximately 4000 papers per annum in 2013 (Fig. 2C). The rise in gap size was approximately linear until 2003, whereupon a steep temporary decline was followed by recovery, such that the value for 2013 fell approximately on the extended trendline for the period 1973–2003.

4.1.2. International collaboration

International collaboration has also risen rapidly during the past four decades. The proportion of Danish papers with at least one foreign coauthor affiliation increased from less than 16% in 1973 to approximately 63% in 2013 (Fig. 2B, Table 1). The corresponding figures for Norway are 11% and 60%. Denmark maintained a slightly higher level of international collaboration throughout the entire time period (mean difference 4.12%, Fig. 2D).

4.1.3. From gap to overlap

The conventional whole publication counts in Fig. 2A, for Denmark and for Norway, are inflated by the contribution of international collaborators to the coauthored papers. The actual publication output must therefore be lower than the conventional publication count, but higher than the number of domestic papers. This region of indeterminacy is demarcated in Fig. 3A for Denmark, and in Fig. 3B for Norway. The widening of the region of indeterminacy over time reflects increasing levels of international collaboration (Fig. 2B). In 2013 the actual publication output of Denmark was somewhere between 6000 and 16 000 paper equivalents, and for Norway between 5000 and 12 000 paper equivalents.

Prior to 1993 the Danish output remained conclusively above the Norwegian output, but the situation changed when the regions of indeterminacy began to overlap as the whole publication count for Norway rose above the count of domestic Danish only papers (Fig. 3C). The period thereafter has been characterized by a widening zone of overlap, which by 2013 had increased to a whole publication count of approximately 6000 papers (Fig. 3C).

The number of domestic Danish only papers has remained consistently about 1000 papers (mean = 997.3) above the number of Norwegian only papers throughout the entire period (Fig. 3D). However, without accurate estimates of each collaborator's contribution to the internationally coauthored papers, it is not possible to determine whether the total Norwegian publication output has in fact remained below the total Danish output.

In summary, the utility of conventional whole publication counts for comparison of the academic output gap between Denmark and Norway has been jeopardized by increased inaccuracy induced by increasing levels of international collaboration in both countries. Concomitant rapid growth of both publication output and international collaboration has produced a widening region of overlap which may contain estimates of either country's actual academic output. To proceed beyond the resulting indeterminacy requires an evidence-based approach which would estimate more accurately the size of each collaborating coauthor's actual contribution. This is possible using the harmonic formula (Hagen, 2013), but has yet to be implemented in a full scale national comparison. It can, however, be done manually for small scale comparisons (Hagen,

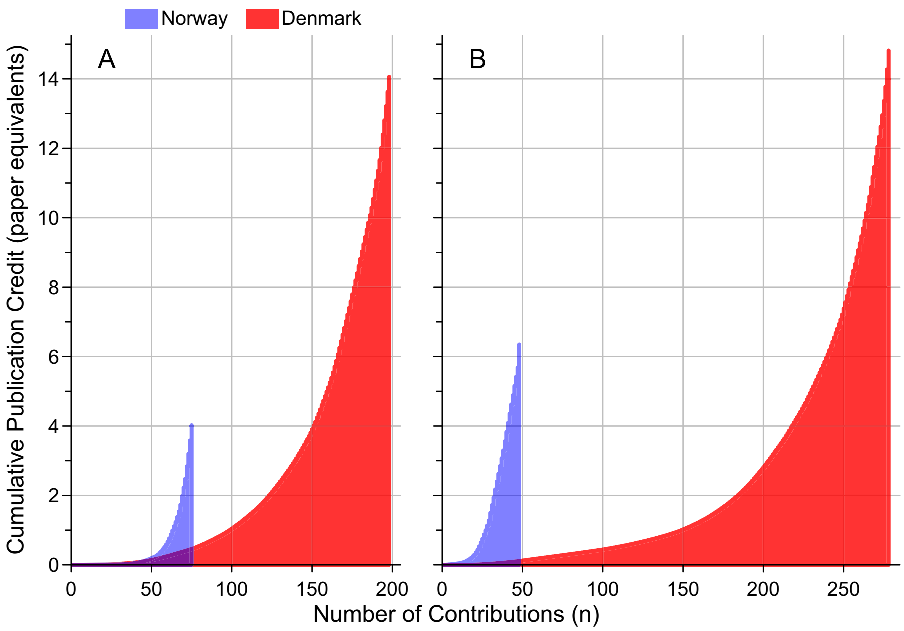

Fig. 4. Top-level close-up. Authorship credit for Denmark and Norway in *Science* and *Nature*. (A) 2012 and (B) 2013. The curves represent cumulative harmonic estimates of actual coauthor contribution sorted in ascending order. Note the remarkable increase in Norwegian publication credit in 2013, despite a large reduction in the number of coauthor contributions.

Table 2
Top-level publication output.[a] Publication metrics for contributions from Denmark and Norway to *Science* and *Nature* in 2012 and 2013.

Country	Harmonic		Fractional		Papers		Contributions	
	2012	2013	2012	2013	2012	2013	2012	2013
Denmark	14.06	14.82	11.57	15.79	57	68	198	278
Norway	4.02	6.35	3.87	4.29	21	23	75	48
Gap size	10.04	8.47	7.7	11.5	36	45	123	218

[a] Articles and reviews.

Table 3
Inequality in top-level publication credit.[a] Comparison of inequality measures for contributions from Denmark and Norway to *Science* and *Nature* in 2012 and 2013.

Country	Gini coefficient		Leimkuhler 50%		Lorenz 50%	
	G_{2012}	G_{2013}	2012 (%)	2013 (%)	2012 (%)	2013 (%)
Denmark	0.6273	0.6761	92.8	94.3	7.2	5.7
Norway	0.7778	0.5081	99.1	89.9	0.9	10.1

[a] Harmonic estimates of publication credit for articles and reviews.

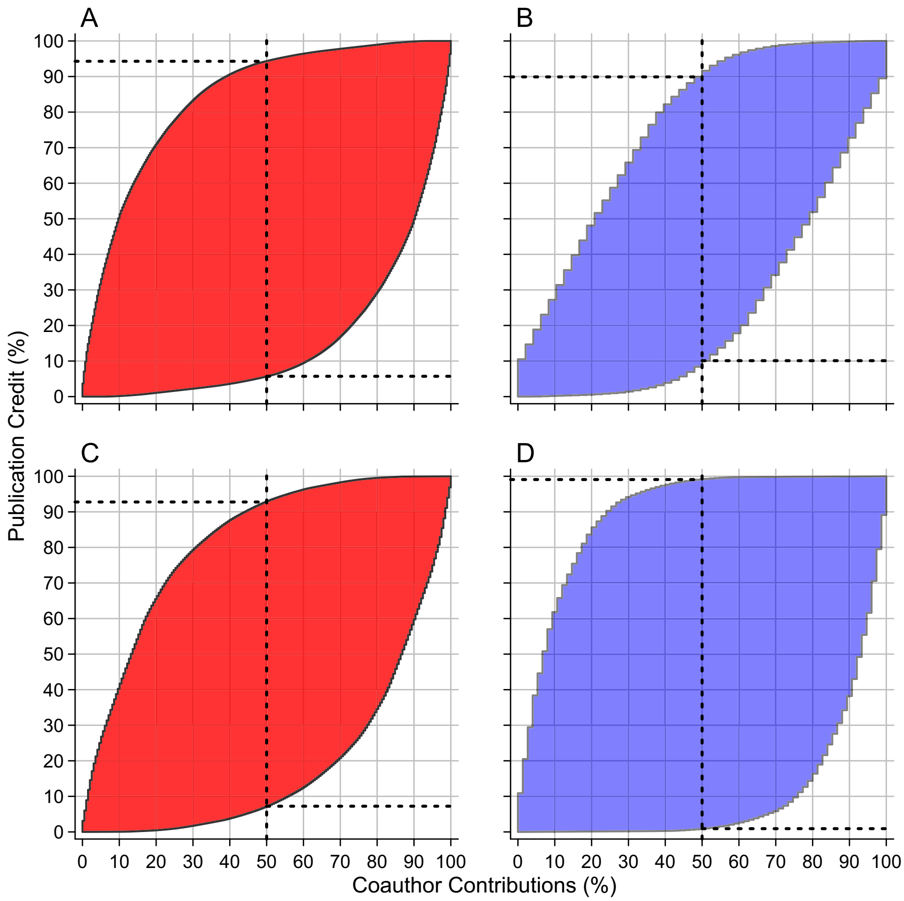

Fig. 5. Inequality curves. Cumulative percentage curves for coauthor contribution and authorship credit in *Science* and *Nature*. (A) Denmark 2013. (B) Norway 2013. (C) Denmark 2012. (D) Norway 2012. The Lorenz curves, below the diagonal, and the Leimkuhler curves, above the diagonal, are complimentary. The only difference is that the Lorenz curves are sorted in increasing order and the Leimkuhler curves are sorted in decreasing order. The coloured area between the Lorenz curve and the Leimkuhler curve is a geometric representation of the Gini coefficient, *G*, a standard measure of inequality. The median contribution is indicated by the vertical dotted line, and its intersection of the Leimkuhler and Lorenz curves is indicated with horizontal dotted lines.

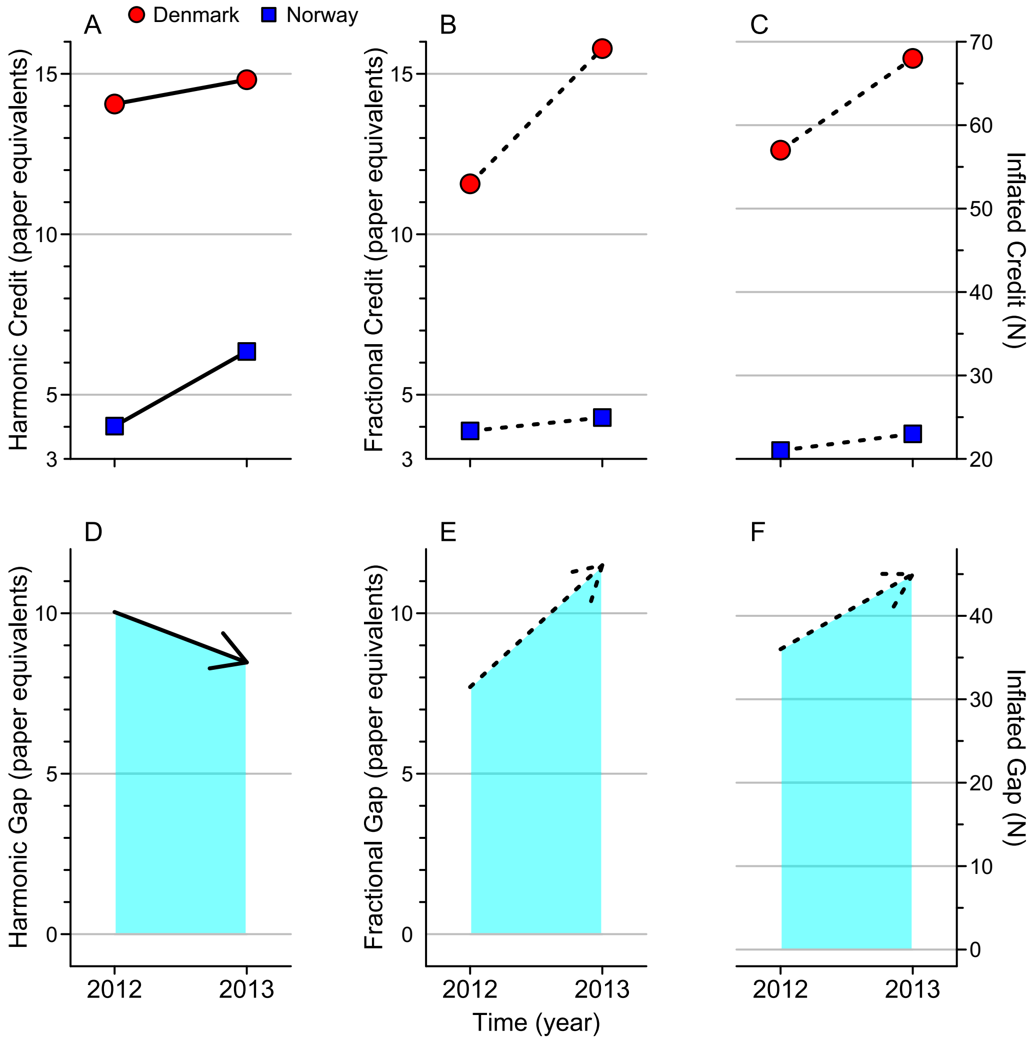

Fig. 6. Effect of bias on perceived change in the top-level academic output gap. (A) Harmonic estimates of actual publication credit. (B) Conventional fractional publication credit. (C) Conventional inflated publication credit; also known as full or whole publication count. (D) Decreasing top-level output gap revealed by harmonic estimates of actual publication credit. (E) and (F) Effect of bias on perceived change in gap size between 2012 and 2013. The dashed lines indicate biased data: in panels *B* and *E* equalizing bias (EqB); in panels *C* and *F* a combination of EqB and inflationary bias. Data for articles and reviews in *Science* and *Nature*.

2014b). The focus of the next section, therefore, is to expand the scope of the evidence-based approach by providing a small scale top-level close-up of the publication gap between Denmark and Norway.

4.2. A top-level close-up

4.2.1. Publication credit

There were large changes from 2012 to 2013 in the pattern of Danish and Norwegian contributions to *Science* and *Nature* (Fig. 4A and B). In 2013, Denmark made more contributions to more papers, and had a higher publication score than the year before (Table 2). But the 40% increase in contribution count, yielded only a modest 5.4% increase in publication credit. In contrast, Norway exhibited a large 58% increase in publication credit, despite a large concurrent reduction in the number of contributions from 75 in 2012, to 48 in 2013 (Fig. 4A and B).

A conspicuous feature of these changing patterns is that the left tail of the cumulative publication credit curve, i.e. the proportion of small contributions, grew longer for Denmark yet shorter for Norway, from 2012 to 2013 (Fig. 4A and B).

4.2.2. Contributory inequality

The level of contributory inequality peaked in the data for Norway 2012, when the most productive half of the contributions accounted for 99.1% of the publication credit (Leimkuhler curve Fig. 5D, Table 3). Conversely, according to the Lorenz curve the least productive half of the contributions accounted for only 0.9% of the credit. One year later, inequality was much reduced and the least productive half of the contributions accounted for 10.1% of the publication credit (Lorenz curve Fig. 5B, Table 3).

In contrast, the most productive half of the Danish contributions accounted for 92.8% of the publication credit in 2012 (Leimkuhler curve Fig. 5C, Table 3), and 94.3% in 2013 (Leimkuhler curve Fig. 5A, Table 3), whereas the least productive half of the contributions accounted for 7.2% in 2012 and 5.7% in 2013.

These results are consistent with the summary provided by the Gini coefficients (Table 3). Norway had a marked reduction in contributory inequality, from 0.78 in 2012 to 0.51 in 2013, while Denmark remained at a comparatively high level of inequality, with a slight increase from 0.63 in 2012 to 0.68 in 2013.

4.2.3. Output gap

Harmonic estimates of actual publication credit (Fig. 6A, Table 2), indicated a narrowing of the top-level publication gap between Denmark and Norway from 2012 to 2013 (Fig. 6D). In contrast, the less accurate fractional (Fig. 6B), and inflated credit estimates (Fig. 6C), arrived at the opposite conclusion and purported that the gap was widening (Fig. 6E and F). The discrepancy is a direct cause of bias in the fractional and inflated estimates.

5. Conclusions

In this paper I have used data for articles and reviews in *Science* and *Nature* to document a recent narrowing of the top-level output gap between Denmark and Norway. Denmark still leads, but the gap narrowed between 2012 and 2013 because the publication credit of Norway rose by 58%, while the credit of Denmark rose by only 5.4%. The narrowing of the gap was detected by using harmonic estimates of actual contribution to remove inflationary bias and equalizing bias (EqB) from conventional publication counts. The narrowing was not detected when conventional inflated or fractional publication counts were used as proxies for publication credit. On the contrary, the conventional approach purported that the gap was widening. This result highlights the utility of increased accuracy in estimates of publication credit in national comparisons.

For Norway, the narrowing of the output gap was accompanied by a large drop in contributory inequality, and a 36% reduction in the number of coauthor contributions. In other words, fewer contributors who produced more publication credit. In comparison, for Denmark the narrowing coincided with a slight increase in contributory inequality, and a 40% increase in the number of contributions, that is more contributors who produced less publication credit. These diverging patterns, in the number and inequality of the two countries' contributions, provide a proximate explanation for the observed narrowing of the output gap by demonstrating that reduced contributory inequality was associated with increased publication output.

The remarkable dynamics of these changes were obscured and distorted by equalizing bias (EqB) in the fractional estimates of publication output, and by a combination of EqB and inflationary bias when using conventional whole counts as a proxy for publication output. Specifically, the diverging patterns in the number and inequality of the two countries' contributions, suggest that the conventional measures did not detect the narrowing of the gap because their inherent EqB overestimated the importance of the increasingly numerous small Danish contributions and underestimated the importance of the increased proportion of large Norwegian contributions.

The recently launched Nature Index (2014b) includes a table of country outputs for *Science* and *Nature*, which uses inflated and fractional publication counts. These conventional metrics are not corrected for EqB, and may therefore misrepresent the gap between comparable countries with high levels of international collaboration. The results of this paper, however, indicate that improved accuracy is readily attainable by including all relevant information about the relative contribution of coauthors, and by using the harmonic formula to quantify hierarchical bylines.

Equalizing bias is of special concern because it carries a large counterproductive element of reverse meritocracy and systemic injustice into bibliometric performance assessment by favouring small contributors at the expense of large contributors. EqB acts in an asymmetrical fashion which precludes top-down compensation for its distortional effects. To correct for EqB in national comparisons requires a bottom-up approach which incorporates relevant byline information from every internationally coauthored publication in the source data. Right now, this still manual task is sufficiently labour-intensive to preclude a full-scale analysis of the total productivity gap between Denmark and Norway. However, immediate implementation of automated harmonic credit allocation could correct for EqB, and facilitate unconstrained bibliometric gap analysis with unprecedented accuracy. In the meantime, the top-tier, close-up approach adopted here demonstrates the feasibility of using EqB-corrected publication credit in gap assessment at the national level.

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