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Global Research Report
Making it count: Research credit management in a collaborative world

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About the Institute for Scientific Information

The Institute for Scientific Information at Clarivate has pioneered the organization of the world's research information for more than half a century. Today it remains committed to promoting integrity in research whilst improving the retrieval, interpretation and utility of scientific information.

It maintains the knowledge corpus upon which the Web of Science index and related information and analytical content and services are built. It disseminates that knowledge externally through events, conferences and publications whilst conducting primary research to sustain, extend and improve the knowledge base. For more information, please visit www.clarivate.com/webofsciencegroup/solutions/isi-institute-for-scientific-information/.

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Cover image: The abacus *(plural abaci or abacuses)*, also called a counting frame

The abacus is a calculating instrument that uses beads that slide along a series of wires or rods set in a frame to represent the decimal places. It is the ancestor of the modern digital calculator. Used by merchants in the Middle Ages throughout Europe and the Arabic world, it was gradually replaced by arithmetic based on Hindu-Arabic numerals. Though rarely used in Europe past the 18th century, it is still used in the Middle East, China, and Japan.

Executive summary

- This report proposes a new method for analyzing the credit for academic papers and their citations. It is complementary to, rather than contradictory of, fractional citation analysis.

- Citation counts are typically greater where international collaboration is higher. The increase in authorship counts on academic papers makes it difficult to understand and interpret the allocation of credit for research publications and their citation impact.

- Credit to researchers feeds through to institutional evaluations, and aggregates to national policy analysis. The need for informed analysis that works across disciplines and global regions is therefore essential.

- There is no formally correct method to assign credit. Whole counting is simplest, but over-credits individuals as authorship rises. Fractional counting has appeal but none of the multiple alternatives is universally applicable. Equal partitioning of papers and citations among authors is widely used but hides information essential to research management.

- We believe that the societal value of bibliometric methodology is boosted by practical utility more than technical purity. In studying existing and innovative analytical methods we ask: will this indicator help to facilitate more, better research?

- We propose and recommend 'Collaborative CNCI' (Collab-CNCI). This retains simple Category Normalized Citation Impact but the accumulated citation count for each paper is normalized against other papers of the same publication year, the same subject category, the same document type and – critically – the same collaboration type.

- Visualizing CNCI values by collaboration type provides new management information about the source and balance of achievement and thus supports decision making. It enables rapid interpretation of summary analytical reports.

- Collab-CNCI is a vital innovation for a period when international collaboration is becoming a dominant feature of global research. It not only confirms that highly collaborative papers can distort summary results at national as well as institutional level but also shows how that happens. It highlights key aspects of achievement and shows where institutions are generating significant academic credit from citations to their more domestic papers.

- We invite research users and managers to comment on the relative benefits of the Collab-CNCI in comparison and as a complement to other methods at ISI@clarivate.com.

Collab-CNCI is a vital innovation for a period when international collaboration is becoming a dominant feature of global research.

Introduction

Acknowledging achievement and excellence is always important. Research evaluation, planning and policy managers examine publications and citations as a proxy for assessing credit due for past research outcomes. This is applied to research management at individual, institutional and national levels.

In the world of research, receipt of credit will influence motivation and reputation. The way we count documents, and their citation links, is critical both to researchers and research management as it may affect employment, promotion and future funding to the individual and their institution as well as the research reputation of their country.

It is also essential to present the data in a way that is relevant and informative to research process and management. In this report we discuss methodologies for counting documents and citations, for analyzing such data, and for presenting the outcome in a way that enables understanding of what the information means.

This report is part of work by Clarivate™ on the responsible use of publication and citation data indexed in the Web of Science and its presentation as profiles rather than simple summary metrics (Adams et al., 2019; Potter et al., 2021, Potter and Szomszor, 2021). Good practice in this context has been widely discussed elsewhere (Moed, 2005; Metric Tide, 2015; Waltman, 2016) and is monitored by the UK Forum on Responsible Research Metrics (https://www.universitiesuk.ac.uk/topics/research-and-innovation/uk-forum-responsible-research-metrics).

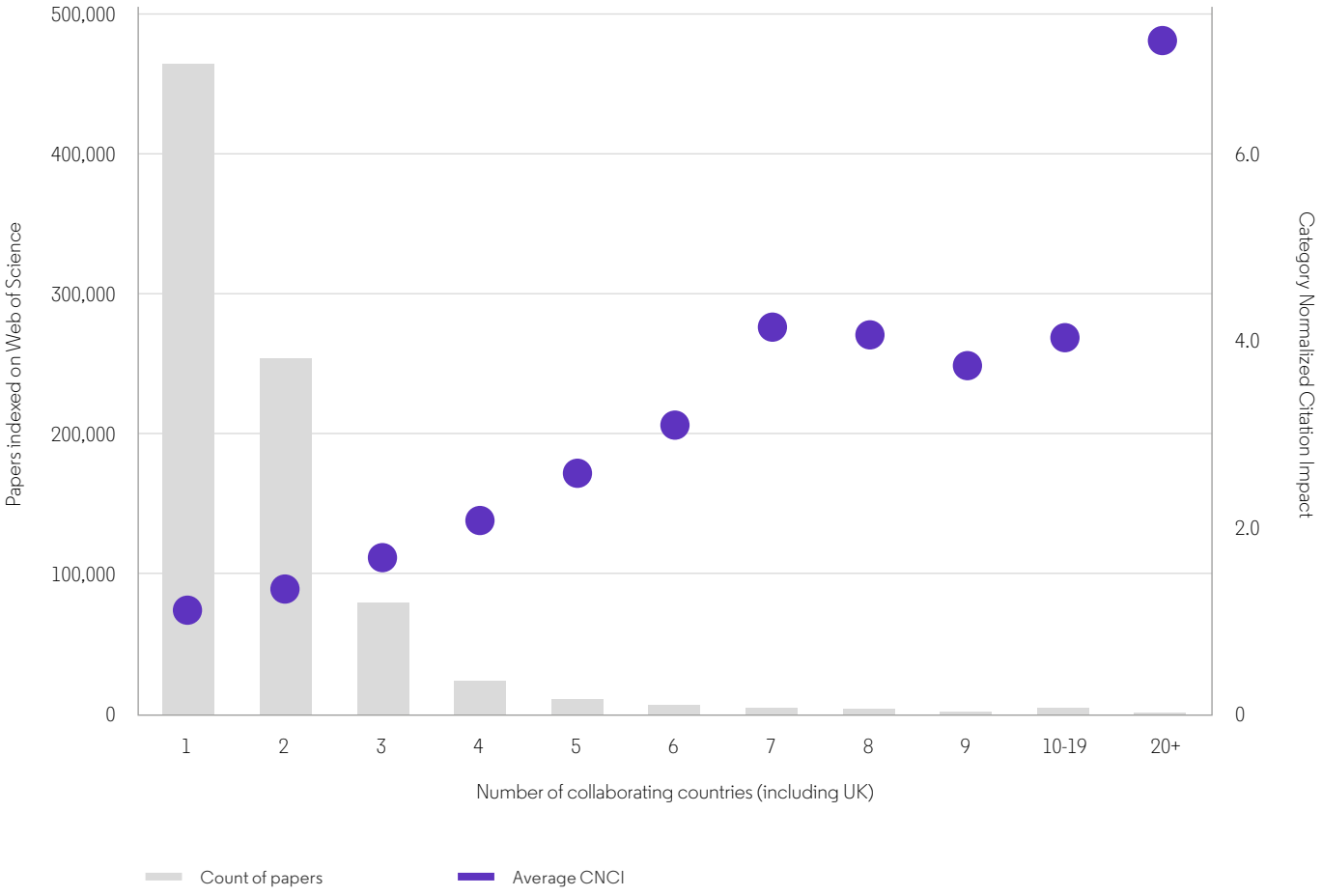
In excess of 2.5 million articles and reviews (original academic papers) are published every year in journals indexed in the Web of Science, with around 14 million author attributions. They reference papers (and other documents) in their own and earlier years, requiring the Clarivate comprehensive editorial systems to add almost 100 million new citation links every year as well. Many papers remain uncited in their year of publication but the percentage of papers that remain unnoticed and uncited, even by their authors, falls to about 10% by the tenth year after publication.

About one-third of the indexed papers have a single author, which usually (but not universally) means that they also have a single institutional address and a single country. Most papers have more than one author, since there are about six times as many authors as papers, which marks a distinct change in culture over the last four decades (Adams, 2013). Globally, about one-third have authors from more than one country, although this varies markedly from one country to another. In 2019, international co-authorship accounted for around 67% of U.K. authored papers, 43% for the U.S. and 27% for Mainland China.

The accumulation of citations to these papers has become an important indicator in research assessment and evaluation and these counts are increasingly used as management information at national, institutional and research group level. Citations acknowledge the usefulness or significance of a published report to subsequent research and influential or 'impactful' papers are likely to be cited more often (Garfield, 1955). Because citations accumulate over time at a rate that is discipline dependent and varies between document types, it is necessary to transform raw citation counts into 'normalized' counts, compared to a relevant global benchmark. Category Normalized Citation Impact (CNCI) is a standard method that compares the accumulated citation count for an article (or a review) to other articles (or reviews) published in the same year and in the same journal-based subject category in the Web of Science. The net CNCI for an author (or institution or country) is the average CNCI of their papers.

Research discipline and time since publication are not the only factors that influence citation counts. There is a widespread awareness that some papers with exceptionally high author counts also attract exceptional citation counts. There is in fact a general pattern where citation counts rise, on average, with author number, with the number of author institutions and, even more so, the number of countries (Adams and Gurney, 2018; Adams et al. 2019; Potter et al., 2020). Such a link has been noticed for some time (van Raan, 1998; Moed, 2005) and has on occasion been attributed to a 'two home crowds' effect where a paper with two 'home' audiences gets exceptional attention.

Figure 1.
The Category Normalized Citation Impact (CNCI) of the U.K.'s papers rises with increasing numbers of collaborating countries, and then plateaus. Average CNCI is erratic for papers with more than 20 collaborating countries. Data from Adams and Gurney (2018).



If CNCI is so high and so inconsistent for highly multi-authored papers then we might ask whether papers drawing on many authors' research are really the same kind of publication as papers produced by lone researchers or small groups? There is some evidence of a general plateau in average citation impact around four times world average for papers with 7-19 collaborating countries (Figure 1), yet the small group of papers with 20 or more collaborators veers into an area of exceptional and erratic citation counts. For these reasons, Clarivate excludes papers with more than 30 named authors, including group lists, from its authoritative annual analysis of Highly Cited Researchers (https://recognition.webofscience.com/awards/highly-cited/2021/methodology/).

Shared authorship raises a more general issue about the credit due for a publication and its attribution among stakeholders. That points to questions about the information derived from citation-based indicators and their responsible use for policy and management. In response to these issues, this report reviews factors that affect the balance of credit and discusses the challenge of acquiring sound management information about the influence and benefit of multinational authorship.

Sharing credit among authors

Derek de Solla Price, Yale historian of science and pioneer of scientometrics, noticed that global research productivity up to the 1970s had long run at around one paper per academic per year - but that author counts were rising. How might due credit be properly acknowledged if an academic paper, or any other publication, has more than one author? (Price, 1981). There does not even need to be multiple authorship for such questions to appear, but simply multiple affiliations for a single author. When a researcher moves to a new job and publishes work from earlier projects, are both the old and new institutions named by the author, and where does the credit lie? Portability of credit has been a real, and contentious, issue in national research assessment exercises. For example, debates around the U.K.'s Research Excellence Framework (REF) required specific discussion of output portability in the REF Manager's Guidance on Submissions.

There is also an obvious and potentially frictional interplay between credit for the paper and credit for the citations that accrue to the paper. An author can readily acknowledge that they share the credit for producing a paper with their co-authors, but they may be less content with the idea that they should get credit for only a fraction of the citation count.

Authors have had to decide amongst themselves how their names should be presented on a publication. Sociologist of science Harriett Zuckerman pointed out long ago that name ordering is inconsistent and ambiguous (Zuckerman, 1968). In some disciplines it has been conventional for names to be alphabetical (a practice recently adopted more widely: Kuld and O'Hagan, 2018); in others, the first-named author can be inferred to be the prime investigator; in still others, it is said to be conventional to include the research group leader as the last-named author (Hodge and Greenberg, 1981). Similar conventions apply to the role of corresponding author. There are exceptions and individual choices in all these areas, and practice varies between sub-disciplines and evolves over time. Consequently, there is no firm and universal rule which would allow a reader to unequivocally identify where the balance of credit should fall.

Another important consideration in assigning credit for research outcomes is the particular role played by each individual in a shared authorship. It may be that one among several is the actual writer, but others conceived the project, performed the work and analyzed the data. How then should credit be distributed? Liz Allen, formerly at the Wellcome Trust and now a Director at F1000 Research, and Amy Brand, Director of MIT Press, worked with a team at the National Information Standards Organization (NISO) to develop a taxonomy of credit (Allen et al., 2014). CRediT (Contributor Roles Taxonomy – https://credit.niso.org/) identifies 14 roles that represent the contributions typically made by authors and others involved in academic scholarly output.

CRediT is about the **qualitative** distribution, and thus consistent acknowledgment, of credit. It enables the reader to be clear about how the work was done and it enables any assessor to see the specialist contribution of each author. It has been widely adopted and many leading journals now require authors to provide an agreed statement of their different contributions.

The **quantitative** distribution of credit is a more problematic challenge:

- Author sequence provides no consistent information: the lead, final and corresponding author do not universally indicate any priority.
- There is no universal consensus on a process for equitable division of publication credit.
- No system exists for authors to agree and report the balance of their contribution.
- As author numbers on individual publications increase, sometimes into thousands, the assignment of fractional credit becomes meaningless.

These problems have not held scientometricians and others back from devising their own solutions. Marianne Gauffriau (University of Copenhagen) identified no fewer than 32 counting methods introduced to bibliometric analysis since 1981. Twenty of these methods are author-rank dependent, fractionalized, and introduced to measure contribution and participation. Her literature search found that only three methods (harmonic counting: Hodge and Greenberg, 1981; productivity analysis: Howard et al., 1987; sequence determines credit: Tscharntke et al., 2007) had been used in four or more research evaluations. Gauffriau's typology and her analysis of the justification invoked for using each method are summarized in the next page.

Gauffriau's typology and her analysis of the justification invoked.
A typology of methods for assigning publication credit and a summary of criteria (arguments) for choosing a particular counting methodology, adapted from Gauffriau (2021). There are analytical units and evaluation objects. A unit of analysis may be an individual author, the institution to which an author is affiliated, or a country (in an author's address) where *m* is the unique number and *n* is the total number of units of analysis in a publication. The object of the evaluation may be an author, the employing institution, or the host country. The counting method may feed a separate analytical methodology to create an indicator.

Table 1. Typology of methods for assigning publication credit

Complete	A credit of 1 is given to each basic unit of analysis in a publication. An evaluation object collects the credits from the basic units of analysis assigned to the evaluation (e.g., a university collects credits from authors using the institutional address).
Complete fractionalized	A credit of 1/*n* is given to each basic unit of analysis. An evaluation object collects the credits from the units of analysis assigned to the subject.
Straight	A credit of 1 is given to the basic unit of analysis ranked first [or last or reprint] in a publication; all other units are credited 0. An evaluation object collects the credits from units of analysis assigned to that object.
Whole	A credit of 1 is given to each basic unit of analysis, assigned one-to-one to a unique evaluation object, in a publication. If a unique evaluation object is represented by more basic units of analysis in a publication, these basic units of analysis share 1 credit in whatever way. An evaluation object collects the credits from the units of analysis assigned to that object.
Whole-fractionalized	A credit of 1/*m* is given to each basic unit of analysis, assigned one-to-one to a unique evaluation object. If a unique object is represented by multiple basic units of analysis, these units share 1/*m* credit. An object collects the credits from the basic units of analysis assigned to the object.

Table 2. Criteria for choosing a counting method

Complete	**Justification**
The derived indicator 'measures' impact, contribution or participation	The counting method targets something that can be 'measured' via a derived indicator, which is a proxy for an activity of interest. For example, whole counting produces an indicator of participation in research.
The method satisfies mathematical requirements	The method has desirable mathematical properties. For example, it is additive and thus avoids 'double counting' of publications.
Pragmatic reasons	The method is chosen for simplicity rather than conceptual or methodological reasons. For example, whole counting uses data immediately available in the main sources for bibliometric indicators, such as the Web of Science.
Influence on/from the research community	The method is chosen not because of what the derived indicator measures but because it is related to the interpretation of the research community under evaluation. For example, a researcher should receive one credit for a publication because this is how a researcher intuitively counts their publications.

What is the correct counting method?

There is - and can be - no definitively correct counting method. It is very important to start by understanding this. Some are better than others, in that they meet Gauffriau's criteria more effectively. Some are very poor, in being arbitrary, partial and applicable only in specific circumstances. From a more practical perspective, what is most important is that the method selected should suit the purpose for which it is used.

Why is there no 'correct' method? Arguments about what equitable research credit assignment means are social and philosophical, not scientific. Each counting method delivers a set of comparative results (a difference or ranking) for a number of papers or an average citation impact for a person or place. But, as Egghe et al. (2000) have shown, rankings differ between methods. They can also differ between data sources since no source is complete and even the most comprehensive may have editorial limitations that miss some data. Even if we had a globally complete and correct dataset, we have no reference model, no independent benchmark, that allows us to say whether one analytical methodology provides a 'better' result than another.

Historically, the standard approach to counting papers and citations has been 'whole counting' where a paper counts once for each author, once for each institution and once for each country among the author addresses. The citations to the paper are similarly credited in full, once to each author, their institution and their country.

The primary objection to this approach is that whole counting is not additive: a paper with two Portuguese authors and two Brazilian authors counts four times in individual (and potentially in institutional) tallies, twice in country tallies and once in the global corpus. When institutional publications are pooled for a country's tally the relative numbers of different collaboration types change. Every single-authored paper is present at institutional and at national level, but a paper that involves collaboration within the country must be 'deduplicated'. The university tally includes just its (less well-cited, on average) domestic papers plus a spread of (better cited) collaborative papers and some international papers (with higher average citation counts). The national tally contains a complete set of all institutional domestic papers and a deduplicated set of international papers where these involved multiple national institutions.

The consequence is that there are ***relatively*** more domestic papers in a national pool than any institutional portfolio, 'over-stating' the degree to which an institution performs against the national average. Although scientometricians have no methodological need to recreate country tallies by adding up individual scores, since they can easily calculate these independently, the objection is often raised. In response, a frequently proposed answer is to partition one credit for one paper among the 'n' authors, and then to assign citation impact on that fractional basis (1/n per author). Waltman and van Eck (2015) present a series of tables laying out the ways in which credit may be assigned at different unit levels by different methods.

Despite the lack of evidence for consistent meaning in author sequence, some analysts have sought to compare and refine the process for assigning credit. One approach is by giving credit to all authors but using a greater weighting for the first and last (e.g., Tscharntke et al., 2007; Weigang, 2017); others have used harmonic weightings or geometric weightings along the author sequence (e.g., Hagen, 2008). However, Leo Egghe and Ronald Rousseau (KU Leuven) have shown that slight differences in the use of such methods not only change the outcomes but may reverse rankings amongst individuals and institutions (Egghe et al., 2000).

'Complete Fractionalized' counting ([1/*n*] credit per author among '*n*' authors) is relatively simple and is an approach favoured by CWTS, the leading research group at the University of Leiden (Waltman and van Eck, 2015). This can, however, result in trivial credit fractions on massively multi-authored papers; Sivertsen et al. (2019) modify the methodology to address this by using (1/[nth-root]). Aksnes et al. (2012) compared citation indicators for full and fractionalized counting among 23 authoring countries. All relative citation indicators were lower when fractionalized counting is used, with the greatest difference where there is a high proportion of internationally co-authored articles, but methodology made little difference to ranked order.

The arguments presented by Ludo Waltman and Nees Jan van Eck are thoughtful, well balanced and comprehensive. They not only present their preferred approach to fractional counting and work through its implications. They also consider and respond to four principal arguments in favour of full counting: (1) equal, fractional weights are arbitrary and do not weight contributions any more accurately than full counting; (2) fractional counting of citations is a disincentive to collaboration; (3) fractional counting is complex for analysis and opaque to interpretation; and (4) full and fractional counting measure different things - participation vs. contribution. Their counter-arguments, which we broadly accept, are well worth reading.

We do dispute, however, their description of the higher average fully counted citation impact of

multi-authored papers as a 'full counting bonus'. This concept is misleading since we have no firm knowledge as to whether a higher or lower citation impact index is truly equitable or not. For example, it is suggested that only the prospective benefit of doing more, better research justifies paying the recognized cost of collaboration in order to deliver more significant outcomes (Fox and Faver, 1984; Smith, 2003). Such research would justly be cited more often, so it is unclear that a fractional approach to credit would in practice provide a more accurate or more precise result.

Similarly pejorative terms to 'bonus' are used elsewhere to justify the spectrum of methods described by Gauffriau. Some authors describe their method as providing a 'correct' outcome compared to full counting. Others describe their method as more 'accurate', and indeed Hagen (2008) claims 'unrivalled accuracy' although no scale for comparative accuracy is provided.

As noted earlier, no absolutely correct quantitative outcome – in the sense of one that would universally be agreed as an equitable allocation of research publication credit – is possible. Our work at ISI has led us to agree with Gauffriau (2021) that "counting methods in the bibliometric literature should not be reduced to a question about the choice between full and fractional counting." We therefore look to a different solution.

Collaborative CNCI

When we consider the societal value of bibliometric methodology, technical purity is less important than practical utility: will this indicator help me to facilitate more, better research? A method that is onerous and challenging and that leads to a complex and obscure outcome has little practical application in research management and policy development since it is of limited value to those who are not academic specialists (Szomszor et al., 2021).

The information benefit of distinguishing between different national and collaborative authorship patterns was reported by Gorraiz et al. (2012), who analyzed these separately to show that Austria's international collaboration with European neighbours was a major influence on citation outcomes.

ISI has addressed the challenge of turning data about shared publications into information that has practical management value by providing not only a summary indicator related to relative citation accumulation but also information about the types of publication on which that indicator is based. This variant index (Collab-CNCI) clarifies the contributions of all entities (base units of analysis) by considering different levels of domestic and international authorship collaboration through an additional normalization in the CNCI calculation.

The weakness in previous methods is that they hide the known citation differences between domestic papers (with no international collaboration) and increasingly complex international collaborative articles. Both full and fractional CNCI analyses compromise subsequent interpretation by removing important management information about the contribution made by different parts of the publication portfolio to an entity's overall performance.

We confirmed the earlier findings of Aksnes et al. (2012), Waltman and van Eck (2015) and others, that different credit counting methods (such as full and fractional) produce different results. We developed a novel methodology as set out in detail by Potter et al (2020):

0. Country citation and CNCI profiles vary significantly across a typology of collaboration types, so papers are first allocated to their respective types (groups; steps 1-3), then citation counts are normalized within each type (step 4); a summary indicator is synthesized from these types, (5) and finally this is reported with the deconstructed type profiles (6).

1. Split domestic papers (with no international co-author) from international papers.

2. Allocate domestic papers to two types (single author and multiple author), because domestic collaboration is associated with higher average citation counts.

3. Allocate internationally collaborative papers to three types (international bilateral, international trilateral and international collaborations with four or more co-authoring countries): there are fewer than 4% of papers with four or more collaborating countries.

4. Normalize the citation count for each paper within each type by the relevant global benchmark (papers of the same type, published in the same year and subject category).

5. Calculate the annual average CNCI from this set.

6. Graph (a) the annual count of papers and (b) the annual average CNCI for each type to show how the overall average is composed and how it changes over time.

For the Collab-CNCI calculation, each paper's full citation count is normalized in a simple way, exactly as for standard CNCI, but with the critical modification that this is done ***within collaboration type***. Consequently, a single author paper (restricted as to document type) is compared only with the average for similar (same year, same subject) single author papers and an international trilateral paper is compared only with similar international trilateral papers.

Thus, we do not address the question of whether a paper is well cited compared to all other papers but whether it is well cited compared to other, similar papers of the same collaborative typology.

Our solution retains the simplicity of conventional full counting of papers and citations for CNCI whilst at the same time categorizing collaboration types to overcome an historical information deficit, normalizing citation counts for each category separately and reporting their separate contribution to the net result. Importantly, from a research management perspective, the methodology behind the indicator provides deeper insight into a country's research portfolio than was possible with previous CNCI indicators, because it considers article and citation share for each collaboration type.

How Collab-CNCI works

The consequence and benefit of using Collab-CNCI rather than direct full or fractional counting of citations is best seen in direct country and university comparisons, which we describe in this and the next section.

We start with three countries with well-established research economies, which have appeared in many scientometric studies and the research output of which will be widely known. To give global spread we have chosen to look at journal articles (and not reviews or other document types) published in journals indexed in the Web of Science and authored by researchers located in Australia, France and the U.S. over the ten-year period 2009-2018. Figure 2 is an illustration and deconstruction of the source data for these three countries by collaboration type, the CNCI indicator values as calculated from these data by three different methods, and the way in which the different collaboration types contribute to the synthesis of the summary indicator.

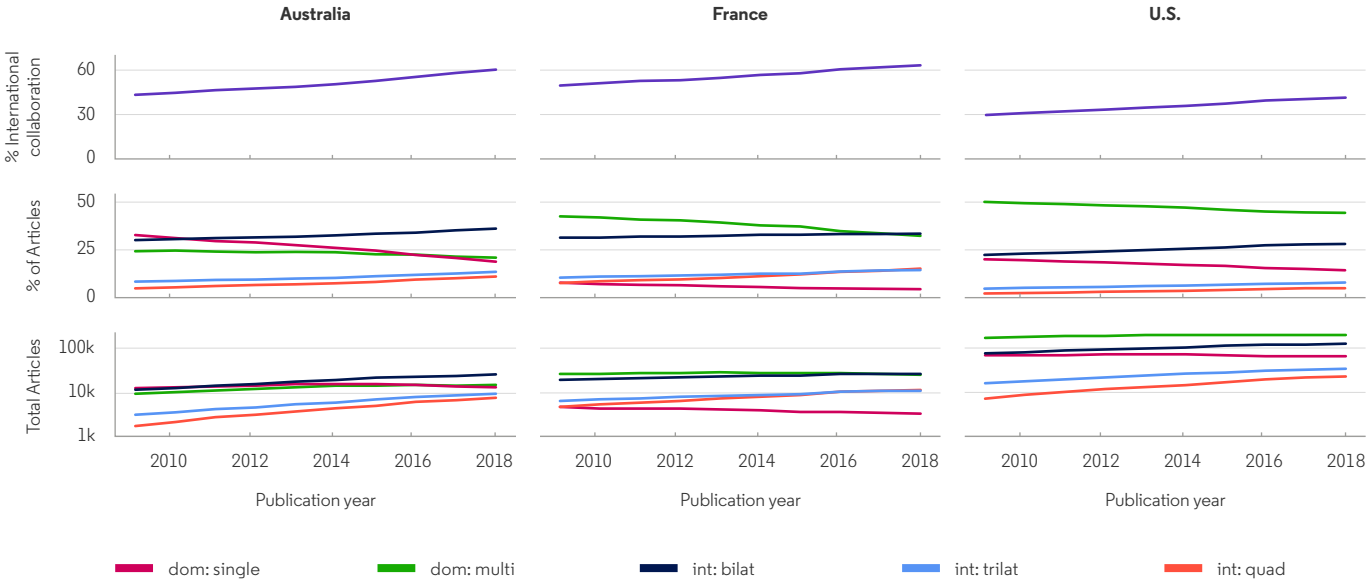
International collaboration is steadily rising for all, and international bilateral articles are becoming the most common output type, replacing domestic multi-authored articles, while international trilateral and quadrilateral articles remain uncommon though rising slowly (Figure 2.a). The U.S., which maintains a greater proportion of domestic articles than most G7 nations, has similar net CNCI for all three analytical methods but fractional CNCI and Collab-CNCI are distinctly lower than standard CNCI for both Australia and France which receive only fractional credit for their frequent collaboration (Figure 2.b).

Both fractional counting and Collab-CNCI reduce the net average compared to standard full counting so the net result of calculating CNCI by these methods is similar for all these countries though the difference is smaller for the less collaborative U.S. It is when the CNCI data are further deconstructed via Collab-CNCI that the differences are clarified.

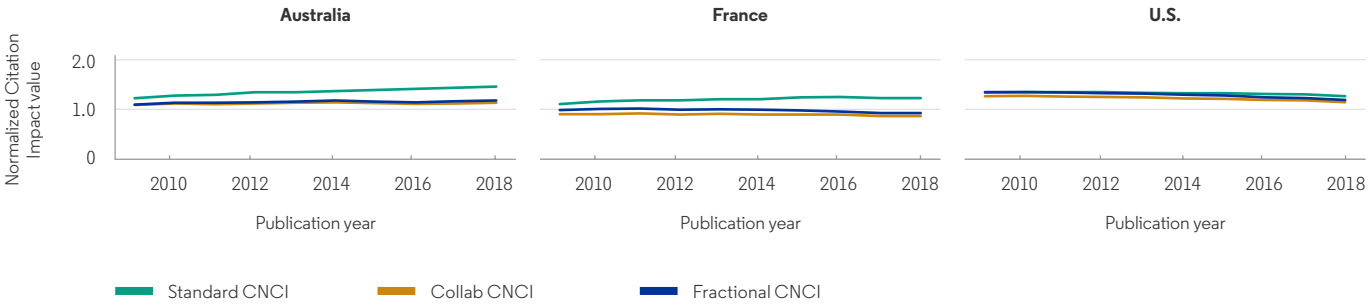
Full and fractional counting typically assign a high average CNCI to the most internationally collaborative and the lowest average CNCI to domestic single-authored articles (for the countries in Figure 2 and for the outcomes in all prior reports). Collab-CNCI reveals that the U.S. gains greater relative citation impact, on average, from its domestic output whereas its well-cited international articles do not stand out as exceptional among articles of similar type (Figure 2.c).

For Australia, by contrast, international co-authorships score relatively highly and it also has domestic single authored articles of high relative impact. By contrast, while France has its strongest relative CNCI in international articles, though not as strong as Australia's, its domestic single authored articles are relatively less often cited, and the other collaboration types all consistently perform lower than Australia or the U.S.

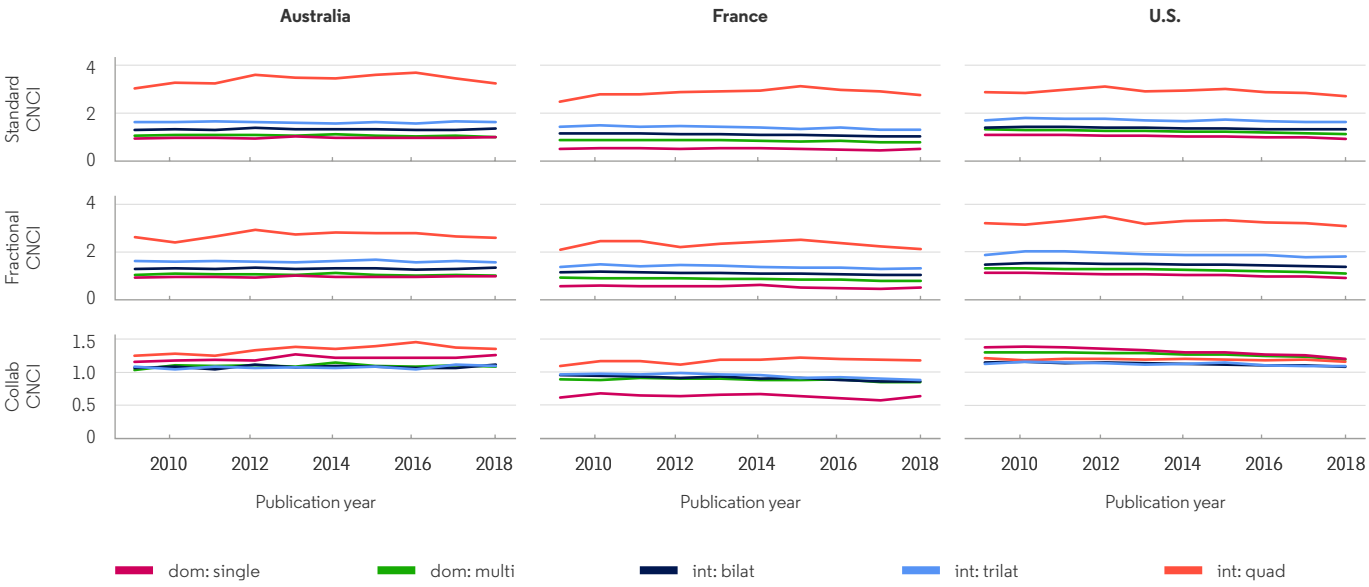
Figure 2. Research output and impact for three established research economies (2009-2018).
2.a International collaboration as a share (%) of total output, articles (%) by five collaboration types and count of articles by each type (dom:single – domestic single authored articles; dom:multi – domestic multi-authored articles; int:bilat – international bilateral articles; int:trilat – international trilateral; int:quad – international quadrilateral plus).



2.b Category Normalized Citation Impact (CNCI) calculated for the data in (2.a) by three methods



2.c The deconstructed contribution of the five collaboration types to the CNCI values in (2.b)



What do we learn from the comparisons in Figure 2? First, net average Collab-CNCI is closely aligned with fractional CNCI and (in most but not all scenarios) both produce a lower index value than full counting. We will never have a 'correct' CNCI but we do have agreement from two somewhat different methods. Second, the relative performance of articles of different collaboration types looks rather similar for full and fractional counting with an increase in net average CNCI with increasing internationality (i.e., domestic single articles have the lowest values and international quadrilateral plus consistently outperform others). Third, the picture varies markedly between national portfolios when Collab-CNCI is applied. It then becomes evident that U.S. international articles are not exceptionally well-cited although domestic articles perform well, whereas for France the opposite is the case.

How does this work for other countries? For comparison with the three established research countries, we have looked at a global spread of three countries with growing research economies: Algeria; Colombia; and Sri Lanka. (Figure 3)

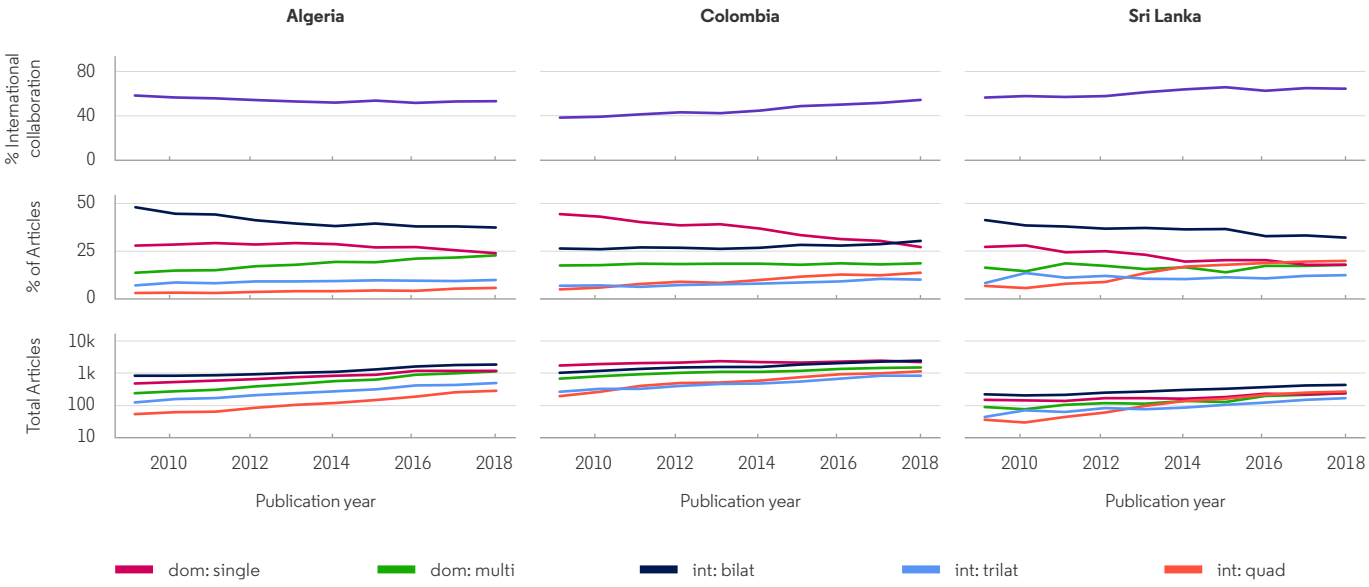
Sri Lanka has the smallest output, Algeria is about twice as productive and Colombia is twice as productive again (Figure 3.a). Sri Lanka has a consistent output share of about two-thirds international collaboration, half of Algeria's output is internationally collaborative (a share that has fallen recently), while Colombia has a growing international network. International quadrilateral plus makes up a significant part of Sri Lanka's relatively small publication activity whereas Colombia's higher output includes a substantial domestic portfolio. International bilateral articles are a growth area for Colombia while domestic multi-authored articles are the growth area for Algeria.

How do these portfolio differences influence a country's net CNCI when analyzed by different methods? It is immediately evident that Sri Lanka's average CNCI as calculated by standard full counting is exceptionally high, up to twice world average, whereas the other countries are generally below world average (Figure 3.b). Collab-CNCI, like fractional counting, moderates the influence of international collaboration and suggests a more comparable performance indicator value for the three countries. However, it is the deconstruction of CNCI by collaboration type that directs attention to the way in which Sri Lanka benefits from international quadrilateral plus collaborations: a small number of articles in the middle of the analytical window have exceptional average CNCI relative to other articles of the same collaboration type and thereby boost – in fact, create a marked spike in - the country's net score (Figure 3.c). These will also be seen in the institutional scores for the collaborating researchers and the Collab-CNCI deconstruction will help managers to understand erratic annual changes in citation impact (e.g., Figure 5).

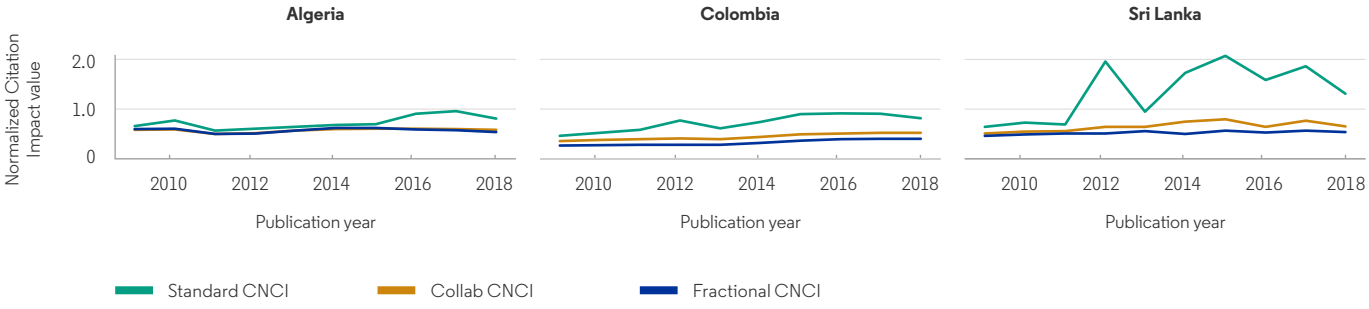
Algeria has relatively good scores for its articles across collaboration categories, including domestic articles (Figure 3.c), but this is hidden in a single net national average (Figure 3.b). Nonetheless, it also has a spike produced by just a few exceptional international articles and this spike is very clear in the deconstructed collaboration types. Colombia, with a larger overall output, has much greater consistency from year to year in the scores for all collaboration types (Figure 3.c). It has had relatively low international collaboration so fractional CNCI tends to suppress its score but the higher score from Collab-CNCI reflects its consistent performance (Figure 3.b).

Collab-CNCI, like fractional counting, moderates the influence of international collaboration and suggests a more comparable performance indicator value.

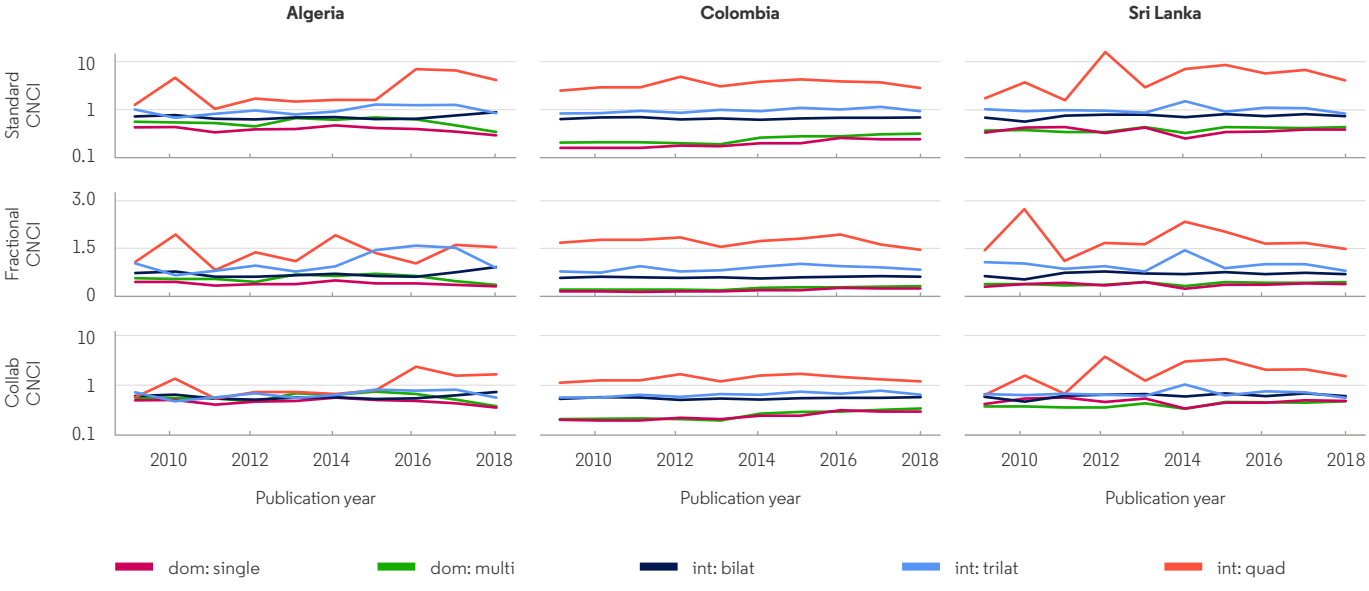
Figure 3. Research output and impact for three growing research economies (2009-2018).
3.a International collaboration as a share (%) of total output, articles (%) by five collaboration types and count of articles by the five types.



3.b Category Normalized Citation Impact (CNCI) calculated for the data in (3.a) by three methods



3.c The deconstructed contribution of the five collaboration types to the CNCI values in (3.b)



Collab-CNCI and institutions

The net CNCI score is now supported by information that points to a swathe of management questions rather than a simple and retrospective report.

To illustrate the information that can be derived from Collab-CNCI and to enable comparison with standard full and fractional counting at institutional level, we have selected three universities from one country and three from a spread of other countries. The analyses and data are presented in the same way as for countries: deconstructed output by collaboration type, net CNCI indicators for three analytical methods and deconstructed Collab-CNCI by collaboration type.

U.S. institutions – Harvard University, University of North Carolina, University of California Davis (Figure 4)

The absolute volume of output for each institution has changed rather little over ten years (Figure 4.a). Harvard has increased its international collaboration output to about 50% of articles, the majority of which are bilateral with smaller numbers of trilateral and above. Multilateral domestic articles make up around half of its output and there are a small number of single author articles. UC Davis has a smaller but similar output profile. However, it appears to have few single authored articles: that is because most UC Davis articles bear a broader UC system affiliation, reminding us that address data are not always straightforward to parse and interpret. The University of North Carolina has similar output to Harvard but is much less international: barely one-third of articles have an international co-author.

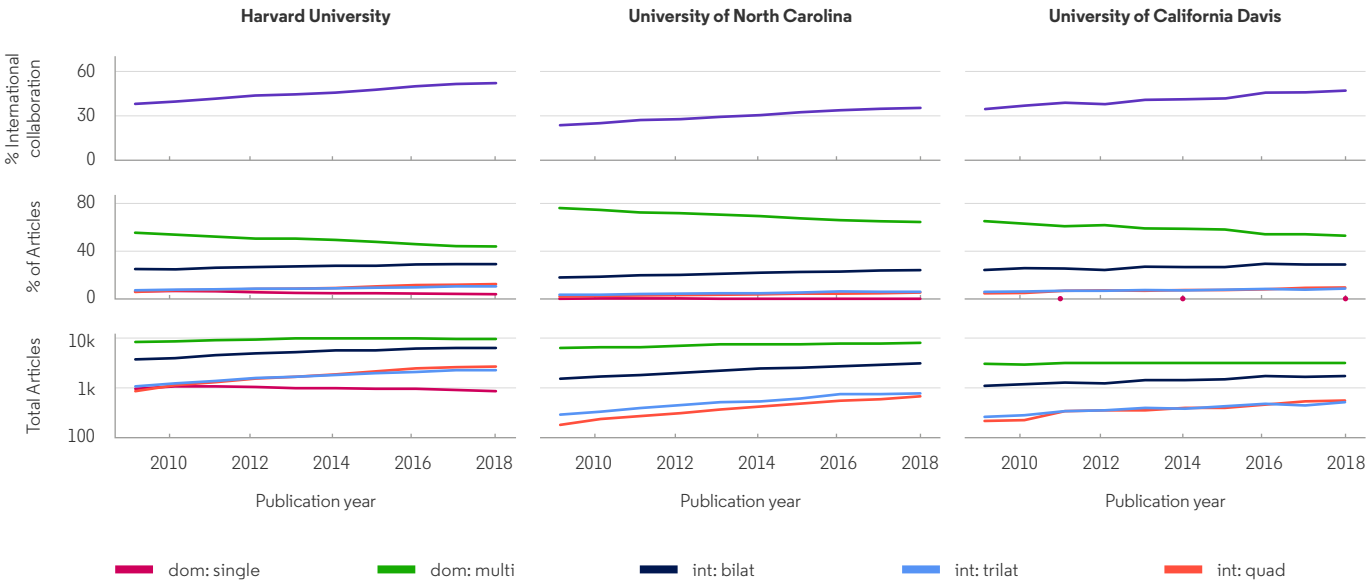
CNCI appears broadly sustained when standard full counting is used but declines for all three institutions under fractional and Collab-CNCI. It is notable that Harvard's remarkably high average CNCI is reduced more by Collab-CNCI than fractional CNCI whereas the opposite is true for the other two institutions. (Figure 4.b)

The CNCI's deconstruction by collaboration type explains the difference. Harvard's domestic articles have remarkably high values compared to other domestic articles, typically more than twice world average, and higher values than its international articles when they are compared to the global pool of similar documents. By comparison, both UC Davis and North Carolina have low scores for their domestic single author articles although the domestic multi-authored have similar CNCIs to their international bilateral and trilateral. Both also deliver a much greater relative citation performance on international quadrilateral plus articles. (Figure 4.c)

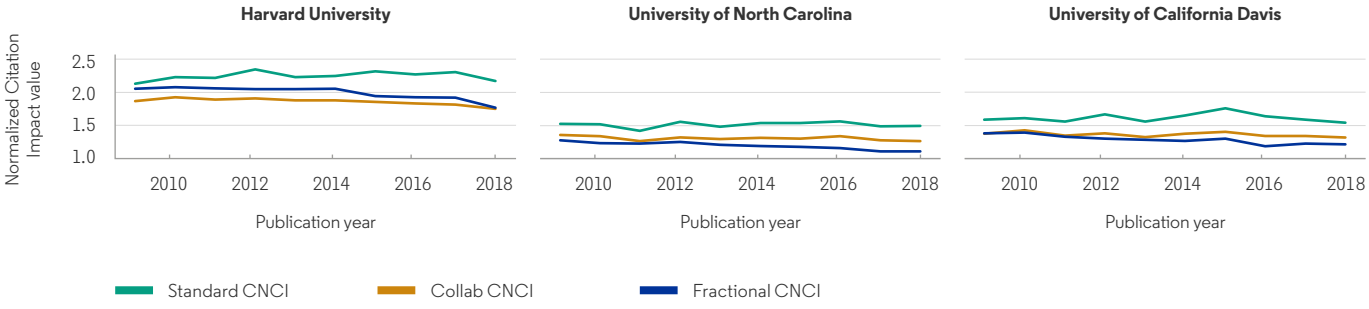
It is immediately apparent that Collab-CNCI provides a transparency to the overall citation score that did not exist before. Within one national system we have not just summary differences in CNCI but an analysis of how this is synthesized from different collaboration patterns that create different relative inputs for each subset of articles. The net CNCI score is now supported by information that points to a swathe of management questions rather than a simple and retrospective report. The differences in institutional performance would need to be studied in detail, at subject level and by those more familiar with the policies and structure of the institutions to address those management questions and this analysis shows where to look.

Figure 4. Research output and impact for three universities in the U.S. (2009-2018).

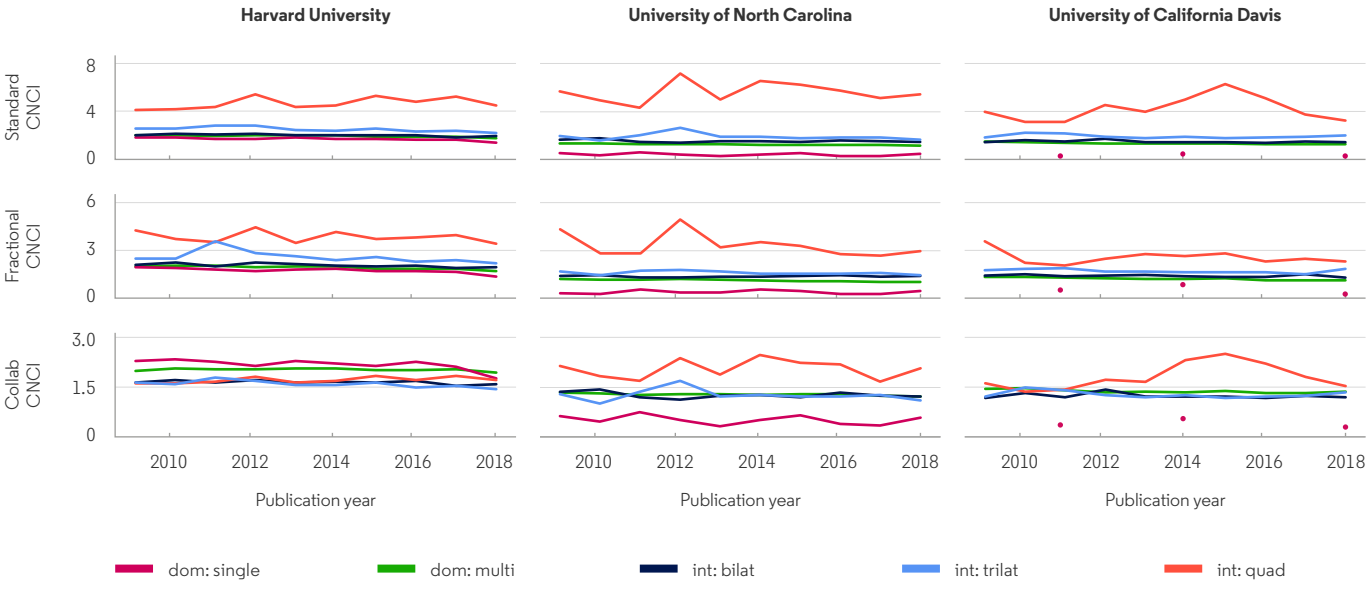
4.a International collaboration as a share (%) of total output, articles (%) by five collaboration types and count of articles by the five types.



4.b Category Normalized Citation Impact (CNCI) calculated for the data in (3.a) by three methods



4.c The deconstructed contribution of the five collaboration types to the CNCI values in (3.b)



Around 60% of the articles from Peradeniya and Béjaïa have international co-authors, compared with 20% of Ulsan's.

Global institutions: Sri Lanka, University of Peradeniya; Algeria, University Abderrahmane Mira of Béjaïa; South Korea, University of Ulsan (Figure 5).

We have selected institutions from three other countries for analysis (Figure 5) and for readers to compare with the U.S. profiles (Figure 4). Algeria is associated both with a network of higher education along the Mediterranean shores and, through strong historical ties, with the French research system. South Korea has a rapidly growing research base with a high level of central and industrial investment and outstanding achievements in technology but is only now growing its wider connectivity. Sri Lanka has a well-established higher education base and links to the U.K.

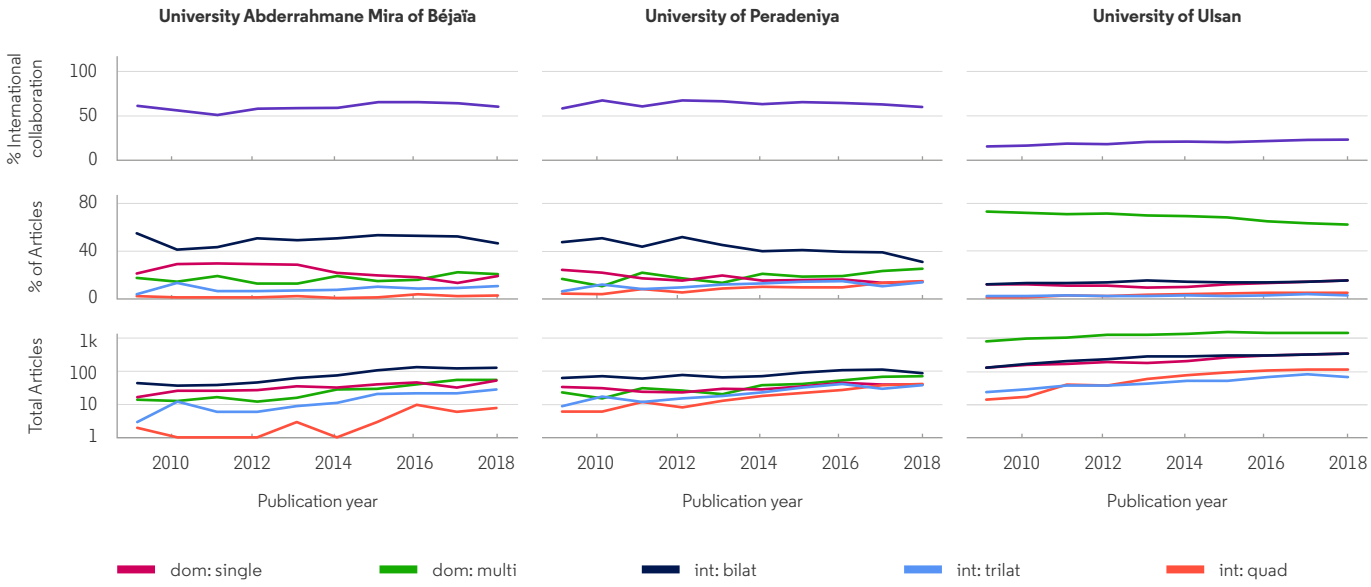
Around 60% of the articles from Peradeniya and Béjaïa have international co-authors, compared with 20% of Ulsan's output. It is therefore unsurprising that the commonest output type from the first two is international bilateral (as it was for their countries as a whole: Figure 3.a), whereas Ulsan – which is also the most productive - has well over 60% domestic multilateral articles. (Figure 5.a)

The value of institutional average CNCI for Béjaïa is hardly affected by the choice of counting methodology. For Ulsan, standard CNCI is highest and Collab-CNCI slightly higher than fractional CNCI. However, Peradeniya's CNCI shows some erratic spikes, rising to values many times above world average in 2012 and during 2014-2017 yet dropping below that benchmark in 2013. This pattern is also seen with Collab-CNCI, which lowers but does not wholly suppress the spikes. The fractional CNCI index for Peradeniya is consistently below world average. (Figure 5.b)

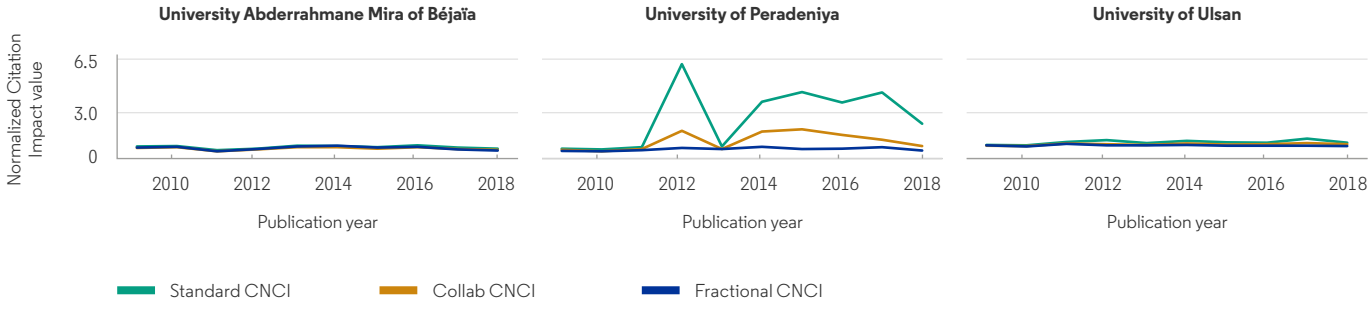
The deconstruction of the components of the CNCI indicators provides the explanation for these differences. The international quadrilateral plus collaborations provide the highest average CNCI for all three institutions, although to only a slight degree for Béjaïa where all source types are rather similar, hence its similar overall CNCI scores by all methods, and where the international quadrilateral plus type is scarce compared to other types. By contrast with the other two, international quadrilateral plus articles are as abundant as international trilateral at Peradeniya and, recently, as abundant as domestic single authored articles. The average CNCI score of these highly multi-authored articles is also extremely variable at Peradeniya. The scores of such articles also varies annually at Ulsan but less so and with little influence because of relative scarcity. (Figure 5.c)

The similarity of the CNCI scores from different methods at Béjaïa and Ulsan is explained by examining the collaboration type deconstruction. International quadrilateral plus articles are a key differentiating influence not only because their CNCI is high and variable but also because they are a predominant component of Peradeniya's output whereas they are scarce elsewhere. This analysis reveals the prime source of Peradeniya's scores and the explanation is consonant with that for Sri Lanka as a whole (Figure 3.c).

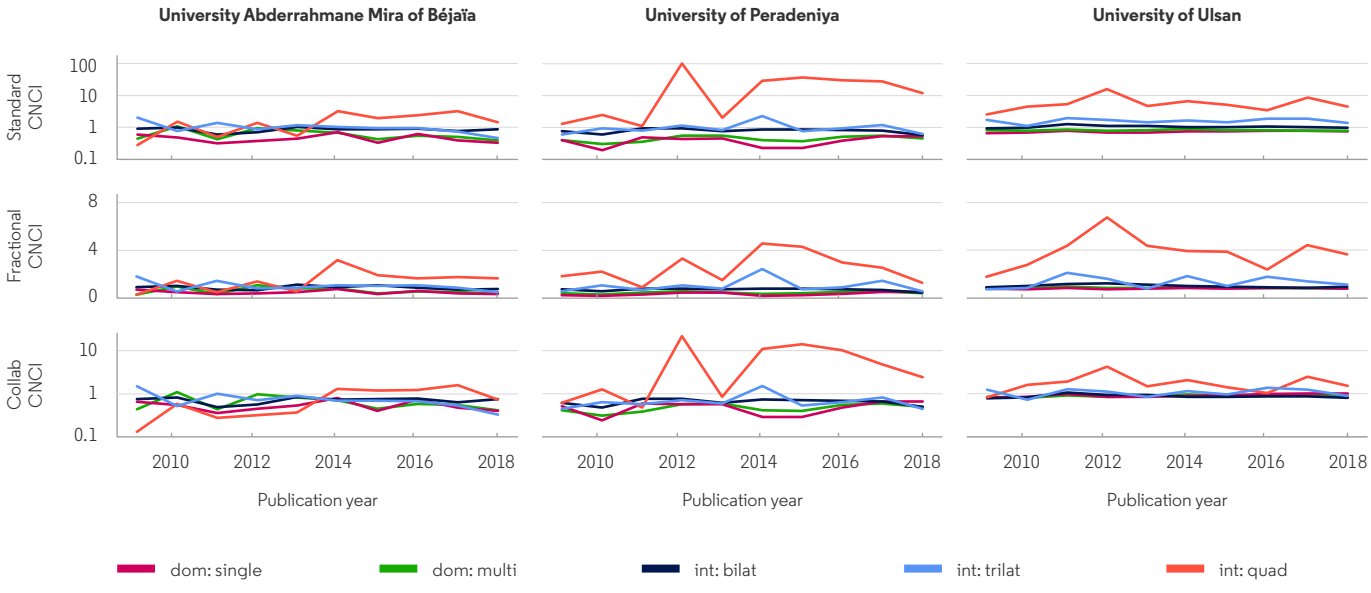
Figure 5. Research output and impact for universities in Algeria, Sri Lanka and South Korea (2009-2018).
5.a International collaboration as a share (%) of total output, articles (%) by five collaboration types and count of articles by the five types.



5.b Category Normalized Citation Impact (CNCI) calculated for the data in (3.a) by three methods



5.c The deconstructed contribution of the five collaboration types to the CNCI values in (3.b)



Discussion and next steps

The ISI approach to responsible metrics for research evaluation and management is to support methods and indicators that make the fullest possible use of the available data, to do so in a transparent way that is accessible to non-scientometricians, and to look for a balance between the (occasionally competing) objectives of academic and technical rigor, on the one hand, and utility and information value, on the other. Our support comes through our reading of the research of other groups around the world, our collaboration with some of those individuals and our own work. In this we also draw on our experience working with a global network of administrators and research leaders in research institutions and public policy units.

It has been clear, for more than 40 years, that the increase in authorship counts on academic papers poses a number of challenges to understanding and interpreting the way that credit for output and for 'citation impact' is attributed to researchers through their publication record. Average citation counts are greater where author counts, and especially international collaborative counts, are higher. Furthermore, credit to researchers feeds through in evaluation to their institutions, and then aggregates to their host country. The need for a well-informed approach to performance analysis that can be implemented across disciplines and across global regions is increasingly important.

There is no demonstrably 'right' way to assign credit: there are a diversity of competing opinions and there is no global benchmark by which they can be evaluated. It is generally agreed that whole counting has the benefit of simplicity, yet it must over-credit individuals and their affiliations as authorship rises. Fractional counting in some form therefore seems to be a sensible route. There are multiple proposals for author-weighting but none with universal applicability. Thus, equal partitioning of citation impact among authors is the default approach, yet this too hides critical information about how the summary indicator is derived.

The solution we propose and recommend is that of 'Collaborative CNCI' (Collab-CNCI: Potter et al., 2020). This retains the simple calculation of Category Normalized Citation Impact but does so for papers categorized by their collaboration. The accumulated citation count for each paper is normalized against other papers of the same publication year, the same subject category, the same document type and the same collaboration type. The same analytical question is thereby asked for each paper: is this a good citation count for other papers like this? The revealed CNCI values by collaboration type provide new management information about the source and balance of achievement.

We now seek feedback from the research community on the sense, accessibility and utility of this proposed method and the Collab-CNCI indicator. We believe the Collab-CNCI indicator will be useful for research managers and policy makers in particular. There is no proposal at this time to make changes to the way in which citation data and indicators are presented in the Web of Science or its analytical products such as InCites. However, the timing, direction and style of any changes would be informed by this feedback, so that the outcome is one that meets the balanced needs of both the scientometric specialists and the much wider network of researchers and research managers that use these data.

Please send any comments, criticisms, suggestions for further development and, in particular, tell us whether this is a feature that you would like to see in Clarivate products and services to isi@clarivate.com.

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