Citation analysis of scientific journals and journal impact measures*

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Eugene Garfield's creative work on journal impact measures served more than one function. These measures were originally designed and applied to monitor the journal coverage of the Science Citation Index (SCI). They constituted a tool to identify on a permanent basis, the most important journals in the scientific communication system, and to highlight candidates to be included or dropped in view of the need to establish a cost-effective Citation Index.

Keywords: Citation analysis, Eugene Garfield, journals, impact factor.

GARFIELD emphasized that journal citation analysis could also be used to study the scientific–scholarly communication system, and could contribute to its better functioning, and hence to a better science[1].

> As a communication system, the network of journals that play a paramount role in the exchange of scientific and technical information is little understood (Garfield[1], p. 471). Using the *SCI* database to map the journal communications network may contribute to more efficient science (Garfield[1], p. 477).

Ever since Garfield published numerous citation analyses of the journal network, investigators in the field of library and information science have carried out hundreds of studies in almost every branch of the natural and social sciences. The journal impact measure most widely spread among the scientific community is the journal impact factor. Nowadays, it is used as a direct reflection of a journal's prestige or quality. Journal editors and publishers communicate the values of impact factors of their journals to reading audiences. Impact factors are not only used to rank journals, but also to evaluate individual scholars and research groups or departments according to the journals they select for publication, even in decisions about salaries or promotion. This article aims to provide technical information about the impact factor, of which potential users should be aware.

The impact factor of a journal J in year T is defined as follows:

$$\frac{\text{The number of citations received in year } T \text{ by all documents published in } J \text{ in the years } T\text{–}1 \text{ and } T\text{–}2}{\text{The number of citable documents published in } J \text{ in the years } T\text{–}1 \text{ and } T\text{–}2}$$

It is a *ratio*, with the number of citations in the numerator, and the number of citable documents (research articles and reviews) in the denominator. It thus represents the arithmetic mean of the distribution of citations amongst documents published in a journal. For a particular year, it takes into account citations to documents published in the two preceding years only. In other words, it reflects the average citation impact of one- and two-year-old documents. In the denominator, only 'citable' documents are counted. This term is explained below.

The following section presents a critical methodological discussion of the journal impact factor published in ISI's annual *Journal Citation Reports* (JCR), and highlights the basic assumptions that underlie it. It does not discuss data on journal citation impact from other ISI information products, such as its 'Journal Performance Indicators'. The next section presents a normalized or relative journal citation impact indicator as an alternative measure. The final section discusses further issues regarding journal impact measures, outlines new developments, and makes concluding remarks.

Issues regarding ISI/JCR impact factor

Why calculate a ratio (citations per article)?

Journals show substantial differences with respect to the number of documents they publish in a year. This is illustrated in Table 1, which presents key statistics on the number of articles, pages and issues per journal processed for the *SCI*. Garfield argued that the citation frequency of a journal is a function not only of the scientific significance of the

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material it publishes, but also of the number of articles it publishes annually.

> 'In view of the relation between size and citation frequency, it would seem desirable to discount the effect of size when using citation data to assess a journal's importance … We have attempted to do this by calculating a relative impact factor – that is, by dividing the number of times a journal has been cited by the number of articles it has published during some specific period of time. The journal impact factor will thus reflect an average citation rate per published article' (Garfield[1], p. 477).

However, the impact factor represents the mean value of a skewed citation distribution. This is illustrated in Figure 1 and Table 2, which compare the distribution of citations among documents published in two journals, *Analytica Chimica Acta* and *Analytical Chemistry*. Many, if not all, journals show skewed citation patterns, such as those presented in Figure 1.

Why count citations to 1–2-year-old articles?

Some journals have a long history, whereas others were founded recently. The former may be cited more frequently in a particular year than the latter, because they have a large number of citable back volumes. Moreover, the citation impact of a journal's older volumes may not properly reflect its current status. In view of this, a measure was constructed that expresses the citation impact of one- and two-year-old annual volumes.

Table 1. Statistics on articles, pages and issues in *SCI* source journals

Indicator	Mean	P25	Median	P75
Articles/journal	210	50	97	204
Issues/journal	9.6	5	8	12
Articles/issue	22.0	9	14	22
Pages/article	6.2	1.5	5.5	8.5
Cited references/article	23.4	5	19	33

Data relate to 3700 journals processed for the *SCI* in the year 2001. P25, P75: 25th and 75th percentile of the distribution. For instance, 25% of journals have less than 50 articles per year and another 25% more than 204 articles. The median number of issues per journal is 8, and the median number of articles per issue is 14. Median values are lower than means, reflecting that distributions are skewed to the right.

Table 2. Parameters of citation distribution for two journals plotted in Figure 1

	Analytical Chemistry	*Analytica Chimica Acta*
No. of documents	1932	1466
Mean citation rate	4.5	1.9
Skewness	2.8	1.9
Uncited documents (%)	12.4	27.8
90th percentile	10	5

> 'In selecting an items-published base for each journal, I have been guided by the chronological distribution of cited items in each annual edition of the *SCI*. An analysis of this distribution has shown that the typical cited article is most heavily cited during the 2 years after its year of publication … Therefore, since my sample consists of references made in 1969, I have taken as the items-published base for each journal the number of items it published during 1967 and 1968' (Garfield[1], p. 472).

But the age distribution of cited references varies significantly among disciplines. This is shown in Figure 2, which presents age distribution for the total ISI database and for two research fields (journal categories): biochemistry and molecular biology, and mathematics. It shows that for the total ISI database, the average cited article is most heavily cited when it is two years old.

In mathematics, however, this maximum is reached one year later. Figure 2 also shows that an average article in

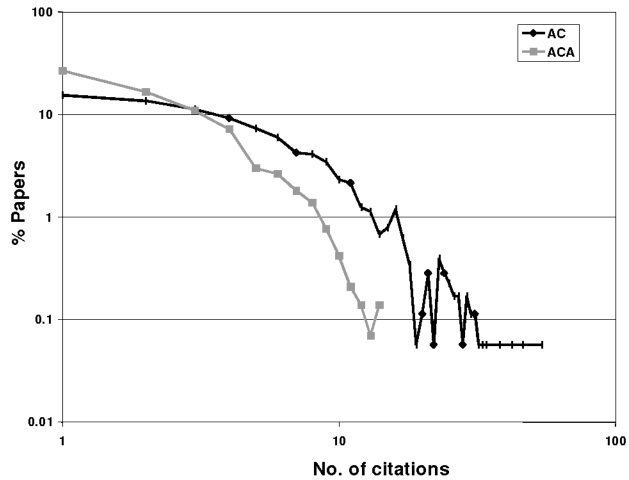

Figure 1. Distribution of citations among documents for two journals. AC, *Analytical Chemistry*; ACA, *Analytica Chimica Acta*. Citation counts relate to the year 2002; cited papers were published in 2000 and 2001.

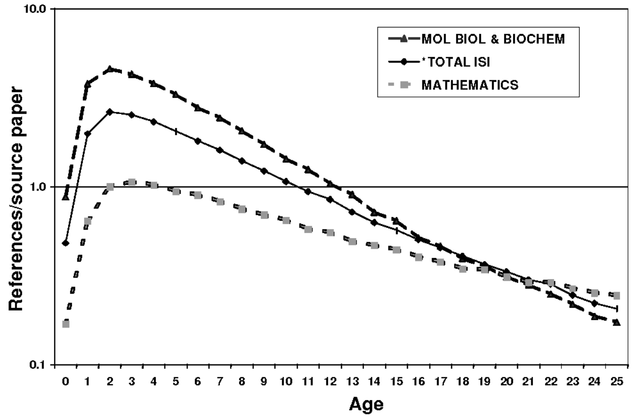

Figure 2. Age distribution of cited references in two disciplines and in the total ISI database.

mathematics cites one- or two-year-old papers less frequently than do articles in biochemistry and molecular biology. To be precise, in the former field a paper contains on average 1.6 references to one- or two-year-old articles, whereas in the latter it is 8.4 references.

That is why impact factors of journals in the former field are generally so much lower than those for journals covering the latter. Garfield was very well aware of such differences, and emphasized in many publications that one should not directly compare journals from different disciplines with one another.

Although the age distributions are to some extent affected by changes in the annual number of articles published in the various fields, Figure 2 reveals that in mathematics the citation impact of papers declines much more slowly with their age than in biochemistry and molecular biology. In other words, older papers tend to be more relevant in the former field than they are in the latter.

But citation impact decline rates vary even among journals covering the same discipline. This phenomenon is illustrated in Figure 3. It compares four journals covering biochemistry and molecular biology on the basis of the average citation rate of articles as a function of their age.

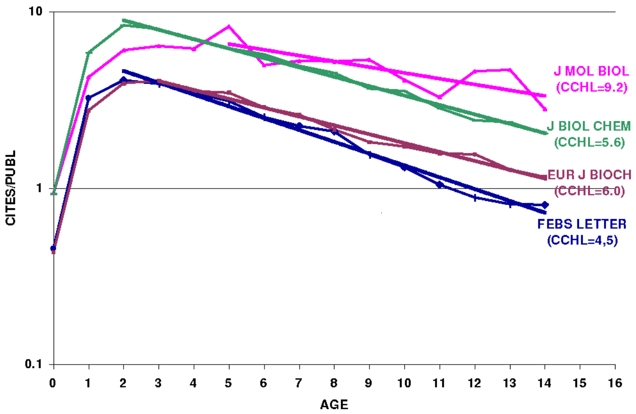

Figure 3. Citation impact as a function of age of cited documents for four journals. FEBS LETTER, *FEBS Letters*; J BIOL CHEM, *Journal of Biological Chemistry*; EUR J BIOCH, *European Journal of Biochemistry*; J MOL BIOL, *Journal of Molecular Biology*. Data are extracted from an earlier study[9] and relate to citations in a single year (1995) to citable papers published during the 14 previous years. The plot gives the average citation rate (cites/publ on a logarithmic scale) of papers as a function of their age. Age 0 refers to citations to papers published in the same year as the citing year. The citation rates for ages 1 and 2 are those that constitute the JCR journal impact factor. Decline was modelled as an exponential decay process. Straight lines in the plot are regression lines resulting from fitting datapoints from the age at which the citation rate reaches its maximum value onwards. From the regression coefficient the decay constant was determined, defined as the (estimated) time period in which the average citation impact is reduced by a factor of two. Since the calculation of this decline constant corrects for differences in the number of documents published per year, it is denoted as the Corrected Citation Half-Life (CCHL). For instance, for *FEBS Letters* a CCHL of 4.5 was obtained. Thus, during the time period between ages 3 and 14, the average citation impact halves every 4.5 years. J MOL BIOL shows a much slower decline with a CCHL of 9.2.

Details are given in the legend to Figure 3. The ISI impact factor is based on the rates obtained at ages 1 and 2. The scores at later ages do not play a role in the calculation of this measure and therefore remain 'out of sight'. During the time period considered, the citation impact of papers in *FEBS Letters* halves every 4.5 years. Its impact factor is higher than that of *European Journal of Biochemistry*, but its impact declines more rapidly.

Well aware of such differences, Garfield (and ISI) included listings of 'cited half-lives' of journals in JCR. This measure is calculated for each citing year, and is defined as 'the number of journal publication years going back from the current year which account for 50 per cent of the total citations received by the cited journal in the current year'. It does not correct for variations in the number of papers a journal publishes over the years, however. Rapidly expanding journals tend to have higher cited half-lives than journals of which the annual number of published papers remained constant or declined over the years. Moreover, this measure is often ignored as impact factors tend to be isolated from their context and conceived as the only significant measure of a journal's impact.

Why use cited journal titles from reference lists?

ISI's JCR provide detailed citation data on all journals covered by the ISI Citation Indexes and constitute the most frequently used information product on journal impact factors. They contain amongst others listings of journals ranked by impact factor and arranged by category – groupings of journals covering the same (sub)discipline. The impact factor's numerator is determined by counting in the total database cited references containing the name of a particular journal. The advantage of this procedure is that a reference to a journal paper is counted, even when it is inaccurate, in the sense that it indicates an erroneous starting page number or first author. It is appropriate to count such an erroneous reference as the citing author intended to cite a particular paper in the journal.

However, there are disadvantages as well. First, it may be difficult to identify a particular journal in a file of hundreds of millions of cited references that use at most 20 characters to indicate the title of the source publishing a cited document. Not all journals may be identified accurately in this way. This problem is illustrated in Table 3. It presents for the journal *Astronomy and Astrophysics*, the title variants used by citing authors in their reference lists when they cite a paper published in it. It is rather obvious that the title variant *Astron Astrophys* relates to this journal. This variant accounts for almost 80% of all citations to the journal: but more than 20% of references indicate the acronym A A. Overlooking this variant reduces the journal impact factor by some 20%.

A second disadvantage relates to the concept of 'citable' document in the definition of the impact factor. Source articles in the ISI Citation Indexes are categorized by type. Important types are normal research articles, review articles, notes (prior to 1996), letters, editorials, news items, corrections and meeting abstracts. As a rule, the JCR includes as citable items in the impact factor's denominator the number of normal articles, notes and reviews. But many journals contain other types of documents as well. When these other types are cited, the citations do contribute to the impact factor's numerator, but the cited papers are not included in the denominator. In a sense, these citations are 'for free'[2]. Table 4 illustrates this problem for one particular journal: *Lancet*.

Both the problem of journal title variants and that of 'free citations' to non-citable documents can in principle be solved by linking cited references to a journal on a 'paper-by-paper' basis and determining citation counts for each individual paper in a journal. However, this solution requires that the linking matching process is carried out carefully, and takes into account numerous variations or errors in cited references. This issue is further discussed by Moed[3] (p. 173 e.f.).

Normalized journal impact measures

Several authors have suggested alternative journal impact measures that account for differences in referencing practices among scientific disciplines. These are denoted as normalized or relative measures, and in principle enable cross-comparisons of journals among disciplines. An overview is presented in Glänzel and Moed[4].

Knowledgeable users of JCR data are aware that review journals tend to have higher impact factors than ordinary journals. In fact, in many disciplines review journals are in the top of the journal rankings. The printed edition of the JCR contained listings giving for each journal the share of review articles published in it. A normalized measure developed at the Leiden Centre for Science and Technology Studies (CWTS), The Netherlands, does not only take into account differences in referencing practices among disciplines, but also the type of cited document and its age relative to the year of citation.

The normalized impact factor can be calculated for a series of citing years rather than one single year, and for cited documents of any age, particularly for those that are older than one or two years as selected in the JCR impact factor. A simple numerical example in Table 5 illustrates how this measure is calculated. The normalized impact measure can be conceived as a ratio of the actual and expected number of received citations. A ratio of 1 indicates that a journal's impact is 'as expected' given the discipline it covers, the type of documents it publishes and the age distribution of its cited papers.

Figure 4 compares the JCR-like impact factors to the normalized measures for all journals in two disciplines, viz. mathematics and biochemistry and molecular biology. JCR impact factors in the former are mostly between 0.1 and 1.0, whereas in the latter they are between 1 and 10.

Table 3. Variants of cited journal titles: the journal *Astronomy and Astrophysics*

Cited journal title variant	Citations *N*	Citations %	Citations/ article
Astron Astrophys	7566	79	2.3
A A	2047	21	0.6
All other	15	0	0.0
Total	9628	100	2.9

Data relate to the year 2002, and are extracted from the bibliometric version of the ISI Citation Indexes on CD-ROM created at the Centre for Science and Technology Studies at Leiden University (The Netherlands). Seventy-nine per cent of references to the journal indicate the journal title *Astron Astrophys*. However, authors citing this journal also indicate in 2047 cases (21%) its acronym A A. Ignoring these references would reduce the journal's impact factor from 2.95 to 2.31. This issue was raised by Sandqvist[10]. The outcomes presented in Table 3 apparently diverge from figures presented by Sandqvist. This is probably due to differences in methodology and in versions of ISI Indexes used (CD-ROM versus Web of Science version). Abt[11] reported that the JCR impact factor of this journal (and several other astronomical journals) was incorrect for the years 1998–2001, due to changes in a computer program used by ISI to calculate impact factors, but that as from 2002, ISI corrected its program and included the 'A A' variant in the counts for this journal. However, the decline in its impact factor in 1998 compared to 1997 and particularly its increase in 2002 compared to 2001 reported by Abt is larger than the 20% for the variant 'A A' presented here.

Table 4. Free citations: *Lancet* (2002)

Type of document	No. of documents	Cites	Cites/documents
Articles, reviews	1,544 (a)	13,106	8.5
Other types	4899	2564	0.5
Total	6443	15,670 (b)	2.4
JCR-like (reconstructed) impact factor = (b)/(a)			10.2

Data relate to the year 2002, and were extracted from the bibliometric version of the ISI Citation Indexes on CD-ROM created at the Centre for Science and Technology Studies at Leiden University (The Netherlands). In 2000 and 2001, this journal has published 1544 documents (articles and reviews) denoted by the JCR as citable. These documents are counted in the impact factor's denominator. There are 4899 other types of documents, mainly letters, editorials and news items published in the journal. Although these are in JCR terms conceived as non-citable, they are cited a total of 2564 times. These citations are included in the total citation count of 15,670 that constitutes the impact factor's numerator. The 'JCR-like', reconstructed impact factor is the ratio of total citations and citable items, and amounts to 10.2. If the numerator included only citations to those document types that are counted in the denominator, the impact factor would be 8.5, which is 16% lower than that based on citations to all types of documents. The value of 10.2 found for the JCR-like (reconstructed) impact factor is somewhat lower than that given in the JCR, because the set of journals used by ISI to calculate its JCR is somewhat broader than that of the CD-ROM version. Therefore, here it is termed the JCR-like or reconstructed impact factor.

Table 5. Example of calculation of a normalized journal impact measure

	Articles		Reviews	
Aggregate	No. of documents	Cites/documents	No. of documents	Cites/documents
Discipline	15,000	3.0	1000	5.0
Journal	500	4.0	100	6.0

Normalized impact = (500*4.0 + 100*6.0)/(500*3.0 + 100*5.0) = 2,600/2,000 = 1.3

The numerical example presented here takes into account only the journal's discipline and the type of cited document it published. The method can easily be expanded with the factor age of cited documents. The crucial point is that a journal's papers of a particular age are compared to other papers of the same age. The normalized impact measure can be conceived as a ratio of the actual and expected number of received citations. Within a discipline, each type of document has its own expected citation rate. In the example, this rate is 3.0 for articles and 5.0 for reviews. Since the journal publishes 500 articles and 100 reviews, the expected number of citations is 500****3.0*** + 100****5.0*** = 2000. The actual number is 500****4.0*** + 100****6.0*** = 2600, so that the ratio of actual and expected citations is 1.3. In calculating mean citation rates in a discipline, the method takes into account all papers in all journals covering that discipline. Alternative methods proposed by Sen[12] and Marshakova-Shaikevich[13] apply a normalization factor that is based only upon documents in a discipline's journal with the highest citation impact or in the five journals with the highest citation impact respectively. Contrary to the methodology outlined here, these methods use journal impact factors obtained from ISI's JCR, and do not take into account the type of document or the document's publication year within the impact factor's publication window. An alternative approach is a ranking procedure similar to percentile ranking, generating rank-normalized impact factors[14].

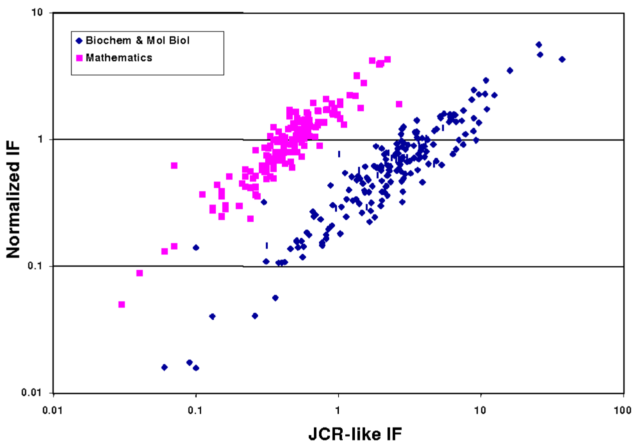

Figure 4. Normalized versus JCR-like impact measures in two disciplines. The JCR-like impact factors relate to the citing year 2003. They are termed 'JCR-like' because they are not obtained from the JCR, but were reconstructed from data included in the combined ISI Citation Indexes on CD-ROM. The normalized impact measure relates to citations given in the years 1999–2003 to documents published during the same time period, but the application of different citation windows, particularly the ISI impact factor window, provides similar outcomes. For more comparisons between ISI impact factor and normalized journal impact measures, see van Leeuwen[15].

But the normalized measures in the two disciplines have similar ranges of values. Figure 4 shows that even within a discipline the positions of journals may vary among the two rankings. For instance, the journal in biochemistry and molecular biology with the highest JCR-like impact factor ranks third according to its normalized citation impact. This is a review journal.

Strong points of the normalized measures are that to some extent they enable cross-comparisons among disciplines and that they are not biased in favour of review journals. But there are some points that should be kept in mind as well. First, it is difficult to calculate normalized measures for multi-disciplinary journals such as *Science* or *Nature* that cover a broad range of disciplines. Secondly, their values depend upon how journals are aggregated into (sub-)disciplines. Even moving a single journal from one discipline to another may have numerical consequences, not only for the journal itself, but in principle also for all other journals in their old and new discipline, even though the latter effect is relatively small in large disciplines. Finally, the range of values it obtains – its scale – differs from that of the JCR impact factor. The latter indicator obtains values between 0 and 50, whereas the former in most disciplines is between 0 and 5.

Further issues and conclusions

Do top journals in large fields have a higher citation impact than those in smaller fields?

The structure of the journal communication system differs significantly from one discipline to another, in the sense that the distribution of citation impact among journals in a discipline varies among disciplines. Figure 5 shows that 'top' journals in large disciplines tend to have a higher citation impact than top journals in smaller ones. This phenomenon should be taken into account in any use of journal impact indicators, regardless of whether one applies normalized measures or those published in the JCR. The analysis presented in Figure 5 underlines the usefulness, particularly of field-normalized journal impact indicators in comparative studies of disciplinary journal communication systems.

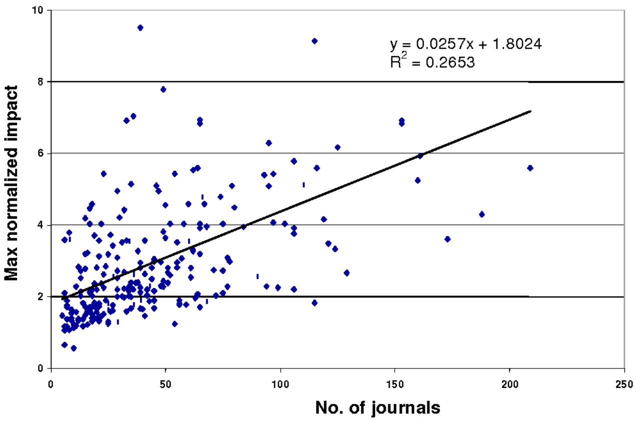

Figure 5. Number of journals covering a discipline versus citation impact of its highest impact journal. Data are extracted from the CWTS database of ISI Citation Indexes on CD-ROM. The normalized impact measure relates to citations given in the years 1999–2003 to documents published during the same time period. Large disciplines in terms of numbers of journals published have higher extreme citation impact values than smaller ones. From a linear regression follows the result that the size of a discipline accounts for 27% of the variance in the normalized impact of a discipline's most frequently cited journal. The regression line is plotted in the graph. The categorization of journals into subdisciplines is derived from the system of journal categories developed by ISI.

Do top groups publish in top journals only and less prominent groups merely in lower impact journals?

A claim often made about journal impact factors and journal performance in general, is that the most prolific authors publish only in the most prestigious journals, whereas less prolific authors publish their papers in journals with a lower status. If this were true, one would expect that in a particular field a journal with a high impact factor and one with a lower impact would have distinct sets of publishing authors.

Empirical analysis of author populations by journal revealed that this is not a general pattern. For instance, it was found that about 50% of the authors publishing during 1999–2003 in the journal *Physica B* also published at least once in the journal *Physical Review B*. Hence, there is a substantial overlap among author populations publishing in these two journals, although the latter has a higher impact factor than the former.

The case study of the two physics journals suggests that prolific authors publish both in high impact and lower impact journals. It underlines the importance of journals with a somewhat lower impact in the communication of research findings by both prolific and less prolific researchers. This type of relationship among journals according to the extent to which their author populations overlap, tends to be neglected when journals are merely conceived as separate entities in journal rankings based on their citation impact. But further empirical research is needed in order to obtain a more detailed insight into the behaviour of author populations of scientific journals, taking into account the authors' country of origin. For instance, one may examine whether authors from USA and Europe show similar publication practices.

Does a group's journal impact predict the citation impact of its papers?

Journal impact factors are quite often used to assess the research performance of individual scientists or departments. Although the status of the journals in which a group publishes is an aspect of research performance in its own right, journal impact factors should not be used as surrogates of citation impact of a group's publications. This point was emphasized by Garfield[5], Seglen[6], van Raan[7], and many others.

A secondary analysis of the outcomes of four bibliometric studies of a large number of research departments undertaken at CWTS and presented in Moed[3] (p. 239 e.f.) found that the normalized impact of journals in which the papers were published explains between only 20 and 40% of the variance in the normalized citation impact of a department's papers.

New developments

A future task would be to develop a field-normalized journal impact indicator that is less sensitive to changes in journal (sub-)disciplinary classification systems; that can be computed for multi-disciplinary journals; and that has a scale more comparable to that of the JCR impact factor. But it would not be wise to concentrate too strongly upon developing the single, 'perfect' measure. Journal performance is a multi-dimensional concept, and a journal's position in the scientific journal communication system has many aspects. It is questionable whether all dimensions can be properly expressed in one single index.

A more productive approach is to develop and present a *series* of indicators for the various dimensions, and highlight their significance and limitations. In addition, it must be noted that JCR journal impact factor is nowadays so widely dispersed and so frequently used that it seems difficult, if not impossible, to have it replaced by a single alternative measure, especially in the near future.

Pinski and Narin[8] developed an important methodology for determining citation based influence measures of scientific journals and (sub-)disciplines. They calculated a measure termed '*influence weight of a journal*', and described as 'a size-independent measure of the weighted number of citations a journal receives from other journals, normalized by the number of references it gives to other journals'[8] (p. 298). One of the methodology's key elements is that it assigns a higher weight to citations from a prestigious journal than to a citation from a less prestigious or peripheral journal. The authors showed how this notion can be incorporated in a 'self-consistent "bootstrap" set of relations, in which each unit plays a role in determining the weights of every other unit'[8] (p. 300). Their notions may play an important role in the further development of journal impact measures.

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