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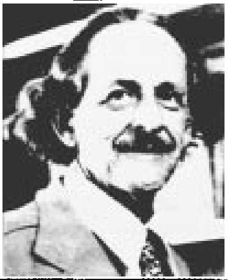

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Evaluating Research: Do Bibliometric Indicators Provide the Best Measures?

Go to Reprint: A Review of Bibliometric and Other Indicators and

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In recent months we have reprinted several studies, originally published elsewhere, involving the use of biblio-scientometric measures to evaluate research. In one such study, Michael R. Halperin and Alok K. Chakrabarti, Drexel University, Philadelphia, examined the relationship between the volume of scientific and technical papers produced by industrial scientists and the characteristics of the corporations employing them.[1] Another study, by economist Arthur M. Diamond, Jr., University of Nebraska, Omaha, evaluated the role that citations play in determining salaries.[2] And we recently reprinted an article from the *Times Higher Education Supplement* (London) in which I discussed the strengths and weaknesses of citation analysis as a measure of research performance in individual university departments.[3]

From those specific studies, we move to a more general discussion by Jean King, then at the Agricultural and Food Research Council, London, UK, now affiliated with the Cancer Research Campaign, London. Her review originally appeared in the *Journal of Information Science*, sponsored by the Institute of Information Scientists. The article discusses a variety of bibliometric measures and the implications of their use in research evaluation.[4] King kindly abridged her paper for publication here.

Beginning with an examination of the peer review system, King goes on to assess various bibliometric indicators, including publication counts, citation and co-citation analysis, journal impact factors, and a newer method known as co-word analysis. (For reasons of space, we have omitted King's discussion of other indicators, such as patent analysis, measures of esteem [which include attraction of outside funding, membership in professional societies, winning of international prizes, and so on], and input-output studies.) She concludes by recommending continued development of new methods, including online techniques for publication and citation retrieval.

Discussing citation and co-citation analysis, King cites various critical assessments of these techniques. Since we have addressed many such criticisms on previous occasions,[3,5-7] I will not do so here. I will simply present King's paper, which is a thorough and valuable review. As budgets and funding for science come under increasing scrutiny at all levels, it is essential that evaluative methods be as accurate, as balanced, and as appropriately applied as possible.

* * * * *

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A review of bibliometric and other science indicators and their role in research evaluation.

Jean King

Back to Introduction

Recent reductions in research budgets have led to the need for greater selectivity in resource allocation. Measures of past performance are still among the most promising means of deciding between competing interests. Bibliometry, the measurement of scientific publications and of their impact on the scientific community, assessed by the citations they attract, provides a portfolio of indicators that can be combined to give a useful picture of recent research activity. In this state-of-the-art review the various methodologies that have been developed are outlined in terms of their strengths, weaknesses and particular applications. The present limitations of science indicators in research evaluation are considered and some future directions for developments in techniques are suggested.

1. Introduction

In recent years policy makers and research managers have become increasingly interested in the use of indicators of scientific output. The background to this development is considered, and in Sections 2 and 3, the need for accountability and the current pressures on the peer review process are outlined. The types of bibliometric indicators that may have value in assessment studies are reviewed in Section 4, ranging from well-documented and widely applied approaches such as publication counting, citation frequency analysis and co-citation mapping, to less-well-known methods such as journal-weighted citation analysis and co-word mapping. Directions for future research are suggested that may lead to more widely applicable and more routinely available indicators of scientific performance.

2. Accountability in science

Prior to the 1960's, funding for scientific research in the UK was relatively unrestricted. Resources were allocated largely on the basis of internal scientific criteria (criteria generated from within the scientific field concerned), which were evaluated by the peer review process. Various factors have resulted in a need for greater selectivity in the allocation of funds: an increase in the capital intensity of research (e.g. the 'sophistication' factor; the growth of 'Big Science'); expanding objectives and opportunities, with many new fields emerging; an increase in collaborative, often multidisciplinary, research projects which require coordination; a coalescence of basic and applied research, with much research now of a strategic nature (i.e. long-term basic research undertaken with fairly specific applications in view); finally, economic constraints require choices to be made between different disciplines, fields and research proposals.[1] The peer review process has thus come under increasing pressure.

3. The peer review system

The peer review system has been criticized on several counts:

(1) The partiality of peers is an increasing problem as the concentration of research facilities in fewer, larger centres makes peers with no vested interest in the review increasingly difficult to find.

(2) The 'old boy' network often results in older, entrenched fields receiving greater recognition than new, emerging areas of research, while declining fields may be protected out of a sense of loyalty to colleagues. Thus the peer review process may often be ineffective as a mechanism for restructuring scientific activity.

(3) The 'halo' effect may result in a greater likelihood of funding for more 'visible' scientists and for higher status departments or institutes.

(4) Reviewers often have quite different ideas about what aspects of the research they are assessing, what criteria they should use and how these should be interpreted. The review itself may vary from a brief assessment by post to site visits by panels of reviewers.

(5) The peer review process assumes that a high level of agreement exists among scientists about what constitutes good quality work, who is doing it and where promising lines of enquiry lie, an assumption that may not hold in newer specialities.

Abridged version of an article that originally appeared in the *Journal of Information Science* 13:5, 1987, p.p. 261-76. Reprinted with permission of Elsevier of Elsevier Publishers B.V.

(6) Resource inputs to the review process, both in terms of administrative costs and of scientists' time, are considerable but usually ignored.

Various studies have addressed these criticisms. For example, an analysis of National Science Foundation (NSF) review outcomes found little evidence of bias in favour of eminent researchers or institutions.[2] However, a later study, in which independently selected panels re-evaluated funding decisions by NSF reviewers, found a high level of disagreement among peers over the same proposals. It concluded that the chances of receiving a grant were determined about 50% by the characteristics of the proposal and principal investigator and 50% by random elements i.e. the 'luck of the reviewer draw'.[3] The interpretation of this data has been questioned, however, and the fact that most disagreement was found in the mid-region between acceptance and rejection emphasized.[4] In another study, a sample of NSF reviewers and applicants was asked which of two equally good proposals the individuals thought was more likely to be funded (a) from a well-known versus a little known institution and (b) containing mainstream versus radical ideas. The prospects of the proposal from the better known institute and with mainstream views were favoured by the majority of respondents.[5] The peer review process remains an essential element in assessing the quality of science, but improvements to the system are warranted. These might include:

(1) The right of reply by researchers to criticisms of their proposals, a system already operating for grant applicants to the NSF (USA) and the Nederlands Organisatie voor Zuiver-Wetenschappelijk Onderzoek (Netherlands Organization for Pure Scientific Research [ZWO]).

(2) The use of external peers, from neighbouring fields and other countries.[6]

(3) Clear guidelines on the criteria to be employed.

(4) The use of objective scientific indicators to complement the peer review process.

4. Bibliometric indicators

The most widely applied indicators for research evaluation to date have been those based on bibliometric analysis, including publication counts and citation analysis.

4.1. Publication counts

The simplest bibliometric indicator is the number of published articles that a researcher or group has produced. For basic research the journal article with its accompanying list of citations has always been the accepted medium by which the scientific community reports the results of its investigations. However, while a publication count gives a measure of the total volume of research output, it provides no indication as to the quality of the work performed.

Other objections include:

(1) Informal and formal, non-journal methods of communication in science are ignored.[7]

(2) Publication practices vary across fields and between journals. Also, the social and political pressures on a group to publish vary according to country, to the publication practices of the employing institution and to the emphasis placed on number of publications for obtaining tenure, promotion, grants etc.

(3) It is often very difficult to retrieve all the papers for a particular field, and to define the boundaries of that field in order to make a comparative judgement i.e. the choice of a suitable database is problematical.[8]

(4) Over the past few decades the number of papers with multiple authorship has increased considerably.[9,10] Although this is largely due to a greater prevalence of collaborative research, the gratuitous conferring of co-authorship is not uncommon. Another recent trend had been the shrinking length of papers, resulting in the emergence of the 'Least Publishable Unit'. This may be associated with various factors including fragmentation of data.[11] Thus, an awareness of the use of publication counts for assessment may encourage undesirable publishing practices.[12]

Despite these constraints, studies have shown a reasonable degree of correlation between publication counts and other measures of scientific merit, such as funding and peer ranking and some of these have been reviewed by Jones.[13] More recently, a correlation of 0.95 was found between the amount of National Institutes of Health (NIH) funds received and the number of biomedical publications produced 2 years later by 120 US medical schools.[14] Similarly, a peer ranking of US faculties and graduate programmes (the Roose-Andersen ranking) was found to correlate most highly with the research 'size' of the institution, as measured by the number of papers it produced.[15]

4.2. Citation analysis

This involves counting the number of citations, derived from the *Science Citation Index*® (*SCI*®), to a particular paper for a period of years after its publication. The exact period will vary from field to field, since the time lag between publication and maximum number of citations received in a year differs between specialities. Citation analysis presents a number of serious technical and other problems beyond those already discussed for publication counts.

Reasons for citing

(a) Citation analysis makes the assumption that an intellectual link exists between the citing source and reference article. Cronin[16] reviews 10 different classifications of reasons for citing including 'hat-tipping', over-elaborate reporting and citing the most popular research trends to curry favour with editors, grant-awarding bodies etc. Murugesan and Moravcsik[17] have produced a four-fold classification which is fairly comprehensive:

(1) Conceptual/Operational
(theory)/(method)
(2) Organic/Perfunctory
(essential)/(non-essential)
(3) Evolutionary/Juxtapositional
(development of idea)/(contrasting idea)
(4) Confirmative/Negative
(supports findings)/(opposes findings)

They found that 41% of citations to 30 articles in the *Physics Review* were in the 'perfunctory' category.

(b) Work that is incorrect may be highly cited. However, it has been argued that even incorrect work, if cited, has made an impact or has stimulated further research efforts, while work that is simply of bad quality is usually ignored by the scientific community.[18]

(c) Methodological papers are among the most highly cited, which, it is argued, reflects their considerable 'usefulness' to science. Conversely, many techniques and theories become assimilated into the science knowledge base and their originators cease to be acknowledged (the 'obliteration phenomenon').

(d) Self-citation may artificially inflate citation rates; in one study of psychology papers, 10% of authors self-cited for more than 30% of their citations.[19]

Database limitations

While all publications databases are subject to various weaknesses, such as typographical errors, inconsistent or incomplete coverage of the literature etc., such problems are particularly serious in the case of the *SCI* since it is the primary source of all citation data. The following factors have been stressed:

(a) A considerable number of citations may be lost in an automated search of the *SCI*, due to such problems as homographs (authors with the same name), inconsistency in the use of initials and in the spelling of non-English names and citing errors.

(b) There have been substantial changes in the journal set covered by the *SCI*, with some journals dropped and a larger number of new ones added, so that no consistent set exists. Also, since 1977 non-journal material e.g. conference proceedings, books etc. were included in the database.[20]

(c) The *SCI* journal set shows a considerable bias in favour of US and other English-language journals and against journals from the USSR and other countries with non-Roman alphabets.[21]

Field-dependent factors

(a) Citation (and publication) practices vary between fields and over time.[20] For example, biochemistry papers now generally contain about 30 references whereas mathematics papers usually have less than ten.[18] A study of one Dutch university's publications found that 40% of mathematics articles, while written in English, were not published in journals but in research reports, and therefore were not covered by the *SCI*. Coverage of physics and astronomy publications, however, was over 80%.[22]

(b) The probability of being cited is also field-dependent; a relatively small, isolated field will attract far fewer citations than either a more general field or research within a narrower field that has a wider focus of interest.

(c) The decay rate of citation frequency will vary with each field, and with the relative impact of the paper, i.e. a little cited paper will become obsolete more rapidly than a more highly cited one.[23]

Some of these problems, and ways of minimizing their effects, have been summarized by Martin and Irvine.[24]

For example, the citation rate of a paper may be considered a partial measure of its 'impact' (rather than of its 'quality' or 'importance'), where impact is defined as "its actual influence on surrounding research activity at a given time". In this context, citation analysis may be used as one of a number of imperfect indicators (including publication counts, peer review and highly cited papers) in Irvine and Martin's "Method of converging partial indicators". This method is based on the application of a range of performance indicators to match research groups using similar

Table 1

Studies using bibliometric indicators to assess specialities in basic science

Speciality	Reference
Radio astronomy	24
Optical astronomy	43
High energy physics	25
Insecticides (industrial development)	44
Weak interactions in physics (experimental *vs.* theoretical)	45
Ocean currents (theoretical *vs.* observational —various techniques)	46
Protein crystallography	46
Integrated optics	47
Genetics—genetic instability: drosophila genetics	8
Solid state physics (theoretical *vs.* experimental) —spin glass, extended x-ray absorption fine structure; quantum fluids	8

research facilities and publishing in the same body of international journals subject to comparable refereeing procedures. When the indicators all point in the same direction, the results of the evaluation are regarded as being more reliable than those based on a single indicator like peer review.[25] The limitations of citation counts, their use as only one of a number of indicators, and the continuing importance of peer review have also been stressed.[26]

High citation counts have been shown to correlate closely with recognized quality indicators such as honorific awards, including the Nobel Prize.[27] Similarly, significant positive correlations between the aggregate peer ratings of departments or institutes and the citation frequencies of their members have been reported.[15]

Citation frequency analysis has been increasingly used in the evaluation of science. National performance in eight major fields was assessed by Irvine et al[28] using aggregate, computer-generated data, while manual citation analysis on several specialities was used by the Royal Society to assess UK performance in genetics and solid state physics.[8] Other studies are summarized in Table 1.

In the Netherlands,[22] and in Hungary,[29] research groups within departments or faculties have been compared using publication and citation analysis. Where such small groups are concerned, extreme care must be taken to recover all relevant data, since a missing highly cited paper would greatly distort the results. It has been suggested that rates of 99% and 95% coverage for publications and citations respectively are required.[20] A further difficulty at the disaggregated level is the selection of groups for comparison with the group being assessed. Another problem is that, to date, most smaller-scale studies have been made manually and although this method, which involves tedious, repetitive tasks, cannot be claimed to be error-free, it is undoubtedly the most accurate one available at present. If bibliometry in general, and citation analysis in particular, are to become more useful tools in science evaluation and policy, then means must be developed of generating databases and of retrieving citations on a semi-automated basis with minimal omissions and errors. In a pioneering study of online retrieval of publications related to chemical oceanography, a French group emphasizes the need to establish a set of standards for writing and indexing papers, which would facilitate the identification of relevant publications using boolean searches.[30]

Table 2

Comparison of direct citation counting and journal influence as research productivity measures

Direct citation counting	Journal Influence Measure
Advantages	
Higher precision: identifies specific papers	Available quickly, as soon as bibliographies are completed. Not as labour intensive or computationally complex. Relatively easily normalized.
Disadvantages	
Must wait 3-5 years after publication.	Only valid for relatively large sets of papers.
Labour intensive and computationally complex.	Lose identification of specific highly cited individuals and papers. Journal influence may change over time.
Must always be carefully normalized.	

Source: 31.

4.3. *Journal 'Impact' or 'Influence'*

Manual citation analysis is labour intensive and suitable only for small-scale studies. For larger, aggregated data, weighted citation counts based on the average number of citations each journal receives, provide an easier if less accurate estimate of citations gained. Garfield's 'impact factor' is the ratio of the number of citations a journal receives to the number of papers published over a period of time. The *Journal Citation Reports®* (*JCR®*) gives yearly impact factors for the journals covered by *SCI*, calculated as citations received that year to the publications of the previous 2 years. However, this approach ignores the relatively high citation rates generated by review articles, the greater weight that arguably should be accorded citations from higher prestige journals, and inter-field variations in citation practices. The advantages and disadvantages of using such weighted citation counts have been summarized by Rothman[31] (see Table 2).

Various studies have used journal influence: for example in the USA a comparison of peer rating and the citation influence rating of journals in 10 different fields found a strong positive relationship.[32] On a smaller scale, the journal 'packet' of journals in which departments published was constructed for university research groups in the Netherlands. Using a 'Journal Citation Score' (JCS) analogous to *SCI*'s 'impact factor' the weighted average JCS value was calculated for each group. The value obtained represented the 'expected' number of citations per article for that journal set, which could then be compared with the actual number of citations received by the research group.[22] However, the use of the journal impact methodology for small-scale, disaggregated evaluations remains controversial, since only approximate measures are obtained.

4.4. *Co-citation analysis*

Bibliographic data have also been used to construct maps of the structure of science using co-citation (cluster) analysis. This is based on 2 assumptions: (1) that when 2 papers are cited together by a third paper, then a cognitive relationship exists between them and (2) that the strength of this relationship is proportional to the frequency of the co-citation linkage (i.e. the number of papers that co-cite them). Clusters of related papers may be constructed for a specified threshold of co-citation and the relationships between clusters displayed spatially using multi-dimensional scaling. The clusters represent specialities or fields, while links between them reveal interdisciplinary relationships.

Thus, co-citation analysis may be used to map various features including: the structure of research fields or specialities; communications between fields or specialities and, using time series, the development of active research fronts or the historical development of a particular area of knowledge.[33] In the *ISI Atlas of Science®*, multiple levels of clusters have been used to produce 'nested maps' which provide hierarchical or regionalized structures of large fields such as biochemistry or biotechnology.

Recent improvements in the methodology make allowances for inter-field variations. 'Fractional citation counting' overcomes the problem of the over-representation of high referencing areas such as biomedicine and the under-representation of low referencing ones such as mathematics. The citing paper now carries a total strength of 1 which is divided equally between all its references. Also, the new 'variable level clustering' sets a limit to cluster size. These techniques improve the disciplinary balance of the maps in the *SCI* file.[34,35]

Used in conjunction with conventional historical methods, co-citation analysis was found to be a valuable tool for identifying important foci of intellectual activity (research fronts) in the speciality of weak interactions in physics.[36] However some authors criticised the methodology on several grounds, including the time lag between the actual inception of a new line of research and the formation of a cluster; the over-representation of theoretical as compared to experimental papers, due to their greater ease of production; and the loss of many relevant papers due to such factors as the circulation of pre-prints, publication in Russian journals (not covered by *SCI*), and the 'obliteration phenomenon'.

Similar objections have been raised for the speciality of spin-glass, where co-citation data were compared with a manually generated bibliography, and additional problems included errors in citations, the inclusion within clusters of papers from related but distinct fields and the subjectivity inherent in the setting of threshold levels although these levels strongly affected the size and content of clusters.[37]

Thus while co-citation analysis has evident usefulness for social scientists who wish to study the structure of science, its role in science policy remains controversial. However it has been applied by the Raad van Advies voor het Wetenschapsbeleid (Science Policy Advisory Council [RAWB]) in the Netherlands to identify those fields in which Dutch scientists have a considerable international impact, and both Germany and Australia are taking an interest in the RAWB Study.[38]

4.5. *Co-word analysis*

This methodology has been developed by the Centre de Sociologie de l'Innovation (Center for Sociology Innovation [CSI]) in Paris. It involves analysing papers to identify keywords that describe their research content and linking papers by the degree of co-occurrence of these keywords to produce a 'map index' of a speciality. Many journals and abstracting services already provide such keywords. One of the main advantages of co-word analysis would seem to lie in its independence from the *SCI* database, which has a considerable US and English-language bias, and may therefore cover only partially the research output of many smaller, non English-speaking countries. Also the considerable time lag associated with citation-based analyses is avoided and the method is not limited to scientific publications but may be applied to all forms of scientific literary output such as technical reports and patent applications, and may therefore be used to investigate applied as well as basic research.

In order to minimize the weaknesses inherent in manual indexing, the CSI has developed a computer-aided indexing technique for full-text databases called LEXINET in which the controlled vocabulary is constructed and updated interactively each time a new document is analysed.[39] Together with the LEXIMAPPE programme for co-word mapping, this technique is being developed as a science policy tool and has already been used to analyse publications from research on dietary fibre and aquaculture; various documentary sources, including project proposals, for macromolecular chemistry research and patents in the field of biotechnology. The authors emphasize that the method is in a developmental stage and raise various technical issues to be resolved.[40,41]

An Anglo-French study in progress on acid rain research is using co-word analysis to identify:

(a) research 'themes' based on small clusters of frequently-occurring keywords in papers (maximum 10 keywords);

(b) the strength of the internal links within themes (when strongly linked, these are said to represent highly cohesive areas of research which may in fact be peripheral to the speciality under study), and

(c) the number of external links between themes, which may indicate centrality to the speciality (where there are many links the theme is deemed to be central to the speciality and *vice-versa*).

Thus a strategic map may be drawn up in which the centrality and internal cohesiveness of themes are related in order to identify either potentially neglected or peripheral themes of research. This methodology is termed 'research network management'.[42] There may therefore be a policy role in the future for co-word analysis at the level of determining priority areas of research.

Conclusion

My purpose has been to outline the different types of science indicator and the various methodologies that have been used in the assessment of scientific performance. Most bibliometric studies have operated at the level of the scientific speciality or field, and the reliability of results obtained by applying bibliometric techniques to small numbers of publications has raised serious doubts, due to the conceptual and technical problems outlined in section 4.2. However, many managers are today confronted with the need for objective indicators, to complement the peer review process, for small or medium-sized, often multi-disciplinary, research groups. There is therefore a need to develop reliable, preferably field-independent, indicators for use at a disaggregated level; whether journal 'influence' or bibliographic coupling can provide such indicators has yet to be assessed. In addition, there is a need for these indicators to be generated on a routine basis; a major constraint to such a system is the labour-intensive nature of the currently accepted manual methodology. The development of online techniques, with minimal and acceptable rates of error, for both publication and citation retrieval, is urgently required; more consistent inter-database formatting and indexing for publications would greatly facilitate this process. It would also be useful to assess whether sampling significantly alters the results obtained from complete sets of publications and citations (e.g. taking peak citation years only), since this would substantially reduce the volume of data to be handled. In terms of research inputs, there is a need for consistent and comparable data at a relatively disaggregated level, to facilitate meaningful input-output assessments. Finally, there is an urgent need for debate among research managers and policy makers about the role that science indicators should play, both in terms of the weight they should carry relative to, for example, peer review, and the level at which they should be incorporated into the decision-making process.

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