2C5 # An Overview of Bibliometrics

○Diana Hicks （科学技術政策研究所）

Introduction

Bibliometrics are quantitative, literature-based methods of studying the scientific community or of evaluating research output. At the simplest level, counts of numbers of publications and numbers of citations are made. More complex studies use sophisticated statistical techniques of clustering analysis to draw maps of the scientific community.

This paper will give an overview of these techniques, as developed by European and American researchers. Since the paper is a survey, it will not discuss one piece of research in depth, nor will it focus on my research alone. I will describe several examples of research using the techniques without going into detail about each technique. Rather the aim will be to indicate what is possible with the techniques, what current research interests are, how the techniques can be of possible policy use and to point to sources of potentially interesting information.

My qualifications for giving this talk arise from the experience gained at my home institution, the Science Policy Research Unit, working in the group of J. Irvine and B. Martin, who have been leading researchers in the development of these techniques. The bibliometric and science policy research projects undertaken by the group are listed in Table 1. However, my talk will not be confined to the work of this group, as the aim is to present a large variety of results.

When describing bibliometrics one must begin by mentioning that the techniques depend heavily on the existence of computerized databases of scientific literature. In particular, the database of the Institute of Scientific

Information (ISI), The Science Citation Index is the most commonly used in citation studies because it indexes not only scientific papers but references to papers or citations. Citations are analyzed to indicate the impact scientific work has on the scientific community and the links between scientists or scientific fields.

Bibliometrics has been used for several different purposes. It has been used in the sociology of science to improve our understanding of the structure and dynamics of scientific communities. It has probably been more widely used, however, in science policy studies, for example in the evaluation of the scientific performance of institutions, evaluation of the effectiveness of government science policy initiatives and comparisons of national performance in various fields.

Many types of policy-relevant studies are possible, but before describing projects in more detail it is very important to mention the caveats associated with bibliometric analysis in general and more specifically in relation to Japan. As my talk will indicate, bibliometric techniques can be very useful, but they should be used with caution.

The first caveat is related to the fundamental assumption underlying all bibliometric analysis, namely that the main output of the research to be studied is papers published in journals. If the research being studied is not like that, if outputs are primarily in the form of "grey literature" (i.e. reports to sponsors or conference proceedings) or innovative processes or devices are the most important output, then the results of the analysis will be of limited applicability, or bibliometrics may be wholly innappropriate.

If bibliometrics is appropriate, one must be careful. Indicators must be constructed with care by skilled practitioners to avoid bias and error which can lead to inaccurate results. Furthermore, they must be interpreted with an awareness of the limits of this type of data. The techniques, particularly when used in evaluations, should never be used alone but should act as a supplement to other methods of evaluation.

Special problems attend the application of bibliometric indicators to countries with substantial publishing in non-English language journals such as Japan. Although counts of publications are possible from Japanese language databases, citation data is only available on the ISI database. Although this database does include some Japanese language journals, obviously coverage is incomplete. Therefore, it may be prudent to say that citation analysis can be conducted on that part of Japanese science which is oriented towards the international scientific community and that citation counts will relate to the impact of Japanese science on international science, and on Japanese scientists writing for an international audience.

Overviews of the field

Perhaps the best distillation of the methodological knowledge acquired by the bibliometrics community through many years of research is a report entitled Literature-Based Data in Research Evaluation: A Managers Guide to Bibliometrics by Cozzens. In this report the author provides a taxonomy of bibliometric techniques, describing for each major technique: sample results, the rationale behind the technique, the caveats associated with interpreting results, and practical problems associated with compiling indicators. I reproduce here the classification of what can be measured and how to measure things using bibliometric techniques. We see that there are five basic categories of measurable characteristics of scientific work: quantity, subject, character, impact and links. There are nine basic techniques used to gauge these five quantities. Quantity of output is measured with publication counts. The subjects in which research are produced are measured using journal classifications, title words or indexing terms. The character of the research is probed through structured analysis of the content of publications. The impact of the research on the scientific community is examined using co-word or co-citation mapping or citation counts. Finally the links within the scientific community are investigated by counting co-authorships or cross-citation relationships. All of these techniques can be applied at at least six levels: national, sectoral (government, industry and academia), institutional, departmental, group or individual, though the results will be much less reliable for small groups or individuals.

The Cozzen's report summarizes the results of many years of research by the bibliometrics community. Such research has very often been conducted with the aim of producing techniques which will be useful to policy-makers. But have policy makers actually found bibliometrics to be of use? This question was examined by Anderson in a report entitled: New Approaches to Evaluation in UK Research Funding Agencies. The author finds that bibliometrics is beginning to be incorporated into policy making by government agencies. In the U.K. several science funding councils now have small in-house policy and evaluation units working on bibliometrics and the computerization of R&D statistics. Their exploratory studies have met with mixed success. They found that the main benefit of such indicators is to focus attention rapidly on areas of low or high productivity, and to pose questions that otherwise might not be obvious. Quantitative data can force 'difficult' funding decisions, preventing the peer review system from becoming too soft. In contrast, where peer review conflicts with the evidence, experts can be required to justify their position, thereby the decision-making process becomes more transparent.

Examples of Bibliometric Research

The reports described so far are fairly general. I will now give examples of recent research results to indicate the state-of-the-art in bibliometrics. I will describe studies of:

1) patterns of international collaboration in science
2) the size vs output of university departments
3) international comparisons of citation rates
4) the output from versus input to national scientific efforts
5) the possible use of patent citations in corporate competitor intelligence studies which examine technological strength

Because I am limited by time and can describe each study only briefly, I cannot describe all the caveats and methodological details of the studies. I refer those who are interested to the references at the end of this paper.

The first study is by Luukkonen et al. and is entitled: "An Outline for Understanding Patterns of International Collaboration". The authors analyzed a comprehensive data set giving the numbers of papers with authors from any two countries. That is, the data can be thought of as a matrix with rows and columns for each country in the world. Each entry is the number of papers with at least one author from the row-country and one from the column-country.

This type of study is of great policy interest to the European Community which would like to know if their programs aiming to increase collaboration between scientists in different nations are effective and if the science produced is good science. One interesting result from this study is shown by a graph of percentage of papers internationally co-authored versus percentage of world papers. Countries to the right of the graph produce more scientific papers than those to the left, while countries at the top of the graph do a higher percentage of their science in international collaborations than do countries towards the bottom of the graph. Although the scatter is large, especially for small countries, the graph indicates that the rate of international collaboration is inversely related to size. Although the absolute number of collaborations may in fact be larger in a bigger country, like the USA, international collaboration will form a smaller share of the scientific output from larger countries. There may be several reasons for this trend. To avoid isolation scientists from smaller countries look for partners from scientifically more central countries. "The increasing specialization in science makes research areas more narrowly focused and scientists from scientifically peripheral countries are likely to find only a few, if any, colleagues in their own country. Another reason for their high rate of international collaboration might be their greater need for cost sharing." (Luukkonen, p. 5)

The graph also appears to confirm the impression that Japan is relatively isolated in the world scientific community as Japan is quite far below the trend line (next to the USSR).

The second study I will describe was conducted by myself and J. Skea at SPRU. It illustrates how bibliometric data can directly address policy-related questions. The British government in recent years has had a policy of closing smaller university departments. This policy has been justified on the basis that both teaching and research benefit when conducted in larger departments. But no good evidence was used to support this argument. We collected relevant data by counting the number of papers produced by UK departments in several scientific fields and plotting output per person against number of staff. As the graph of the results for physics shows, the amount of variance explained by staff size is very small indicating that there is little or no relation between output per person and staff size - indicating that the government policy may have been misguided. However, there is a slightly significant increase in output per person versus staff size on this graph. When Oxford and Cambridge are removed this disappears, suggesting that perhaps all UK science should be concentrated in Oxford and Cambridge to obtain maximum efficiency (and maximum house prices!).

The next result demonstrates how international comparisons of scientific output are made. It was produced by the second theory oriented research group at NISTEP which is developing a science indicator system for Japan. The graph was made using the Science Literature Indicators database and gives data for five countries and the eight main scientific fields. The statistic plotted is the percentage share of citations divided by the percentage share of papers (or the relative citation ratio) minus one. If the relative citation ratio is equal to one, the country's share of citations is equal to its share of papers. If the ratio is greater than one the country's papers are earning a greater share of citations than the country's share of output, and one could consider the field an area of scientific strength for the country. If the ratio is less than one the country's papers are earning a lesser share of citations than the country's share of output, that is the impact of the country's research is less than one might expect. To make more dramatic the picture of strength and weakness on the three dimensional graph, the relative citation ratio minus one was plotted. Therefore, areas of strength are shown by pyramids and areas of weakness by upside down pyramids. The graph shows that the United States earns a greater share of citations than its share of papers in every field. The UK is strong in mathematics, chemistry and biology. Japan is strong in biology, chemistry and engineering and technology.

The next study that I will describe is the result of many years of research into both science funding and bibliometric analysis at the national level. This work, by B. Martin and J. Irvine of SPRU has produced numerous internationally comparative analyses of the inputs to and outputs from science. These provide some evidence, for example, that Japan has been pursuing a more selective or targeted approach to research than the other main scientific nations. The area of Japan's greatest concentration is engineering and technology. (Martin, p 8)

In the latest work in the series, an attempt is made to link the two sets of data in order to look at the efficiency with which science is produced by different countries, in different fields and how this is changing over time. Although I have not mentioned the caveats to be applied to the other studies, I must mention them here because a strong word of caution is needed about the very provisional nature of the results, partly because this type of work is so new. The problems with the data are as follows:

- Different research classification schemes were used for the funding and bibliometric data, though it was possible to rearrange the data and find a reasonable match.

- A second problem is that data is available for only four years, so rigourous statistical analysis of the input-output relationship is not yet possible.

- Finally, the funding and bibliometric data do not relate to exactly the same set of research activities. The funding data is for government-funded 'academic and related' research which excludes the research of industry, charities and mission-oriented national laboratories - all of which publish paper included in the bibliometric data. Publication data is biassed towards the English language. The best that can be said is that there is a large overlap between the two sets of data. (Martin, pp. 10-11)

The results are shown in this graph in which both sets of data are plotted as the percentage share of the combined total of the six countries studies in the expenditure survey. "If the relationship between inputs and outputs were a simple linear one, (i.e. if it cost the same amount to produce a scientific paper anywhere in the world)" one would expect all countries to lie on the 45 degree line shown on the graph. (Martin, p. 11)

Both the UK and US (not shown) lie above the line. This might be because these two countries have an above average scientific productivity or because all their publications are in English, and the data base is biased against non-English language publications.

One would expect Japan to be quite far below the line, given the large volume of Japanese language publication. However, Japan is quite close to the line, probably because a higher percentage of Japanese publications come from companies. The graph also shows trends, which indicate that Japan has been moving in the opposite direction to the other countries and is approaching the 45 degree line.

That graph showed results for science as a whole. It is possible also to look at subfield data although the trend lines are more erratic since the numbers are smaller. The UK graph shows that funding decreases do generally result in decreased publication output. However, there is an anomaly: Mathematics and computing. This anomaly illustrates how the data can be extremely policy relevant. By pointing up the surprising result that funding for mathematics and computing increased dramatically but publications did not we can ask: why not? There are two possible explanations. The funding increase was associated with the national information technology initiative in the UK, which may have turned researchers towards more applied research or may have reduced their time for research because the initiative required close collaboration between researchers in a number of institutions. To initiate and maintain such collaboration, researchers had to forfeit research time. This ability to probe the effects of science policy initiatives is one of the benefits that bibliometrics can offer science policy makers.

But the benefits are not only available to governments. Recently patent counting and patent citations has shown promise for use in corporate competitor intelligence. Patent citation indicators, like bibliometric indicators first were applied to the evaluation of national technology. However, the CHI Research company has pioneered the use of these techniques in industry. Recently they have conducted a study to validate the use of patent citations. They asked researchers, managers and patent lawyers at one company to rate the technical importance of a selection of their own company's patents. A key point here is that <u>technical</u> and not <u>commercial</u> importance is rated. The results, shown here in the graph, demonstrate that although patents with a low level of citations are similar in technical importance, i.e. a patent with six citations is the same as a patent with one citation, highly cited patents are clearly those perceived by experts in the technology to have the largest technical importance. This result increases confidence in the usefulness of patent citation analysis particularly of very highly cited patents which are likely to be leading indicators of future areas of high impact technology.

Summary

In this paper I have aimed to describe what bibliometrics is and how it is useful in policy analysis by showing examples of current results. I hope these have illustrated both the range of bibliometric research currently in progress and the practical utility of the results to those interested in managing science, whether in industry, government or academia.

Table 1

Research conducted by the Science Policy and Research Evaluation Group at the Science Policy Research Unit

Subject	Application
scientific performance of 'big science' facilities	optical telescopes particle accelerators
technological 'spin-off' and training benefits from basic research	radio astronomy
scientific performance of groups working in small science	condensed matter physics protein crystallography
output and impact of applied research groups	integrated optics biomass research
effectiveness of government R&D programmes or research support mechanisms	NTNF in Norway EC steel R&D programmes SERC biotech. directorate in UK
national scientific performance	relative international standing of British science
future prospects for major new research facilities	accelerators under construction at CERN and elsewhere
methods for identifying longer-term priorities for strategic research	1984 & 1989 studies on research foresight
research inputs	1986 & 1989 comparisons of academic & academically related research funding in 6 countries
factors affecting research performance	condensed matter physics
research performance of universities and university departments	study currently in progress
links between industry and universities	study currently in progress

Sources

Albert, M.B. "Direct Validation of Citation Counts as Indicators of Industrially Important Patents", to be submitted to Research Policy.

Anderson, J. New Approaches To Evaluation in UK Research Funding Agencies, SPSG Concept Paper No.9, 1989. For details of how to obtain the report see Appendix 1.

Cozzens, S.E. "Literature-based Data in Research Evaluation: A Managers Guide to Bibliometrics", SPSG Concept Paper No. 11, August 1990. For details of how to obtain the report see Appendix 1.

Hicks, D. and J.E.F. Skea, "Is Big Really Better?", Physics World, December, 1989, p. 31-34.

Luukkonen, T., O. Persson & G. Sivertsen, "An Outline for Understanding Patterns of International Scientific Collaboration". Paper presented at the International Conference on Science and Technology Indicators, held at Bielefeld, 10-12 June 1990.

Martin, B.R. and D. Crouch, "Science in the Federal Republic of Germany, France and the UK - An International Comparison of Inputs, Outputs and Impact", Paper presented at the international conference on Science and Technology Indicators, held at Bielefeld, 10-12 June 1990.

Addresses

M.B. Albert
CHI Research Inc
10 White Horse Pike
Haddon Heights
NJ 08035 USA

B. R. Martin
Science Policy Research Group
University of Sussex
Falmer, Brighton
BN1 9RF, UK

T. Luukkonen
The Academy of Finland
Science Policy Studies Unit
Hameentie 68
SF-00550 Helsinki
Finland

Appendix I

The Science Policy Support Group
22 Henrietta Street, London WC2E 8NA
Telecom Gold 87:WQQ119
Facsimile (071) 497 9061
Telephone (071) 836 6515

LITERATURE-BASED DATA IN RESEARCH EVALUATION: A MANAGERS GUIDE TO BIBLIOMETRICS.

Susan E. Cozzens, Rensselaer Polytechnic Institute.

As academic research is increasingly subjected to evaluation the need for a good understanding of the methods involved is vital. Within the evaluation process publications have long being considered one of the main sources of information for research assessment. In this overview of publications data Susan Cozzens addresses the commonly raised questions such as:

Why and when are literature-based indicators appropriate in evaluation?

What kind of information is available in literature-based indicators?

How should literature-based data be incorporated into the evaluation process?

Where do evaluators get literature-based indicators?
How much does literature-based data cost?

Finally, the main forms of analysis available are summarised and their strengths and weaknesses discussed.

This study, originally undertaken for the National Science Foundation in the USA, is the eleventh in SPSG's Concept Paper series.

ORDER FORM

Please send copies of the following SPSG Concept Papers

Concept Paper No.	Price	No. Req.	Amount £
No.1	£3.00 each		
No.2	£3.00 each		
No.3	£3.00 each		
No.4	£3.00 each		
No.5	£3.00 each		
No.6	£3.00 each		
No.7	£3.00 each		
No.8	£5.00 each		
No.9	£6.00 each		
No.10	£5.00 each		
No.11	£5.00 each		
Sub Total			
Plus postage and packaging 50p per paper UK/£1 per paper overseas			
Total			

I enclose a cheque made payable to SPSG for £..................*

Please send an invoice to the address below*

I wish to pay by Visa/MasterCard; please charge to my account, details below*

* Delete as applicable

Name ....

Address ....

....

....

Visa/Mastercard No:																
Expiry date: /	Name on Card:															
Address of cardholder if different from above:																
Signed:																