Jointly published by Akadémiai Kiadó, Budapest
and Springer, Dordrecht

Scientometrics,
Vol. 62, No. 1 (2005) 145–153

The system of research and development indicators: Entry points for information agents

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A system of input, output, and efficiency indicators is sketched out, with each indicator related to basic research, applied research, and experimental development. Mainly, this scheme is inspired by empirical innovation economics (represented in Germany, e.g., by H. Grupp) and by "advanced bibliometrics" and scientometrics (profiled by van Raan and others). After considering strengths and weaknesses of some of the indicators, possible additional "entry points" for institutions of information delivery are examined, such contributing to an enrichment of existing indicators. And to a "Nationalökonomik des Geistes", requested from librarians in the twenties of the last century by A. von Harnack.

Introduction

Science has become an industry; and big science has become a big industry. Every branch of industry is usually accompanied by clusters of services of most different shape and aim. For efficient and effective performance, also science needs services of different kinds. Think of lab technology supply and services, of computer services, of publishing and editing services, of information design services, of statistical services, to mention just a few. As a core service especially for basic and applied research, of course library and information services have to be mentioned. It is ridiculous to think that this kind of service will vanish in the future "because of the Internet", as sometimes is assumed; on the contrary, more information and knowledge management and services than ever will be needed to keep science productive, including the management of digital sources and libraries.

Every enterprise and almost every organization or corporation is confronted with the task to monitor and evaluate the performance of its individuals, of its teams, or of the whole unit. From the view of such enterprises or organizations, this is useless as a mere retrospective exercise: The main purpose of such evaluations is to improve the future performance. So, evaluation is a key to the future development of an organization. To monitor and evaluate in this sense is especially difficult and arduous in science. Here bibliometrics was coming in.

Received August 17, 2004

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0138–9130/2005/US $ 20.00

Bibliometrics is sometimes understood as evaluation of science with the help of bibliographical statistics. But I find this interpretation misleading, even nonsensical. Think of econometrics, for example: econometrics surely is not the evaluation of economies with the help of economical statistics. I would like to remind you of a simple and elegant short definition coined by van Raan: Bibliometrics is the quantitative study of the written output of science. In my eyes, those studies began in the last decades to contribute to a deeper understanding of the functioning of science as a self-organizing system. Direct scientific connections to theories and models of other natural self-organizing systems were explored, and those studies begin to complement the theory and logical analysis of science which have made so much progress in the last decades. We have to do with basic research *on* research using quantitative insights into the research process or the scientific communication process.

Thus, bibliometric descriptions and models introduced a new macroscopic, empirical perspective on science, and made science a bit more transparent. For a long time it was impossible even for insiders of an area under examination to gain such a perspective. With the help of bibliometric indicators it is now possible to get basic information on key players, on most cited institutes, on research fronts, and so on; and it turned out that in some respects a more objective, more balanced and more comprehensive overview is gained than delivered by individual experts - although subject experts are indispensable for interpreting such a picture or map. This is not only valid for natural science. The well-known philosopher of science Nicholas Rescher (who 25 years ago also used some bibliometrics in his path-breaking book *Scientific Progress*) once stated that to yield an adequate overview even of a philosophical field one is now drawn back to bibliometric analysis, apart from content analysis which remains necessary, of course. All this has nothing to do with evaluation, rather with statistical description and transparency. Obviously, bibliometrics may thus *contribute* to an evaluation process as a mosaic piece. Contributions of this kind offered in a professional manner I would like to call service for science, and understand as part of a service industry for science.

A "system" of indicators

One of the possibilities to explore bibliometric indicators (for such a service as well as for research on research) is to examine their role and their place in the process of knowledge production. In different phases of knowledge production different bibliometric indicators will be needed.

Phases of knowledge production in research and development are basic research, applied research, and experimental development. Basic research leads to scientific discoveries, development leads to – often patentable – inventions, whereas applied research lies in the zone between basic research and experimental development. These phases should not be understood as a necessariliy linear sequential scheme, although such a sequence can appear. Rather it is a functional scheme: successful technological experiments can precede, stimulate, and lead to basic research, for example. The different lines of knowledge creation are interacting.

Furtheron, I would like to distinguish, in accordance with authors like H. Grupp or E. Geisler, between input indicators, output indicators, and efficiency indicators. Input indicators capture what is used to produce knowledge; financial means as a basic necessity, for example, furtheron equipment, labs, and so on.

Output indicators deal with the outcome of knowledge production. Outcome could be in mathematics, for example, a new theorem, a paper in a respected journal.

Efficiency indicators try to capture the relationship between investment and outcome. For technological research and development in enterprises, this is, of course, a most crucial relationship.

For each of the three categories and each of the three functional phases I distinguish between four descriptive statistical approaches to the indicator in question: a manpower, a financial, a technological, and an informational indicator approach.

Plenty of the indicators I shall describe in the following are apparently no bibliometric indicators. I hope that to include these non-bibliometric indicators improves the understanding of the specific meaning of bibliometric indicators and their possible interplay and interconnections with other indicators.

Mainly, I have profited from a standard text of E. Geisler, *The Metrics of Science and Technology*,[1] and of Hariolf Grupp's *Messung und Erklärung des Technischen Wandels*.[2] In describing these indicators, I will not go into details which can be drawn from these sources. The category "informational indicators" cannot explicitly be found in the current literature; in what follows, I view bibliometric indicators as part of such informational indicators. When I speak of a *system* of research and development indicators one must not presume that these indicators form a coherent and smoothly interconnected system. Progress has been made, but such a system has yet to be developed fully.

Input indicators

Table 1 shows a summarizing scheme of input, output, and efficiency indicators. The scheme is heuristic and only tentative, and by far not exhausting. The quantitative treatment of the indicators is not always established. For further differentiations the standard texts of Grupp or Geisler are recommended. I cannot go into every cell of that scheme, rather I would like to highlight only some aspects.

Let us begin with input indicators for basic research.

Table 1. Indicators for basic research, applied research, and experimental development. The scheme is heuristic and exemplary, not exhaustive. Micro- and macroscopical levels are not differentiated systematically. For further explanations, see text.

Indicator category	Indicator type	Basic research	Applied research	Experimental development
Input	manpower, human resources	scientists, engineers, other staff	scientists, engineers, other staff	engineers, other staff
	financial	expenditures, grants)	expenditures, grants	expenditures, subsidies
	technological	equipment, labs	equipment, labs	equipment, labs
	informational	literature use, scientific library and documentation use	literature use, enterprise library and documentation use	unpublished information, tacit knowledge, patent library use
Output	manpower, human resources	post-graduates	unclear – intellectual resources?	unclear – intellectual resources?
	financial	human capital	human capital, business scenarios	business prospects
	technological	technological ideas	technological concepts and models	new technological products and processes
	informational	publications (discoveries), communicative influence (citations)	publications, patents (technical ideas, inventions); communicative influence	patents (new economically relevant technological knowledge)
Efficiency, effectivity, returns	manpower, human resources	increased scientific problem solving capability	increased applied problem solving capability	increased inventive productivity
	financial	cost per output unit	cost per output unit	returns on investment, effects on economic growth and welfare
	technological	technometrically plausible progress	technometrically proved progress	technometrically confirmed progress
	informational	impact of information on scientific progress	impact of information on technological progress	impact of information on productive progress

Among the established indicators are figures of the personnel engaged in basic research. From a human resources point of view one has to consider here different levels of education. Difficult is the assessment of the degree of involvement in research, separated, for example, from administrative or teaching duties. For university research, the extent to which scientists or teachers are able to devote themselves to research has to be estimated. Despite I cannot go into detail here I would like to mention that "evaluating" universities one has to pay attention to their disciplinary profiles: research in arts and humanities, social sciences, and natural science, respectively, is of quite different direct economic meaning so that behind the same university research manpower volume (also of two countries) quite different types of research and different potentials are hidden.

One can count the number of employees, but one can also try to get figures of the expenditures connected with research personnel. One has to distinguish here between expenditures for wages and expenditures for equipment.

After personnel and expenditures, with equipment a third category has to be introduced: the technological input into basic research. In many disciplines, technological progress plays a crucial role for the development of research possibilities. Enhanced and new technological capacities lead to new scientific insights; N. Rescher postulated here, with exponentially growing costs of research technology and comparatively slower growing knowledge, a principle of diminishing marginal returns of scientific research at work. To the best of my knowledge, however, no indicators were developed so far in a sufficient systematic manner for the influx of technology into basic research. Promising would be, in my view, the use of technometric indicators which are sketched in a minute. Usually, financial indicators have to function as surrogates.

In principle, the same or similar indicators can be used for applied research. However, the major part of applied research is conducted not in universities, but in enterprises and in state laboratories.

A remark on informational input indicators

In the literature I did not meet so far a systematic and comprehensive approach to indicators of the informational input neither for basic nor for applied research nor for development. It goes without saying here and without possibilities of quantification that an important part of information and knowledge work of applied research and of experimental development in enterprises happens without any direct involvement of formal documents. For experimental development the direct worth and impact of published information is by far not as high as for basic or applied research. Although tacit knowledge is important for conducting basic research, too, I consider tacit knowledge and informal communication as the most important informational component of experimental development.

Conversational exchange, meetings, informal memos or reports, and drafts of ideas determine the picture. Information Professionals in this context are primarily involved in delivering access to (from the standpoint of a research unit) external information resources through the Internet channel or through the supply and delivery of printed or electronic documents. Information Professionals stress the importance of that input. But for the general importance of this kind of external information sources can also be argued based on the results of innovation research. There is empirical evidence of a significant difference between innovating firms with regard to the successful introduction of innovations. In one sentence: The higher the openness to external information, the more successful firms are performing innovations.

The informational input of certain works, on a microscopic level, can partially be studied by the analysis of references given in papers. Of course there are uncountable studies of that kind; I would like to mention only one not yet so well-kown approach. To study the use of science in applied or experimental research, one can study the extent to which publications of applied or experimental research refer to basic research. One can examine this phenomenon also in patent documents, and the Fraunhofer Institut für Systemtechnik und Innovationsforschung in Kalrsruhe presented results of such an approach in a book called *Wissenschaftsbindung* (science intensity).[3] In addition, statistics of firm libraries may supply a general view of information input in the sense described above. There is an additional entry point. Interesting enough, H. Grupp mentioned the extent to which firms use external scientific libraries as a possible indicator of research or science intensity of enterprises. He suggests to develop a systematic geographical overview of that library use in order to supplement other indicators of science intensity. Of course, in High Tech fields the research intensity should be higher than in low tech fields. Such a geographical comparison of user statistics with concern to the involvement of enterprises would add quite an interesting mosaic piece to innovation studies.

In any case, bibliometric methods obviously allow to study input aspects as well as output aspects of knowledge production.

Output and efficiency indicators

We now come to output indicators. It can be counted to one of the major shifts of science studies and science evaluation of the last decades that in addition to input indicators as described above (foremost personnel and financial figures) also output indicators were developed and used to a much greater extent than ever before. Among output indicators bibliometric indicators play a central role. For basic science, paper counts are appropriate. For experimental development, bibliometric indicators insofar they deal with publications are not suitable, because for developers it is of no or only secondary importance to publish knowledge gained through development work. Sometimes it may be even quite foolish to disclosure knowledge at the competitive edge of an area. However, if that work leads to inventions which are worth, in the view of the inventor, and suitable, in the view of a patent office, to be protected against imitation by patent law, the inventor is forced to publish a description of his invention in a patent document. Applied research stands between basic research, on the one hand, and experimental development, on the other hand, in this respect. Sometimes it was overseen that the more applied orientated a research is the less publication plays a role as output, and so some research analyzers as LePair and others warned to ignore a "bibliometric gap" of this type of research.

Among bibliometric indicators, citation indicators are used to reflect the influence or visibility of a work. For the sake of bibliometric correctness I only mention here that in the last decade bibliometric methods have developed further as advanced bibliometrics. In advanced bibliometrics, for example, citation counts are given with and without self-citations; citation scores are related to a subfield, not to a discipline, and so on; plenty of differentiated bibliometric aspects are presented.[4]

With the help of publication and citation indicators input aspects of research and development can be illuminated, but they obviously also belong to the informational output. However, to measure whether communicative acts in the form of papers or citations lead to scientific (or technological) advancement one has to establish a relationship between papers or citations and scientific progress, the latter in the sense of new theorems, technological improvements, improved scientific explanations, convincing refutations of theories, and so on. Of course, only for a small part of these phenomena quantitative bibliometric indicators are known at the present time.

However, with which output indicator could the above mentioned "bibliometric gap" of technology-related indicators be filled? The answer are technometric indicators. With the help of these indicators, developed in Germany by the Fraunhofer Institut für Systemtechnik und Innovationsforschung in the last years, it is tried to measure important performance properties of technologies in a systematic manner.[5] Such a performance property could be, for example, the efficiency of engines, the computing speed of computers, failure-free operation time, and so on. Improvements might be visible in technometric time series. This aspect may be of no direct concern for Information Professionals. We see, however, that technological progress can be measured in a more objective manner than scientific progress. The analogy in science would be that a certain problem is better understood or is even solved. All existing quantitative indicators are far from characterizing such a scientific state. Only quite vague conclusions are drawn: If, for example, a new scientific method is cited highly, the usefulness of the method is presumed. But the improvement is neither measured in a technometric-like way nor any input-output relationship to study efficiency is established so far.

Conclusions

The purpose of the scheme parts of which I discussed is to stimulate an integrated view of the working of information infrastructures and personnel and a debate how to include this in a systematic manner, of course with concern to all statistical information which is available (and which is not available, but desirable) on that infrastructure. It would be a subject of a philosophical dissertation, in my eyes, to establish such an integrated view. And of an additional pioneering dissertation to investigate possible correlations between indicators of information work and informational infrastructure, on the one hand, and other science and technology indicators as they are outlined in the scheme, on the other hand. This should be done considering a longer period of historic time. It would not be a work of only historical interest, because systematic insights into macroscopic features of knowledge production lure.

Bibliometrics must not solely be understood as a service for science and technology. Not only can information specialists in libraries and documentation centers enrich the system of indicators through suitable statistics of their institutions. Moreover, they are called upon to play a more active and substantial role in the discussion and further development of bibliometrics because many of them are not only experts for media and information tools, but in addition subject experts. Bibliometrics is intricate if details of publications, databases, publication market and a specialty's publication behaviour have to be considered together. Thus, German Information Professionals could outplay their educational strength and join bibliometrics and scientometrics to the same extent as many collegues abroad.

But apart from the service side of bibliometrics, there is also much interesting theoretical work to be done, not only on the level of indicator building. To understand scientific progress as a process of information and knowledge production and diffusion, the topic of Erhard Oeser's oevre;[6] the understanding and interpretation of technological progress as a process of information accumulation brought forward by the economist Werner Pfeiffer many years ago in a thorough treatise;[7] the interpretation of science in terms of a "cognitive economy", as N. Rescher did some years ago[8] – all that is potentially connected with bibliometrics and scientometrics, and all that is only in the beginning, as far as I can see. The increasing current interest in improving foresight capabilities with the help of bibliometric and scientometric approaches sheds light on another aspect of the use of differentiated indicators.[9]

In any case, the idea of quantitative analysis of information processes has old roots in Germany even in the so-called Geisteswissenschaften, even in the 19th century where Wilhelm Dilthey was an outstanding humanities scholar, well-known until today, but certainly not as an advocate of statistics in humanities. In 1883, once he stated the following:

"Von der Epoche der Geschichte ab, in welcher der Bücherdruck auftritt [...], sind wir durch die Anwendung der statistischen Methode auf den Bestand der Bibliotheken imstande, die Intensität geistiger Bewegungen, die Verteilung des Interesses der Gesellschaft in einem bestimmten Zeitintervall zu messen".[10]

("From the inception of book printing on [...], through application of the statistical method we are able to measure the intensity of intellectual movements, the distribution of interests of a society for a certain time interval".)

But he was not the only German humanities scholar with such a far-sighted assessment. Fourty years later, an ecclesiastical historian and theologist, and among others, president of the former "Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften" (the precursor of the Max-Planck-Society), also director of the "Preußische Staatsbibliothek", coined the apercu on library science to belong to national economics in a special sense: in the sense of a cognitive economy.[11] I would like to add that an economical approach must not be confused with a commercial approach. Rather, with his apercu Adolf von Harnack obviously anticipated most important modern currents of thinking on science, and I find it adequate and attractive also from this pivotal point to let bibliometrics come in.

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This paper is an edited version of the author's contribution to the conference "Bibliometric Analysis in Science and Research" held in Jülich (Germany), on 5-7 November, 2003.

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