Handbook of Quantitative Science and Technology Research

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The Use of Publication and Patent Statistics in Studies of S&T Systems

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Preface

This handbook offers a state-of-the-art overview of quantitative science and technology research. It focuses on the development and application of indicators derived from data on scientific or scholarly publications and patents. It comprises 34 chapters written by leading specialists in the various sub-domains. These chapters deal with theoretical and methodological issues, illustrate applications, and highlight their policy context and relevance. Authors present a survey of the research topics they address, and show their most recent achievements.

The 34 chapters are arranged into 5 parts: Disciplinary Approaches; General Methodology; The Science System; The Technology System; and The Science–Technology Interface. The Editor's Introduction provides a further specification of the handbook's scope and of the main topics addressed in its chapters.

This handbook aims at four distinct groups of readers:

– practitioners in the field of science and technology studies;
– research students in this field;
– scientists, scholars and technicians who are interested in a systematic, thorough analysis of their activities;
– policy makers and administrators who wish to be informed about the potentialities and limitations of the various approaches and about their results.

The current handbook can be considered as the successor of the Handbook of Quantitative Science and Technology Studies edited by Anthony van Raan and published in 1988 (Amsterdam: North-Holland).

We are most grateful to all contributors to the handbook for their enormous efforts to provide us with a series of excellent papers. We wish to thank Suze van der Luijt, Ed Noyons, and Renald Buter (CWTS) for their help in the technical editing process and in the preparation of the handbook's Subject Index.

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Henk F. Moed, Wolfgang Glänzel, and Ulrich Schmoch

EDITORS' INTRODUCTION

Henk F. Moed, Wolfgang Glänzel, and Ulrich Schmoch

This handbook deals with the quantitative study of the science and technology system from a global perspective. It provides a state of the art of the development and application of indicators for that system that are derived from publications, particularly — though not exclusively — from the scholarly literature and the patent literature. The science and technology (S&T) system comprises a wide range of activities from basic, or fundamental, science or scholarly activity, via strategic or application oriented research, to applied research and developmental activities aimed at the production of new products and processes. It can be conceived as a part of the various national or regional innovation systems.

During the course of the twentieth century, particularly after the Second World War, science and technology have become driving forces in society and vehicles of economic growth and development. The more important they became, the more the need was recognised to monitor their development, to examine the conditions under which they reach an optimal performance, and to formulate and carry out policies aimed at enhancing its performance and setting its priorities.

Science and technology policy and management — at the level of research group leaders, company technology managers, research programme managers, institutional directors, funding agencies, or at a regional, national or even supra-national political agencies — is itself scholarly based. In order to be effective, policy measures and decisions should be informed, and based upon proper insight into the functioning of the S&T system.

The contributions to this handbook reflect a wide variety of attributes of the S&T system that are relevant in such policies and numerous methodologies assessing such attributes. Central concepts are scientific or technological performance, and productivity or efficiency of the S&T system and its constituent parts. Crucial research questions are: how performance or

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productivity could be measured; how the various parts in an S&T system react one with another; how this interaction influences the overall performance; whether there are significant differences in performance amongst parts and how such differences can be explained.

The general issue that all studies deal with — most explicitly, some more implicitly — is the identification of factors or conditions which may positively or negatively effect the S&T system's performance defined broadly in terms of the needs and criteria expressed by the societies in which they are embedded. An overview of all contributions is presented in Table 1 at the end of this chapter.

This handbook presents analyses at the level of individuals, research groups, researcher networks, institutions, and at a regional, national and even supra-national level. Important attributes related in the various contributions to performance or productivity are: the availability of scientific–technological information; quality control mechanisms in knowledge production processes; internationalisation and globalisation; collaboration; knowledge networks and knowledge flows; multi- or interdisciplinarity; knowledge specialisation and integration; and participation of women.

In addition, several contributions discuss the wider policy and political context in which S&T indicators are actually used. Important aspects are criteria and conditions for a proper, informed use of indicators in performance assessments, and the possible effects that application of such indicators in assessments or funding procedures may have upon scholars and technicians subjected to such assessments.

As indicated above, this handbook primarily relates to indicators derived from scholarly publications and patents. A most important data source for analysis of the science system is the *Science Citation Index* (SCI) and related Citation Indexes published by the *Institute for Scientific Information* (ISI–Thomson Scientific, Philadelphia, PA, USA), or, in a more recent version, ISI's *Web of Science*. Once citation indexing became available for bibliographic research, it was apparent that they could be used to answer inquiries into the nature of scholarly activity: how it is structured; how it develops and how its actors perform. Garfield expressed this as follows:

> "If the literature of science reflects the activities of science, a comprehensive, multidisciplinary citation index can provide an interesting view of these activities. This view can shed some useful light on both the structure of science and the process of scientific development" (Garfield, 1979, p. 62).

As pointed out by Lionel Nesta and Pari Patel in this handbook, a patent is a legal instrument which confers a temporary monopoly of an invention in exchange for the publication of its details. Thus a patent has two functions: it protects the invention; but at the same time it disseminates knowledge about it. A patent can therefore be conceived as a publication which makes scientific–technological content public, similarly to a research article in a scientific journal. As discussed by Elise Bassecoulard and Michel Zitt in their contribution, scholarly publications and patents as formal information sources have many features in common. Similarly to the relation between publications and science, patents are used in the construction of indicators of trends, performance and structures in technological activity.

The development of S&T indicators takes place in various disciplinary contexts. The disciplinary approaches most prominently represented in this handbook use methods adopted from *physics*, *economic sciences*, *sociology*, *history of science and technology* and *information and communication science*, respectively. The first part of the handbook presents a number of contributions which illustrate such approaches, and may in this sense be seen as exemplifications.

A first disciplinary approach is that of *physics*. This approach has a long tradition in quantitative science and technology studies. Science and technology are conceived as a physical system of interacting sub-units the behaviour of which can be described by more general laws analogously to physical laws. In the first chapter ***Anthony van Raan*** reviews recent studies adopting this approach that are inspired by modern developments in the physics of non-linear phenomena. Van Raan also gives a thorough survey of main methodologies applied in the measurement of scientific activity.

A second disciplinary approach is that of *economics or econometrics*. It considers activities in the S&T system essentially as an economic activity in which the consumption of essentially scarce input resources leads to a number of identifiable scientific or technological ‘outputs’. Patenting is particularly conceived as an economic act. ***Andrea Bonaccorsi*** and ***Cinzia Daraio*** review and discuss the use of econometric methods in the study of the S&T system, and focus on the concept of productivity. They conceive S&T production as a non-deterministic, multi-input, multi-output relation, in which both inputs and outputs are not only qualitatively heterogeneous but also sometimes truly incommensurable.

Hariolf Grupp and ***Mary Mogee*** apply an economic policy approach and describe the increasing use of S&T indicators in the context of national policies, with a focus on the United States and Europe, and critically discuss the appropriateness of composite indicators, national benchmarking, and scoreboarding.

A third disciplinary approach is of *sociology* focussing either on social relationships and activities within the S&T system or on the relationships between this system and the wider socio-political environment. Activities of the various actors in the system are essentially conceived as social acts that are studied in their broader social context. This is also true for scholars' publication and referencing practices.

In order to be really informative, and particularly to constitute a sound basis for S&T indicators, scientific publications must meet professional standards. *Gatekeepers*, that is, the members of the editorial and advisory boards of science journals occupy powerful strategic positions in the collective activity of science. In a sociological study of the science system, ***Tibor Braun*** discusses characteristics of the journal gatekeeping system aimed at ensuring such standards.

Rémi Barré analyses the changing relationships between the S&T system and society in general, and highlights their implications for the role of science and technology indicators and their producers in S&T policy-making processes.

A fourth disciplinary approach is the *history of science and technology,* adopting a historical or evolutionary perspective. Bibliometric indicators can be used to trace developments in scholarly disciplines or technological areas and identify key events that can be used as reference points. As such, they are tools for a historian of science and technology for obtaining a historical account of such developments and for relating such developments to other factors from their wider socio-political or economic environment. The contribution by ***Birgitte Andersen*** represents an example of this approach. It aims to identify and measure changes in technological opportunities during the last century in order to trace the evaluation of their trajectories governed by technological 'paradigms'. This perspective is, of course, closely linked to evolutionary economics as well.

Information and communication science constitutes the fifth disciplinary approach represented in this handbook. It analyses how scholars or technicians in any field use and disseminate information through formal and informal channels, and identifies patterns or structures of the communication system. A bibliometric viewpoint thus focuses on scholarly or technical texts or documents. The contribution by ***Subbiah Arunachalam*** highlights the crucial importance of having access to up to date scientific and technical information, particularly for S&T practitioners in developing countries. In relation to this he presents an overview of current developments which could make access to information for scientists in those countries more affordable, including the emergence of open access journals and e-print archives.

The contributions in the subsequent parts of the handbook — although equally important and informative — apply elements from several disciplinary approaches rather than one, or use other disciplines not mentioned above, and structure these either within a particular methodology or within specific attributes or sub-systems of the S&T system. These contributions were grouped into four parts on the basis of their main emphasis: *methodological contributions*; and contributions specifically dealing with the *science system*, the *technology system*, and the *science and technology interface*.

The series of primarily methodological chapters starts with a contribution by ***Edda Leopold***, ***Michael May*** and ***Gerhard Paass***, who provide a general introduction to data and text mining techniques which are useful for analysing large publication and patent databases. Such techniques combine elements from mathematical statistics, machine learning, and information retrieval. The authors present several examples, including one regarding authorship attribution, i.e., classifying documents according to whether they were authored by a specified person or not.

A next contribution deals with issues in patent analysis. Many papers using patent statistics do not accurately define the methodology that was applied. As a consequence different studies on the same topic sometimes produced contradictory results. ***Sybille Hinze*** and ***Ulrich Schmoch*** illustrate how the outcomes of patent analysis depend upon the way in which time scales are defined, the country of origin is identified, patent offices are selected, a patent's quality is measured, and search strategies are conducted. They suggest preferred methodologies and thus contribute to a further standardisation in the field of patent analysis.

The S&T system comprises a wide range of cognitively or technically distinct activities. In order to differentiate and analyse its internal subject heterogeneity analyses of the system should apply adequate subject or content classification systems. Particularly must scientific papers and patents be assigned to scientific disciplines or sub-fields, or grouped into classes on the basis of technical specifications.

Most studies apply existing classification systems, for publications based on a journal category system developed by ISI, and for patents the International Patent Classification (IPC) System. ***Ed Noyons*** illustrates in his contribution how accurate, tailor made subject classifications of documents can be generated, particularly at the level of research topics or specialities. He reviews the potentialities of mapping and data-analytical methods applied in co-word and co-citation analysis, and shows how groupings or clusters obtained can be evaluated in terms of their main actors and the institutions to which they are affiliated.

Collaboration and globalisation are important features of the S&T system. ***Wolfgang Glänzel*** and ***András Schubert*** focus on the science system and show how these phenomena can be studied by analysing co-authorship in scientific publications. They review earlier work on this topic, and present illustrative analyses at the level of individual scientists and that of countries. They depict the global network of science, and discuss empirical, bibliometric findings in terms of the effects that international scientific collaboration may have upon scientific research performance.

A recent development in patent statistics is the renaissance of citation analysis. Citations reflect relations in terms of content and social context and can be used for constructing quality measures. But as derived, indirect indicators they have to be interpreted with caution. ***Bhaven Sampat*** and ***Arvids Ziedonis*** critically examine the motives and functions of patent citations and develop a more differentiated concept of the economic value of patents. Using the example of university patents, they illustrate the different dimensions of value and show a significant relation between patent citations with respect to the probability of licensing.

The participation of women in the S&T system has gained substantial interest and policy relevance during the past decades. ***Fluvio Naldi***, ***Daniela Luzi***, ***Adrianna Valente***, and ***Ilaria Vannini Parenti*** present a methodology that provides a gender classification of authors of scientific publications and inventors of patents, based on their first names. Thus indicators can be calculated of the participation of women in publishing or patenting networks.

Measurement of productivity relates inputs of the S&T system to outputs. Therefore input statistics on spending and human resources are essential elements in a comprehensive system of S&T indicators. ***Marc Luwel*** presents in his contribution a review of the efforts made by the international organisations OECD, UNESCO, and EUROSTAT to generate standardised statistics on R&D input, and discusses major methodological issues. He notes that attempts to calculate per scholarly field productivity measures relating these input measures to output indicators are hampered by the two types statistics giving aggregate measures based on different subject classification systems.

Scientific journals and patents constitute by far the most important data sources in quantitative studies of the S&T system presented in this handbook During the past decade the World Wide Web has become a most important general source of information. More and more scientific and technological information, including publications, are made available and actually retrieved through the web. In addition, bibliometric methods play an important role in the quantitative study of the web, denoted as webometrics.

Therefore the final contribution in the methodology part deals with issues of webometric studies. Peter Ingwersen and Lennart Björneborn wrote it. The authors discuss problems of data collection from the Web, typologies of Web links and numerous conceptual questions. The contribution also briefly addresses Web 'impact factors' that bear some resemblance to the well-known journal impact factors published by the *Institute for Scientific Information*.

This handbook's part on the **science system** starts with a contribution by ***Thed van Leeuwen*** on the measurement of academic research performance. He critically discusses academic research assessment exercises carried out in the Netherlands and in the UK, and highlights potentialities and limitations of the use of bibliometric indicators in such assessments. He discusses conditions for proper use of bibliometric indicators in research performance assessments.

Linda Butler investigates changes in the publication behaviour of scientists that the consistent use of bibliometric indicators in the policy domain may induce. She gives a critical view on the effects of such policies for academic output on the example of Australian where a composite index encapsulating a number of performance measures — such as graduate student numbers or completion rates, research income and publication activity — is used to allocate the research component of university block funding.

Michel Zitt and ***Elise Bassecoulard*** present a multi-faceted chapter on internationalisation and globalisation of scientific communication. The authors identify the main engines of science internationalisation, and discuss internationalisation measures applicable to bibliometrics. Internationalisation is studied in terms of journal profiles as well as in the context of scientific collaboration and other networks of interdependencies in science. The authors finally discuss the distribution of knowledge production in the context of internationalisation and the issue of convergence as possible consequence of globalisation.

The increasing mutual dependence amongst science disciplines requiring knowledge flow beyond disciplinary boundaries as well as the fading frontiers between science and technology request increasing attention from all possible perspectives.

The chapter by ***Maria Bordons, Fernanda Morillo*** and ***Isabel Gómez*** provides a bibliometric review of interdisciplinarity in science. Interdisciplinarity is described as the emergence of a new mode of knowledge production, which coexists with the traditional disciplinary science. They analyse, among others, the trend towards interdisciplinarity in scientific research, field-specific characteristics in the context of cross-disciplinary activity, the effect of interdisciplinary research on the relationship among disciplines, and the interaction of interdisciplinarity and bibliometric performance indicators.

Citation analyses are standard methods in bibliometric literature. Conventional bibliometric analyses, however, measure the impact of scientific papers within the research community, in particular, through citations from other scientific papers in the serial literature. In order to provide new indicators of the utility of biomedical research ***Grant Lewison*** studies citations to research papers from different document types, such as clinical guidelines, textbooks, government policy documents, international or national regulations and newspaper articles.

Most studies presented in this handbook relate to the natural sciences, life sciences, and technical sciences. Other domains of human scholarship are discussed by ***Diana Hicks***, who presents a review of methodologies aiming at assessing research performance in social sciences and humanities. Her premise is that bibliometric assessments of research performance in these fields face severe methodological problems. In these fields she identifies four types of literatures, briefly denoted as international journals, books, national journals and the non-scholarly press. She concludes that ignoring the latter three types may produce a distorted picture of social science fields.

During the recent reform of the Chinese scientific system, quantitative evaluation has been introduced into research management and decision making related to national S&T. The number of Chinese publications indexed by the *Science Citation Index* (SCI) has spectacularly increased in the last decade. Nevertheless, most Chinese research results are still published in domestic journals not covered by this database. Therefore, it was decided to develop their own local, Chinese citation indexes. ***Bihui Jin*** and ***Ronald Rousseau*** give a survey of the use of both, the SCI and the Chinese database for the evaluation of national research performance in China.

Macro-indicators, especially national science indicator are standard tools in evaluative bibliometrics. They provide a prompt and comprehensive picture on national research output in science fields under study. But what if trends reveal a decline of national research performance? ***Olle Persson*** and ***Rickard Danell*** show that the breakdown, the *decomposition* of national indicators helps to identify those actors who are most concerned by negative trends, and might support appropriate and targeted policies. They conduct research at different levels of aggregation, particularly at the level of research institutions, research groups, and individual authors. The decomposition method is applied to Swedish neuroscience papers.

The quantitative analysis of trends, performance and structures in technology is a complex task owing to the large variety of technical artefacts and processes. Many studies refer to rather indirect indicators such as foreign trade, labour force, or investment in R&D-intensive sectors. Grupp (1992) suggested, with reference to specific technologies, collecting specification measures and deriving integrated indicators; he labelled this approach as ‘technometrics’. The papers related to technology in this handbook exclusively refer to the use of patent indicators which proved to be a very flexible and powerful analytical tool. Since patent documents were easily accessible through electronic databases, many scholars used patent indicators for different purposes. However, the statistical analysis of patents did not develop to an independent sub-discipline comparable to publication statistics. Hence the term ‘patentometrics’ suggested by some authors as equivalent to ‘bibliometrics’ did not become generally accepted.

Patent analyses are not always employed for assessing technology. In particular, in economics the appropriateness and efficiency of the patent system itself is often investigated by means of patent indicators. In this handbook, we focus, rather, on their use for quantitatively analysing technology, and the editors are well aware that some important approaches based on patent indicators are not considered.

Patent indicators provide a favourite tool for analysing the technological performance of countries in a differentiated way. In this context ***Lionel Nesta*** and ***Pari Patel*** suggest a novel indicator combining the analysis of present performance and specialisation with a dynamic perspective. In addition they give a short and comprehensive introduction into the advantages and shortcomings of patent statistics on the country level.

Various scholars have shown on the macro level that in recent decades technology is a major driving force of economy. However, it is quite complex to show the linkage between technological and economic performance on the level of enterprises. In their contribution ***Francis Narin***, ***Anthony Breitzman***, and ***Patrick Thomas*** give convincing evidence that the technological performance of firms measured by patent indicators has a relevant impact on their stock market value. For that purpose they refer to a combined index, which primarily refers to different dimensions of quality rather than pure quantity.

Patent indicators are not only useful at the macro level of countries, but are strategic instruments of firms for assessing the technological orientation and performance of competitors and to benchmark their own competence. In this handbook this type of analysis is represented by two contributions with different approaches. Both chapters illustrate that patents are an important source of strategic information for firms.

Koenraad Debackere and ***Marc Luwel*** present benchmark indicators to assess the technological strengths and weaknesses of companies taking up characteristic elements of economic portfolio analysis. ***Alan Porter*** and ***Nils Newman*** collect a broader set of more straightforward, but informative indicators from patent databases for generating competitive intelligence for technology managers. They highlight the relevance of a careful match of the selected indicators to the specific needs of the users, so that the close interaction of data producers and users is important.

A next contribution addresses novel aspects in the use of patent citations. ***Stefano Breschi*** and ***Francesco Lissoni*** use patent citations for identifying social relations and empirically describing social networks. In their contribution they discuss in detail the methodological appropriateness of this approach and demonstrate its validity by the example of Italian patent applications.

The internalisation of the economy has different aspects such as the increasing foreign trading with technology-intensive goods, production in foreign countries, or the growing R&D activities in foreign countries. As to the latter aspect, the available statistics are sketchy, hardly comparable, and only coarsely differentiated by sectors or fields. ***Dominique Guellec*** and ***Bruno van Pottelsberghe de la Potterie*** impressively show how patent analyses can be used to examine different forms of knowledge flows and thus of the internationalisation of technology.

The last part of the handbook deals with the science and technology interface. ***Elise Bassecoulard*** and ***Michel Zitt*** review various ways of studying this interface. Next, they explore the possibility of relating science and technology on the basis of lexical linkages between articles and patents. It is generally recognized that standard scientific publication and patent subject classification systems do not match. Therefore, the authors particularly examine the possibility of creating correspondence tables between these two types of systems using these lexical linkages.

Robert Tijssen presents a review of the study of the interactions and knowledge flows between science and technology, and focuses on two methodologies. The first is based on citation flows and analyses citations made in patents to the scientific literature and also those from scientific papers to patents. The second can be denoted as a person oriented approach and deals with scientists–inventor relationships, assessing the extent to which authors of scientific publications act as inventors in patents.

Ulrich Schmoch analyses the patent applications of scientific institutions as a proxy for their direct contribution to technology. He shows that these institutions focus their activities on knowledge based fields and that their participation therein is much higher than often assumed.

Stefano Brusoni and ***Aldo Geuna*** approach the S&T interface from an opposite perspective by looking at the science reference of firms in the pharmaceutical sector. For that purpose they analyse the citations in patents to scientific publications. By indicators of specialisation and integration they characterise the different pattern of performance and orientation of the firms analysed. In addition, they apply this multi-dimensional description to characterise the performance of countries.

The discourse on the interaction of science and technology primarily refers to the situation in advanced industrialised countries. In contrast to this general trend, ***Eduardo da Motta e Albuquerque*** examines this topic for less developed countries by using patent and publication indicators. He demonstrates that these indicators are also useful for characterising these countries, and by more detailed investigations for specific countries, he can derive structural indicators supporting the conception of adequate innovation policies.

The current handbook can be considered as the successor of the *Handbook of Quantitative Science and Technology Studies* edited by Anthony van Raan and published in 1988. It is tempting to compare the contents of the two handbooks and to identify major trends in the field during the past 16 years, assuming that both handbooks adequately reflect the state of the art in the field at the time they were published.

A major trend is that publication and patent data have become more widely available for publication analysis and construction of indicators. This reflects developments in information technology during the past two decades. Nowadays large publication and patent databases are available, under certain restrictions, in electronic form. As to publications, the *Science Citation Index* and related Citation Indexes published by the Institute for Scientific Information (currently Thomson Scientific) is the most important database. Many other databases in specific areas are available, most of them, however, without recording citations. As to patents, the major patent offices such as the *US Patent and Trademark Office* or the *European Patent Office* have supported the distribution of patent information through various channels. The launch of electronic information on CD-ROMs stimulated its use for analytical purposes. Many large publication databases and patent databases are currently available through online services, and on CD-ROM, bibliometric macro indicators at the level of countries and scholarly subfields can be purchased as standard indicator products.

In the 1980s there were only three integral 'bibliometric' versions of the complete ISI Citations indexes, at ISI and at CHI Research, both located in the U.S., and in Europe at the Hungarian Academy of Sciences. Nowadays several other institutions have such integral versions — or huge extracts from them — that they can use under a number of conditions for large scale bibliometric analysis. This is clearly reflected in the contributions in the current handbook by authors affiliated with these institutions.

At the end of the eighties a broad part of the discourse on indicators focussed on methodological issues, reflecting a latent uncertainty regarding their meaningfulness. Many scholars had no appropriate ideas of how to react to the demand of users for the application of indicators in a policy context. Since that time many experiences have been made of the appropriateness and the practical use of indicators. Today publication and patent indicators tend to be more tailor made, and they are more often designed for answering particular research questions. Indicators appropriate in one research or policy context may be less so in other contexts, and may have to be substituted by other more sophisticated counterparts showing more detail or arranging sub-units from analysed systems in a different way.

If there is any general trend at all in the topics addressed in the various science studies, it is one that reflects a shift from a sociological towards an economic perspective, or from an emphasis on the science system's internal functioning and performance criteria towards an emphasis on the science system's potential technological and economic utility, and on the relationship between science, technology and innovation. Similarly, current technology studies tend to focus more on the technology's science base and on its economic role and value.

Finally, the role of S&T indicators in evaluation and decision making processes in the policy domain has become more prominent. Indicators are not only more frequently produced and more easily available, but are also more frequently used in recent years than they were some 15 years ago. As a consequence several contributions in the handbook propose criteria for their proper use in the sphere of policy, assess the political dimension of S&T indicators, and reflect upon its implications for practitioners in the fields of science and technology studies.

Table 1. Chapters in the Handbook

Attributes; policy context	*Disciplinary approaches; methodologies; types of indicators*	*Authors*
Disciplinary Approaches		
Measuring science	Historical–methodological overview; physical approach	van Raan
Productivity of S&T systems	Econometric, nonparametric approach	Bonaccorsi and Daraio
Use and misuse of S&T indicators for national SD&T policy	Economic policy approach	Grupp and Mogee
Journal gate keeping system	Sociological approach	Braun
S&T policy processes; political dimension of indicators	Socio-political approach	Barré
Technological paradigms and long term trajectories	Economic–evolutionary approach using patent data	Andersen

Attributes; policy context	*Disciplinary approaches; methodologies; types of indicators*	*Authors*
Access to S&T information for developing countries	Information–scientific approach with emphasis on Open Access	Arunachalam
General Methodology		
Data and text mining	Statistical, machine learning, and information retrieval approaches	Leopold, May and Paass
Basic characteristics of patent data	Patent time scale, country of origin, office, quality and search strategies	Hinze and Schmoch
Socio-cognitive structures in S&T activities	Mapping techniques; co-word, co-citation analysis	Noyons
Scientific collaboration; globalisation	Co-authorship links; multinational research articles	Glänzel and Schubert
Economic value of patents	Patent citation analysis	Sampat and Ziedonis
Participation of women in S&T	Use of first names of authors or inventors for gender classification	Naldi, Luzi, Valente and Vannini Parenti
R&D input data	Efforts by OECD; combination with macro bibliometric indicators	Luwel
Studying the World Wide Web	Data collection; link typologies; conceptual issues; impact factors	Ingwersen and Björneborn
The Science System		
Academic research performance	Conditions for proper use of indicators in research assessments	van Leeuwen
Effects of funding formula upon scientists' publication practices	Use of publication counts in Australian academic funding	Butler
Internationality of science	Journal internationalisation indexes; international co-authorships; disciplinary specialisation profiles	Zitt and Bassecoulard
Multi- and inter-disciplinarity of research	Co-classification of journals; cross-disciplinary co-authorships and citations	Bordons, Morillo and Gómez

Attributes; policy context	*Disciplinary approaches; methodologies; types of indicators*	*Authors*
Practical effects of biomedical research	Citations from clinical guidelines, textbooks, regulations and newspapers	Lewison
Performance in social sciences and humanities	Publication analyses of four types of literatures	Hicks
Chinese science system	Publication based indicators from ISI and Chinese Citation databases	Jin and Rousseau
Scandinavian science system	Breakdown of macro indicators in terms of institutions and authors	Persson and Danell
The Technology System		
Performance of national innovation systems	Patent performance and dynamics by country and by technology sector	Nesta and Patel
Technological and stock market performance	Patent and stock market statistics by company	Narin, Breitzman, Thomas
S&T portfolio management of companies and regions	Patent statistics measuring relative technological specialisation	Debackere and Luwel
Competitive technical intelligence for company managers	Manipulating information from patent databases	Porter and Newman
Knowledge networks in technological innovation	Patent citations; co-inventions, social network analysis	Breschi and Lissoni
Internationalisation of technology	Foreign inventors of domestic applicants and v.v.; international co-inventorship	Guellec and Pottelsberghe de la Potterie
The Science–Technology Interface		
Correspondence tables between patent and scientific classifications	Lexical linkages between research articles and patents	Bassecoulard and Zitt
Knowledge flows between science and technology	Scientist–inventor relationships; citations from articles to patents	Tijssen
Contribution of public non-profit science institutions to technology	Scientists as inventors of patents in science intensive fields	Schmoch

Attributes; policy context	*Disciplinary approaches; methodologies; types of indicators*	*Authors*
Knowledge specialisation and integration of companies and countries	Publication, citation and patent based indicators of depth and breadth of a knowledge base	Brusoni and Geuna
S&T systems in developing countries	Differentiation of countries using statistics based on patents and research papers	da Motta e Albuquerque

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PART 1: DISCIPLINARY APPROACHES

Chapter 1

MEASURING SCIENCE

Capita Selecta of Current Main Issues

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Abstract: After a review of developments in the quantitative study of science, particularly since the early 1970s, I focus on two current main lines of 'measuring science' based on bibliometric analysis. With the developments in the Leiden group as an example of daily practice, the measurement of research performance and, particularly, the importance of indicator standardisation are discussed, including aspects such as interdisciplinary relations, collaboration, 'knowledge users'. Several important problems are addressed: language bias; timeliness; comparability of different research systems; statistical issues; and the 'theory–invariance' of indicators. Next, an introduction to the mapping of scientific fields is presented. Here basic concepts and issues of practical application of these 'science maps' are addressed. This contribution is concluded with general observations on current and near-future developments, including network–based approaches, necessary 'next steps' are formulated, and an answer is given to the question 'Can science be measured?'

1. TOWARD A METRIC OF SCIENCE REVISITED[1]

From the early sixties onwards we see a strong increase in quantitative material on the state-of-the art in science and technology. National institutes of statistics, UNESCO, OECD, and the European Commission are main examples of organisations starting to collect systematically data on the

[1] The book *Toward a metric of Science: The Advent of Science Indicators* (Elkana et al., 1978) has always been a one of my major sources of inspiration. This contribution to the Handbook is based on earlier publications by the author (Van Raan 2000a; Van Raan and Noyons 2002).

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development of science and technology. An important milestone is the first issue of the OECD 'Frascati Manual' (OECD, 1963), a handbook devoted to the development of a standard practice for surveys of the measurement of scientific and technical activities. At the same time, and strongly related to this data explosion, the quantitative appraisal of current science gains influence. As a genre in the study of the history of science, the quantitative approach of the development of science, 'scientometrics', is certainly not new. A remarkable early piece of work is "Histoire des sciences et des savants depuis deux siècles". The author, Alphonse de Candolle (1873), described the changes in the scientific strength of nations by membership of scientific societies, and he tried to find 'environmental factors' of all kinds (even including the role of the celibate) for the scientific success of a nation. Later, in the 1920s, Lotka (1929) published his famous work on the productivity of chemistry researchers. Here scientometrics is clearly differentiated into 'bibliometrics'.

Undoubtedly the invention of the *Science Citation Index* by Eugene Garfield is a major breakthrough (Wouters, 1999). This invention enabled statistical analyses of the scientific literature on a very large scale. It marks the rise of bibliometrics as a powerful field within the studies of science. Such great scientists as Derek de Solla Price and Robert Merton recognised the value of Garfield's invention, Price from the perspective of contemporaneous history of science, Merton from the perspective of normative sociology.

Scientists are fascinated by basic features such as simplicity, symmetry, harmony, and order. The *Science Citation Index* enabled De Solla Price to start with the development of a 'physical approach' to science, in which he tried to find laws to predict further developments, inspired by the ideas of Newtonian and statistical mechanics. In this perspective, quantitative measures of science, '*indicators',* are guides to find and, as a crucial next step, to understand such basic features. The most basic feature concerns the cognitive dimension: the development of content and structure of science. More on the mundane surface science indicators relate to the social dimension of science, in particular to aspects formulated in questions such as 'How many researchers? How much money is spent on science? How 'good' are research groups? How does communication in science work, particularly what is the role of books, journals, conferences (Borgman, 1990)? And longer than we often realise there is another question: 'What is the economic profit of scientific activities?' A landmark in the development of science indicators is the first publication in a biennial series of the *Science Indicators* Report in 1973. Stimulated by the success achieved by economists in developing quantitative measures of political significance (e.g., unemployment, GNP), the US National Science Board started this indicator report series in which we find more emphasis on the demographic and economic state of science than on the cognitive state of science (National Science Board, 1973).

Making quantitative indicators of anything thinkable fascinates some people and horrifies others as being nonsense and taking us back to the cabbalistic magic number world of Paracelsus. But there are famous classical pronouncements to support the attempt to measure things. Horace (65–5 BC): “There is a measure in all things” (Est modus in rebus), Johannes Kepler (1597): “The mind comprehends a thing the more correctly the closer the thing approaches toward pure quantity as its origin”, and, from the place where I live and work, Leiden, the discoverer of superconductivity, Heike Kamerlingh Onnes (1882): “Measuring is knowing”.

There is no final theory of science providing *the* methodology of measurement. It is a returning hype in the social studies of science to incite the scientific community with this observation. But are we really troubled by this poverty of theoretical content? I don’t think so (van Raan, 1997). Do not expect a classical mechanics of scientometrics. With very high probability: it does not exist. The absence of any explicit theory to guide the making and use of indicators may not be good, but the adoption of a single one, for instance, a trendy dominating ‘theory’, is likely to be worse (Holton, 1978). It is normal practice in empirical science to begin a search without a theoretical clarification and try to establish a model to explain the findings later. Certainly in such measurements we do have at least implicit basic ideas about ‘how things work’ and the same is true for the construction and use of science indicators. Therefore it is crucial to make these implicit assumptions clear to the outside world. This will allow us to turn the absence of a general theory of the development of science into a very profitable situation, in the words of Gerald Holton: ‘perhaps indicators may be developed eventually that are *invariant* with respect to theoretical models. They and only they allow rival theories to be put to empirical tests’. To put it more bluntly: we cannot develop a sound theoretical model of the ‘sociology of knowledge’ yet, as we simply need more empirical work based on the richness of available and future data in order to develop a better quantitative understanding of the processes by which science and society mutually influence each other’s progress. In this contribution I will argue that advanced bibliometric indicators approach the above characteristic of invariance.

What is the difference between data and indicators? An indicator is the result of a specific mathematical operation (often simple arithmetic) with data. The mere number of citations of one publication in a certain time period is *data*. The measure in which such citation counts of all publications of a research group in a particular field are normalised to citation counts of all publications worldwide in the same field, is an *indicator*. An indicator is a measure that explicitly addresses some assumption. In our example the assumption is: this is the way to calculate the international scientific influence of a research group. So, to begin with, we need to answer the question: what features of science can be given a numerical expression? Thus indicators can not exist without a specific goal in mind, they have to address specific questions, and thus they have to be created to gauge important 'forces'; for example, how scientific progress is related to specific cognitive as well as socio-economic aspects. Indicators must be problem driven, otherwise they are useless. They have to describe the recent past in such a way that they can guide us, can inform us about the near future. A second and more fundamental role of indicators is their possibility to test aspects of theories and models of scientific development and its interaction with society. In this sense, indicators are not only tools for science policy makers and research managers, but also instruments in the study of science. But we also have to realise that science indicators do not answer typical epistemological questions such as: How do scientists decide what will be called a scientific fact? How do scientists decide whether a particular observation supports or contradicts a theory? How do scientists come to accept certain methods or scientific instruments as valid means of attaining knowledge? How does knowledge selectively accumulate? (Cole et al., 1978).

De Solla Price (1978) strikingly described the mission of the indicator maker: find the most simple pattern in the data at hand, and then look for the more complex patterns which modify the first. What should be constructed from the data is not a number but a pattern, a cluster of points on a map, a peak on a graph, a correlation of significant elements on a matrix, a qualitative similarity between two histograms. If these patterns are found the next step is to suggest models that produce such patterns and to test these models by further data. A numerical indicator or an indicative pattern, standing alone, has little significance. The data must be given perspective: the change of an indicator with time, or different rates of change of two different indicators. Crucial is that numerical quantities are replaced by geometrical or topological objects or relations (Ziman, 1978).

We know already from the early indicator work that these 'simple patterns' exist: the rank of countries by the number of publications is remarkably stable from year to year (Braun et al., 1995). The absolute size of the scientific research activity in the number of publications of any nation is in very good agreement with its electrical power consumption in kilowatt-hours, indicating that scientific power, economic power, and national wealth are strongly related.

More or less at the same time as the above thoughts on the metric of science, Francis Narin coined the concept of 'evaluative bibliometrics'. His pioneering work on the development of research performance indicators (Narin, 1976, 1978), mainly on the macro level, i.e., the performance of countries, was a new, important breakthrough which contributed substantially to the measurement of scientific activities. In 1978 Tibor Braun founded the journal *Scientometrics*. This event marks the emancipation of the field of quantitative studies of science. Also in journals such as *Research Policy* and the *Journal of the American Society for Information Science* we find more and more publications about 'measuring science', and most of them are on topics that are still very relevant. We mention, without being exhaustive, the seminal papers in the 1970s on the development of 'relational' methods such as co-citation analysis for the mapping of scientific fields (Small, 1973), on scientific collaboration by deB. Beaver and colleagues (Beaver, 1978), on measuring the growth of science (Moravcsik, 1975; Gilbert, 1978), the meaning of citation patterns for assessing scientific progress (Moravcsik and Murugesan, 1978), and on mobility in science (Vláchy, 1979).

In the early eighties we see the rapid rise of co-citation analysis (Small and Greenlee, 1980; Sullivan et al., 1980; Price, 1981; White and Griffith, 1981; Noma, 1982; McCain, 1984) and of co-word analysis (Callon et al., 1983; Rip and Courtial, 1984), an increasing emphasis on advanced statistical analysis of scientometric parameters (Haitun, 1982; Schubert and Glänzel, 1983), the application of bibliometric methods in the social sciences (Peritz, 1983), indicators of interdisciplinary research (Porter and Chubin, 1985), and comparison of peer opinions and bibliometric indicators (Koenig, 1983).

An important further breakthrough was the work of Martin and Irvine (1983) on the application of science indicators at the level of research groups. Around the same time (the beginning of the eighties) our Leiden institute had also started with bibliometric analysis oriented on research groups (Moed et al., 1983) and Braun and co-workers focused on the scientific strength of countries in a wide range of research fields (Braun et al., 1988).

Now, almost thirty years after Narin's *Evaluative Bibliometrics*, twenty-five years after the publication of *Toward a Metric of Science: The Advent of Science Indicators* (Elkana et al., 1978), twenty years after Martin and Irvine (1983), and fifteen years after the *Handbook of Quantitative Studies of Science and Technology* (van Raan, 1988) we may state *plus ça change, plus c'est la même chose*. What changed is the very significant progress in application oriented indicator work based on the enormous increase of available data and, above all, the almost unbelievable, compared with the