Handbook of Quantitative Studies of Science and Technology
A.F.J. van Raan (editor)

Chapter 13:

BIBLIOMETRIC INDICATORS FOR ASSESSING STRENGTHS AND WEAKNESSES OF WEST GERMAN SCIENCE

P. Weingart, R. Sehringer and M. Winterhager

Center for Science Studies,
University of Bielefeld,
P.O.Box 8640, D-4800 Bielefeld 1,
Federal Republic of Germany

Summary

Two approaches in the bibliometric study of science are employed to analyze the relative standing of national science systems: time-series indicators of publication and citation counts and co-citation analysis. The former are combined to a "performance indicator". The potential of co-citation analysis for the determination of strengths and weaknesses of science is discussed. Also, the possibility to use both approaches in sequence as well as the limitations of such a coupling are analyzed.

1. Science indicators as measures of research performance

1.1 Science policy functions of research measurement and research evaluation

Until recently statistics of expenditures were the traditional form of performance evaluation and control of government agencies. Not only are they well suited to legitimate government policy but also no unified criteria of evaluation exist for the efficiency control of non-economic service administrations. Thus, in science policy, too, the conviction has ruled so far that its achievements and successes are not susceptible to measuring but can only be grasped in terms of expenditures. In the area of R&D-policy this self-limitation was given additional support by the conviction that measuring success is ruled out in principle because of the indeterminacy and incalculability of the process of discovery and the temporal decoupling of discovery and application. In general as well as with respect to the specific area of R&D-policy this abstinence vis-a-vis a more precise control of the achievement of government action is changing. A series of reasons are responsible for that.

Generally an enormous expansion of governmental services and welfare administration and their factual exemption from public control of performance have led to a growing legitimation crisis. Continuously increasing costs have no counterpart in precise controls of their effects. This deficit of legitimation becomes politically virulent when budgets contract and the internal allocation battle intensifies, which happened at the end of the seventies. A further reason must be seen in the nature of those social sectors which have come under the control of service administrations and in the specific types of interventions and direction which the state has to provide. Education, public health, public transport, social security or family welfare are such sectors each of which calls for specific measures which cannot adequately be counted nor compared by monetary units of input. It is not accidental that the practise of constructing indicators of achievement and success first introduced in the area of economic policy is now being extended to these areas as well. At first the indicator movement has penetrated into the area of social policy with the construction of social indicators.

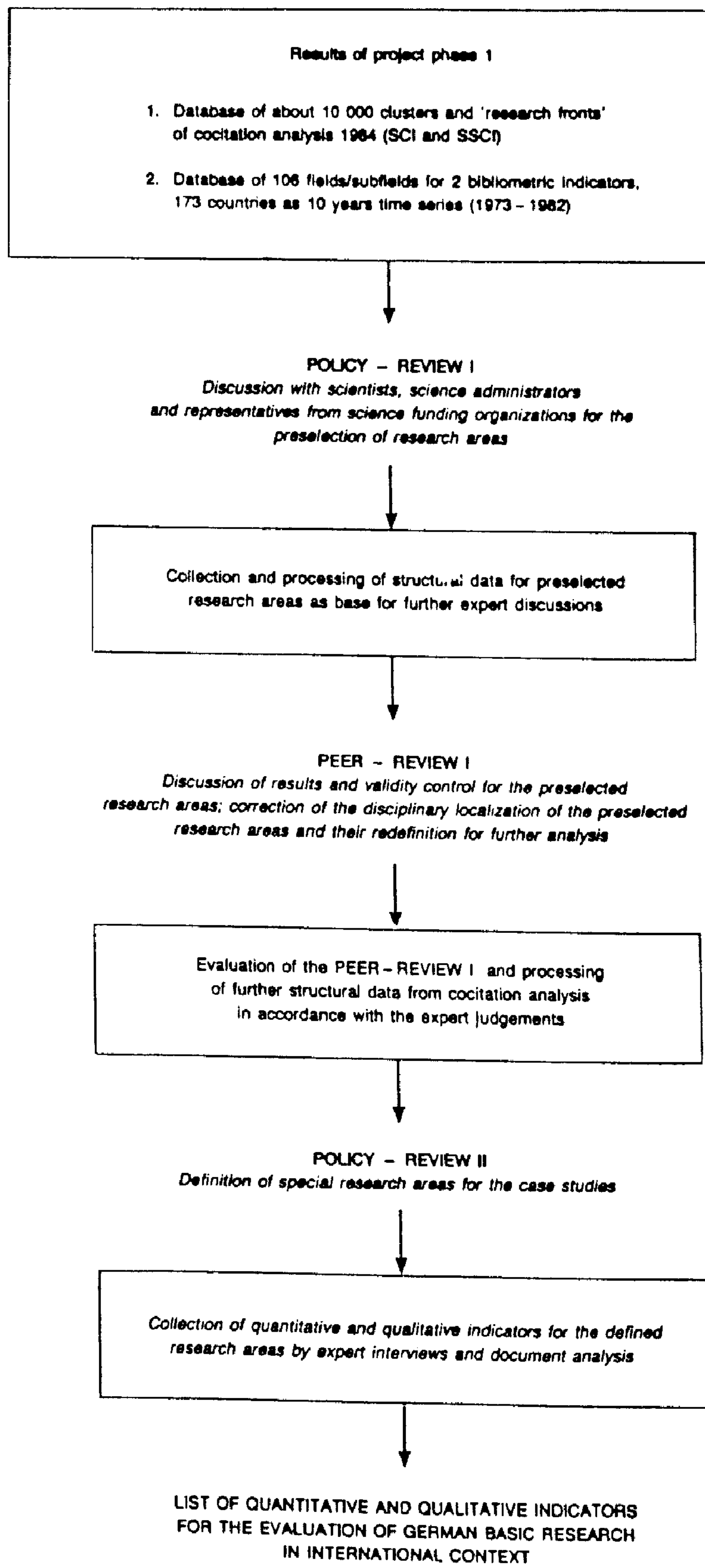
In the area of R&D-policy one reason for the reluctance to measure performance is that only a fraction of governmental expenditures is devoted to the support of basic research for which alone arguments of incalculability can be mustered. Even for this sector it can be said that in highly developed industrialized nations since the institutionalization of a systematic science policy it has been coupled quite closely to the development of technologies and thus to economic strategies. A direction of research is within certain limits very well possible and is being practised de facto by all governments through the allocation of budgets and the definition of priorities. The diagnoses and stock taking, as precise as possible, of the state and the development of technically and economically relevant areas of national basic research thus becomes an important element of R&D-policy. Meanwhile, international comparisons of achievement have become a firmly established element of science policy since in "high-technology-countries" relative advantages in the knowledge industries decide over medium and long-term advantages on the export markets. Deficits in 'high tech' relevant research diagnosed in recent years in the Federal Republic of Germany and other European nations, above all relative to Japan and the United States indicate a higher sensitivity for the relative position in basic research. However, with respect to the diagnoses of such 'deficits' one can note considerable insecurity and even contradictions. Therefore, the construction of science indicators seems to be in line with a general rationale of development.

Pioneer work on the construction of science indicators was carried out in the U.S. by Derek Price and then, though with other intentions, by Eugene Garfield and his Institute for Scientific Information (ISI). Price took the step in the direction of output measures and defined publication activity for basic research as well as patents for technology as "products" of knowledge production. For the purpose of information processing Garfield developed the citation index, first for the natural sciences. It could be used and developed further as a bibliometric tool of measuring achievement. It is important to note this origin because the development of indicators in science has been largely determined by it and the data base of ISI today factually holds a monopoly in the construction of science indicators. All other indicators have to be newly developed at high costs, they do not encompass by far the same amount of information, and they do not allow a broadly defined international comparison. Not surprising, the vast majority of common indicators which are developed by commercial institutes are based on ISI-data.

This situation was also the context for a project to diagnose the situation of German basic research in international comparison. The following principles are the operative guidelines for such a diagnosis:

- Those research areas were to be identified in which the Federal Republic is under-represented in comparison to the leading 'scientific nations'.
- The state of German basic research is to be described in terms of a broad overview over the relative strengths and weaknesses.
- Given the priority on the targeted support of 'top research', internationally relevant research areas are to be identified in which German scientists are well represented.
- Likewise relevant research areas whose development is rapid but which have been ignored in German scientific discussions.
- As far as data allow, time-series are to reveal the longer term trends in the development of basic research since relevant changes in research usually occur in longer time intervals only.
- Utilisation of co-citation analysis is to provide the possibility to trace findings on the level of "clusters" or research areas back to participating research institutions in order to analyze the reasons for success or lack of success by way of detailed qualitative studies. (The latter objective is reserved for a second phase of the project).

Figure 1: Project plan



1.2 The structure of the project

Construction and application of science indicators are subject to a number of general and science specific conditions. In general, indicators have to be easily managable and cost-efficient. At least they have to be cheaper than their information value, i.e. than the savings they make possible. Although indicators must have a relatively high degree of consensus among those affected by their use, this is particularly problematic in basic research because here the system of science directs itself through internal referees, i.e. experts. This science specific feature inadvertently creates opposition against any evaluation from 'outside' checked only by the fact that financing also comes from outside and is subject to the usual public accounting.

At the present state of the development and application of indicators for the measurement of success in basic research there is neither an indicator that could be regarded as ultimate nor is there a consensus over different indicators within the scientific community. Indicator construction is still research, i.e. the validation of measures of success and achievement, and possibly the experimental implemention.

The basis of the project are two sets of commonly used data with different objectives (both rest on the Science Citation and the Social Science Citation Index, respectively): the cluster analysis of co-citations 1984 and the publication and citation counts based on the fixed journal set for the time span 1973-1982 of Computer Horizons Inc. (CHI). The latter are relatively rough indicators of "activity" and "impact" of research in the respective nations but are available as time-series for the decade starting in 1973. The cluster analysis provides a picture for the year 1984 only, but allows a much more precise structural analysis. The parallel use of both data sets is supposed to create a complementarity of detailed structural analysis and a relatively superficial trend analysis. It has to be pointed out, however, that this goal cannot be reached properly with the data presently available, as the units of analysis in both data sets are divergent: "Fields" and "subfields" of the fixed journal set which are defined by CHI are not compatible with the "clusters". A method to achieve compatibility is presently unavailable.

The following steps of analysis can be characterized as successive steps of searching (cf. figure 1). The objective is to sort and limit the entire mass of data according to the criterion of relevant German participation in international research activity. Lists generated in this fashion are presented to scientists and representatives from science policy and administration for discussion in a first so-called policy review. A selection of those areas is to be achieved which will be subjected to further analysis. The political decision involved in this should not be a matter of indicator construction. On the other hand the first so-called "peer review" is designed to achieve evaluation of the data. This step underscores the research character of the project. It has to be ascertained that the aggregated data do not contain artefacts or are otherwise mistaken. On the basis of these decisions the structural data for the selected and validated "research fronts" and "fields/subfields" are produced. These will then provide the basis for a further "policy review II" in which those research areas are selected which should be submitted to detailed and quantitative analysis with respect to the strengths and weaknesses of research performance. Such a selection is nessessary because of the implied volume of work for this part of the study.

The repeated feedback of indicator construction and data generation built into the project serve both to validate the data and to increase acceptance of the indicators. If, in the dialogue between scientists and those who generate and process the data, a sufficient agreement between the 'objectively generated' data and the subjective evaluations can be achieved the construction of indicators can be considered finalized, at least in principle.

2. German publication activities and citation rates in Science

2.1 On the methodology of bibliometric time series analysis

General considerations

There are basically two indicators for measuring scientific output: publication counts and citation counts. The publication indicator serves as an approximation for scientific activity and productivity. Citation indicators are supposed to reflect the impact of scientific papers, i.e. the reception of scientific work by other scientists. The bibliometric indicators presented in the following chapter are constructed as time-series which could, in principle, complement cross-section data such as those derived from the ISI 84-co-citation analysis. "Striking" results from both procedures are to be confronted with each other or, rather, the time-series can serve as a first filter guiding the attention to areas of special interest. This does not amount to a mutual validation of data but is a sequential ordering of two fundamentally different approaches based on the same data source (SCI).

On the state of the CHI-data set

Since the beginning of the 'Science Indicators Reports' in 1972, Computer Horizons Inc. (CHI) produces biannualy bibliometric indicators for the National Science Foundation which are based on the Science Citation Index. For this purpose CHI has developed a longitudinal data set which consists of approximately 275,000 scientific articles, notes and reviews per year. These 'publications' together with their references are accumulated since 1973 to set up indicators for the evaluation of national research performance in international comparison. The "Science Literature Indicators Data Base 84" (SLI84) which was analyzed by us, has a 10 year time-series of publication and citation counts as well as measures of international cooperation and further bibliometric indicators for the years 1973 to 1982 and 173 countries. Until now, it is the only source for longitudinal and internationally comparative data on scientific activities.

The fixation of the journal set

The basic condition for time-series analysis is that the reference of the data base has to be fixed and that classifications used for the construction of indicators have to be kept constant. This is the only way to assure control over the changes of the indicators. At the same time fixing the classification (in this case scientific "fields" and "subfields" as defined by journals) imposes a restriction whereby changes of the observed entiti'ies are ignored. In the case of the CHI data, all information on national activities of publication and citation is based on a 'fixed' set of 2300 scientific journals which had been integrated into the SCI in 1973. It is evident that such 'defined' channels of scientific communication have been subjected to changes themselves in the meantime. Some of these journals do not exist any more or have been dropped by ISI. Some journals have segmented and, furthermore, new scientific journals which are not represented in the 1973 journal set may have appeared. The fact that the SCI has increased in 1981 to 3100 scientific journals is an indication of such processes. The adjustment of the "CHI fixed journal set" in 1981 is an attempt to adopt to these fluctuations. This step reveals the fundamental dilemma of any time-series construction which can only be resolved pragmatically. It cannot be ignored, though, that the CHI time-series cannot be robust against such fluctuations in the compilation of raw data by ISI. Therefore the results of these bibliometric measures must be carefully scrutinized.

The classification of journals in "fields" and "subfields"

For the purpose of disciplinary assignment CHI classified the data according to distinct criteria, i.e., journals from the Science Citation Index were assigned by expert ratings to 9 respectively 8 different fields: clinical medicine, biomedicine, biology, chemistry, physics, earth and space sciences, engineering and technology, mathematics. (Since 1980 ISI counts psychology as part of the Social Sciences and it has been taken out of the SCI.)
For the construction of subfields journals were weighted by the coherence of the pattern of mutual citations (the so-called "journal-journal-citing" or "journal-impact-factor"). In this manner originally 106 subfields were formed and after excluding psychology there are still 99 subfields which are distributed unequally over the remaining 8 fields.

LIST OF FIELDS AND SUBFIELDS:

Clinical Medicine

General and Internal Medicine, Allergy, Anesthesiology, Cancer, Cardiovascular System, Dentistry, Dermatology & Venereal Diseases, Endocrinology, Fertility, Gastroenterology, Geriatrics, Hematology, Immunology, Obstetrics & Gynecology, Neurology & Neurosurgery, Ophthalmology, Orthopedics, Arthritis & Rheumatism, Otorhinolaryngology, Pathology, Pediatrics, Pharmacology, Pharmacy, Psychiatry, Radiology & Nuclear Medicine, Respiratory System, Surgery, Tropical Medicine, Urology, Nephrology, Veterinary Medicine, Addictive Diseases, Hygiene & Public Health, Miscellaneous Clinical Medicine.

Biomedicine

Physiology, Anatomy & Morphology, Embryology, Genetics & Heredity, Nutrition & Dietetics, Biochemistry & Molecular Biology, Biophysics, Cell Biology Cytology & Histology, Microbiology, Virology, Parasitology, Biomedical Engineering, Microscopy, Miscellaneous Biomedical Research, General Biomedical Research.

Biology

General Biology, General Zoology, Entomology, Miscellaneous Zoology, Marine Biology & Hydrobiology, Botany, Ecology, Agriculture & Food Science, Dairy & Animal Science, Miscellaneous Biology.

Chemistry

Analytical Chemistry, Organic Chemistry, Inorganic & Nuclear Chemistry, Applied Chemistry, General Chemistry, Polymers, Physical Chemistry.

Physics

Chemical Physics, Solid State Physics, Fluids & Plasmas, Applied Physics, Acoustics, Optics, General Physics, Nuclear & Particle Physics, Miscellaneous Physics.

Earth and Space Sciences

Astronomy & Astrophysics, Meteorology & Atmospheric Science, Geology, Earth & Planetary Science, Geography, Oceanography & Limnology.

Engineering and Technology

Chemical Engineering, Mechanical Engineering, Civil Engineering, Electrical Engineering & Electronics, Miscellaneous Engineering & Technology, Industrial Engineering, General Engineering, Metals & Metallurgy, Materials Science, Nuclear Technology, Aerospace Technology, Computers, Library & Information Science, Operations Research & Management Science.

Mathematics

Probability & Statistics, Applied Mathematics, General Mathematics, Miscellaneous Mathematics.

Table 1: Share of German and world scientific and technical articles 1973-1983 (by fields)*

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Total number of articles (all fields)	271413	264959	267273	268817	275072	272913	274054	277075	283837	259830
Number of German articles (all fields)	15954	17071	17085	17681	18000	18155	17373	17[illegible]14	17810	16134
German publication rate (in %)										
All fields	5.9	6.4	6.4	6.6	6.5	6.7	6.3	6.3	6.3	6.2
Clinical Medicine	6.8	7.3	7.2	6.8	6.7	6.8	6.3	6.2	6.1	5.9
Biomedicine	6.0	6.1	6.1	6.4	6.0	6.3	6.0	6.0	6.1	6.0
Biology	3.6	3.8	3.5	4.1	4.2	3.6	4.3	4.0	3.7	3.6
Chemistry	5.9	6.5	6.2	7.0	6.9	7.3	6.7	7.1	6.9	7.1
Physics	5.1	6.0	6.5	6.8	6.9	6.9	6.9	6.6	7.0	7.1
Earth & Space Sciences	3.3	4.0	3.5	3.4	3.8	4.4	3.9	4.1	4.5	4.7
Engineering & Technology	7.1	7.9	8.4	8.2	8.2	8.2	8.0	7.6	7.5	7.9
Mathematics	6.7	7.3	7.0	8.2	9.9	10.1	9.5	10.0	9.3	7.7
Relative citation index (for German articles)**										
Clinical Medicine	0.5	0.5	0.6	0.5	0.6	0.5	0.6	***	-	-
Biomedicine	0.8	0.8	0.8	0.9	0.9	1.0	1.0	-	-	-
Biology	0.9	1.0	1.0	0.9	1.1	1.1	1.0	-	-	-
Chemistry	1.1	1.2	1.2	1.1	1.2	1.2	1.2	-	-	-
Physics	1.1	1.1	1.2	1.1	1.2	1.3	1.3	-	-	-
Earth & Space Sciences	0.7	0.9	0.8	0.8	0.9	0.8	0.9	-	-	-
Engineering & Technology	0.7	0.8	0.8	0.8	0.8	0.9	0.7	-	-	-
Mathematics	0.8	0.8	0.9	0.9	0.8	0.8	0.8	-	-	-

* Based on the articles, notes and reviews in the influential journals carried in the Science Citation Index.

** A relative citation index of 1.0 reflects no over- or under-citing of the German scientific and technical literature, whereas a higher ratio indicates a greater influence, impact or utility than would have been expected from the number of German articles for that year.

***Shortened time series on account of time-lag of citation.

All data based on over 2100 journals of the 1973 Science Citation Index.

Science Studies Unit, University Bielefeld, FRG — Source: CHI Inc.

Since labeling of the subfields is oriented towards the title of the journals these subfields should on no account be considered as subdisciplines. They rather form synthetic units which are sometimes not discriminating but overlapping. This is an especially important factor for the interpretation of the data. By far the largest number of journals are assigned for 100% with a specific subfield whereas interdisciplinary journals are divided proportionally over a number of subfields corresponding to their citation impact.

The construction of bibliometric indicators

Bibliometric indicators are constructed on the basis of the country code or, as the case may be, the institutional address listed in the publication. Articles published in a particular year are classed with a country or, in the case of multiple authorship, with the countries corresponding proportionally to the 'national quota' of the authors. The decisive factor is the publication year of the article. Originally, the publication indicator is available on the tape as an absolute figure, only. Therefore the publication rate was calculated on the basis of a specifically developed computer program.

The citation indicator is available in four variants: as absolute number, as citation rate computed from it (i.e. as the national quota of the total citations), as mathematical quota of citations per publication as well as a relative citation index in which the national citation rate is normalized according to the world average. The relative citation index is defined as the statistical expectation ratio due for the national proportion of publications. A value of 1.0 corresponds exactly to the world average; values above 1 show the extents to which articles of a particular country were quoted more often than expected. (A value of 1.3 for example means that the publications in this field obtain 30% more citations than could have been expected on the basis of the publication rate). Correspondingly, values below 1.0 refer to a subproportional citation frequency. In contrast to other citation indicators which are used for bibliometric analyses the relative citation index has the great advantage that it shows immediately the relative position of a particular country in a particular field/subfield and a given year.[1] As a result of the standardization, the size of the subfield - except the very small ones - is not decisive for the construction of this indicator. In the case of the publication rate all figures between 1973 and 1982 are included in the tables since publications up to 1982 are registered completely under the restrictions of the 73 fixed journal set. 1982 publications which are registered on the 1983 ISI data tape can only be integrated after the CHI tape has been updated. (Meanwhile, the prolongation of publication and citation counts up to 1984 is available.)

Figure 2: Typology of research performance

relative citation index (rci)		publication rate (p): low	publication rate (p): high
	high	type 1: inactive/effective scientific fields	type 2: active/effective scientific fields
	low	type 3: inactive/ineffective scientific fields	type 4: active/ineffective scientific fields

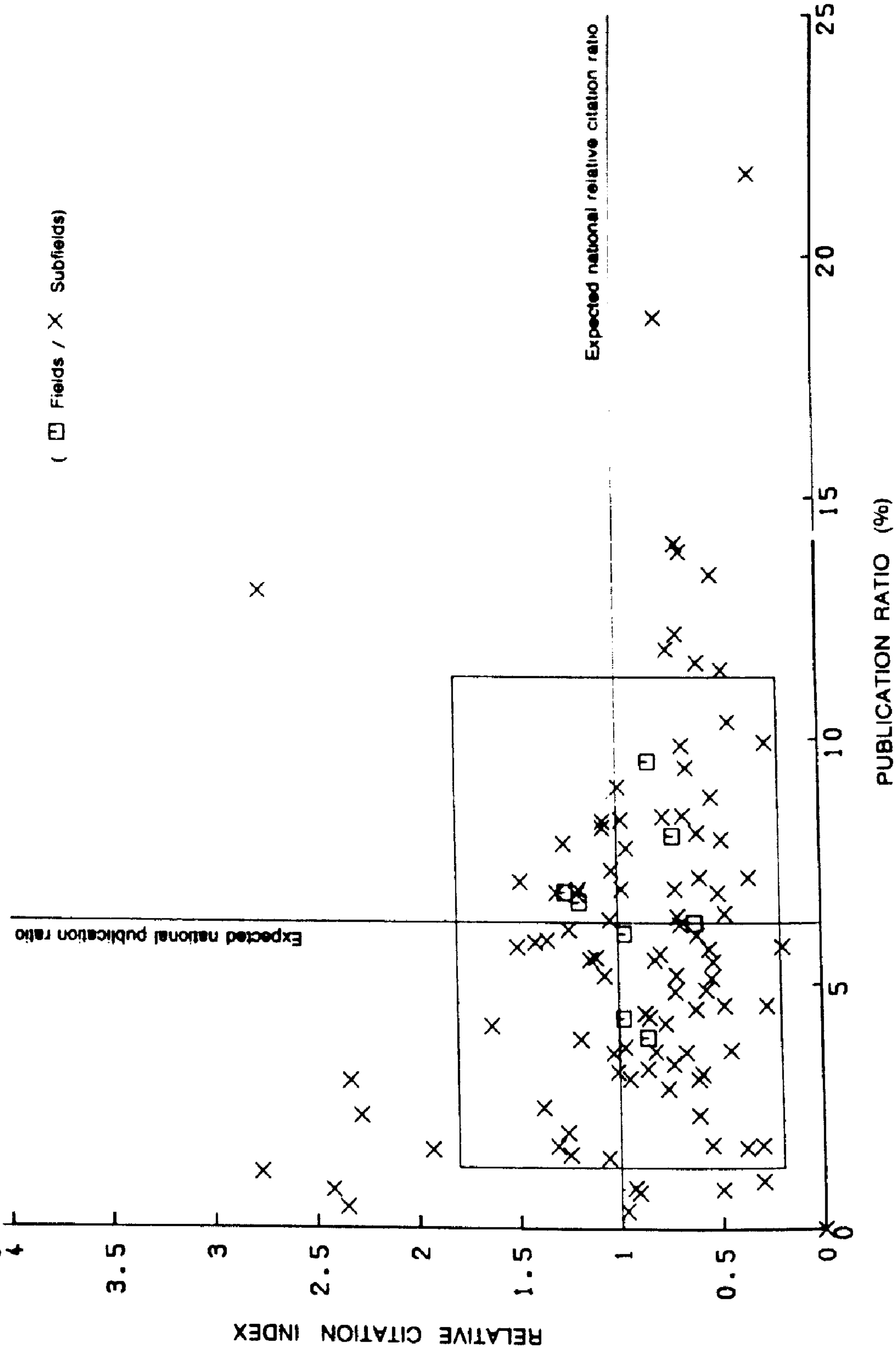
The following presentation of time-series for the relative citation index is, however, shortened to allow for the time-lag between a publication and its reception in citations. Statistical analyses from ISI show that publications receive approximately 20% of all citations within the first 3 years after publication but the 'peak' of citations in the third year. On average it is only after 6 years that 50% of all citations are reached. [2] In order to obtain sufficiently valid results no data beyond 1979 should be included in the analysis of the SLI84. On account of this decision to shorten the time-series it is of secondary concern that the so-called subfield citation tape used additionally to illustrate citation counts also on the subfield level only includes the 1973 fixed journal set and neglects the enlargement of 1981.

2.2 Results of the time series analysis: publication- and citation-indicators for German basic research between 1973 and 1982 (by fields)

Table 1 gives an overview over the development of scientific activities measured by publications and their reception in the "scientific community" in the period between 1973 and 1982. If we take the average German publication rate of about 6% as a measure of comparison to rank scientific fields, there are relatively significant deviations from this average value. Deviations of about 2.5 percentage points below and about 4 percentage points above the national average correspond to a fluctuation of approximately 40% below and approximately 60% above the average German publication rate. In 'biology' and 'earth and space sciences' the German publication rate is generally below the average. In 'clinical medicine' and 'biomedicine' which, taken together, constitute the largest part of the data set (30% plus 16%) the German publication rates are within the average range. 'Physics' is only slightly above the average publication rate whereas 'chemistry', 'engineering & technology' as well as 'mathematics' are clearly above the average German publication rate. (At the level of subfields the German publication counts for 1979, for example, range from 0,4% in 'diary and animal science' to nearly 22% in 'orthopedics'.)

The results of the citation indicator show the following pattern: Only 'chemistry' and 'physics' are generally above the statistically expected relative citation index of 1.0; 'biology' fluctuates marginally around the expected value. Besides 'clinical medicine', which generally receives only half as many citations as could be expected from its number of publications, all other fields lie only slightly below this value. The rates of change within a field are marginal and most fields remain almost stable over the whole period. 'Biomedicine', 'biology'

Figure 3: Distribution of fields and subfields for the Federal Republic of Germany 1979



Science Studies Unit, University Bielefeld, FRG

Source: CHI Inc.

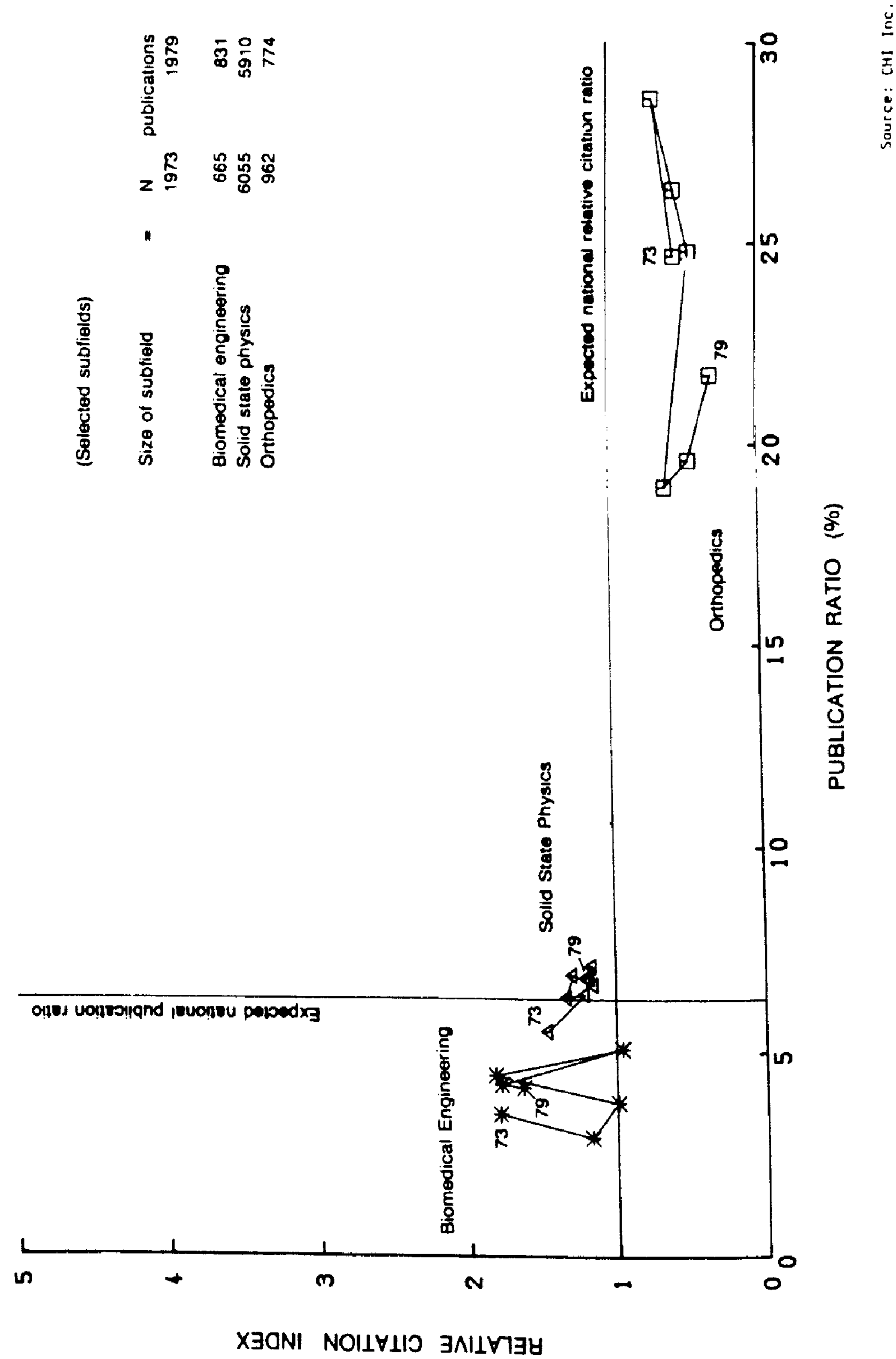
and 'physics' display a slight tendency to improve their citation index.

2.3 Selection strategies for the identification of "conspicuous" research areas: on the typology of research performance

The hitherto presented results describe the performance of German and international basic research on the basis of two highly aggregated and relatively crude indicators: the publication rate and the normalized citation index. These results are only suitable for a preselection of fields/subfields but are not qualified to determine research areas which represent national 'strengths and weaknesses'. To answer such questions we must examine the development in smaller scientific units. For this analysis we need the disaggregated data set, the so-called subfield citation tape because the SLI84 does not include citation counts on the subfield level. This specified data set has some advantages over the SLI84-standard version: scientific innovation and regression takes place at the level of small, distinct subfields and not at the aggregated level of fields. Since contrary developments of both indicators can balance each other out at the level of fields and appear as stagnation, the disaggregated citation indicator offers more information. The additional disaggregated SLI84-subfield citation tape has the advantage of better discrimination but it only includes the 1973 fixed journal set without the enlargement of 1981. Furthermore, only such citation counts were evaluated where both the citing as well as the cited articles had been published in journals which had been included in the 73 journal set which leads to a reduction of the data base and limits the span of interpretation. Moreover, is has to be remembered that "subfields" created by titles of journals can not be identical with the institutional boundaries of subdisciplines.

As shown above, the total list of fields and subfields contains 107 categories for a single country and a single year. True, the values of some subfields deviate significantly already at first sight from the average or expected values. Nevertheless, it is necessary to develop a selection strategy which takes into account both good and poor visibility of German articles and citations in the total data base and which at the same time preserves the information of the time series. One possibility of evaluation would consist in seperate trend analyses of each indicator. Since both indicators often show different trends it is difficult to decide which of these isolated results should serve as a basis for the selection of "conspicuous" research areas. Thus, in order to achieve a higher validity of both measures they were correlated and a measure of "performance" was constructed.

Figure 4: Trends in selected subfields for the Federal Republic of Germany 1973-1979



For the classification of scientific fields and subfields a matrix (see Fig. 2) was developed in which the publication rate forms one axis and the relative citation index forms the other one. The national average of publications and the expected value of the relative citation index (= 1.0) serve as a demarcation line for the segregation of the matrix fields. In this way we can differentiate between two types of research activity and two types of research efficiency which altogether lead to four different 'classes' of research performance. The combined indicators for all scientific fields and subfields for each year can be integrated in this matrix.

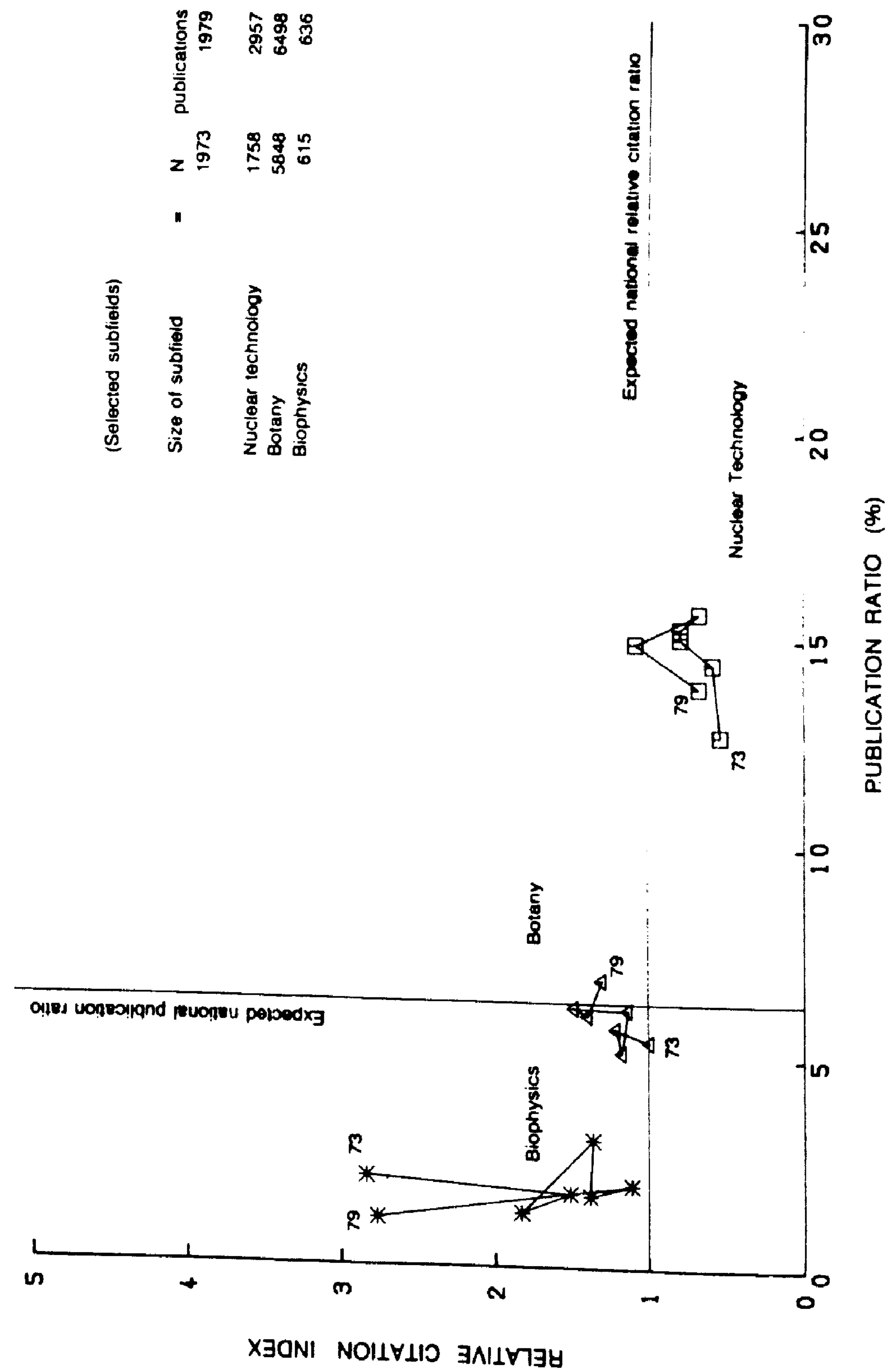
Figure 3 illustrates the procedure for 1979 which was set as the final point of the time-series. For the discrimination between "average" and "conspicuous" subfields about 80% of the matrix scope was marked beginning from the middle to the left and to the bottom. At this stage it would be certainly premature to start operating with a formula "top quality research" versus "research gaps" without a serious validity check of the data. Nevertheless, subfields with high publication activities but low impact (type 4, the so-called "inefficient" science fields), must certainly be rated differently from those subfields which, in spite of their low publication activity, are highly noticed by others (type 1, the so-called "highly efficient" scientific fields). Undoubtedly, scientific fields of type 2, which lie above the average publication activity and have a high impact, can be characterized as "successful" research fields in contrast to those of type 3 which we have called "marginal".

It is important to point out that in contrast to the results from the ISI-cocitation analysis these time series indicators illustrate national research performance only at a highly aggregated level; disaggregations at the institutional or even individual level are not possible with these data supplied by CHI.

2.4 Examples of German research performance in selected subfields

Out of the total number of 99 subfields which are represented in the data set 12 subfields representing types 1,2 and 4 are chosen for further analysis and presented in their trend. Since the data have not been validated by expert rating nor has it been clarified how homogeneous or how varied publication and citation structures between single subfields are, the following results should not be taken as a comparison between individual subfields as the presentation chosen in figures 4 - 7 may suggest.

Figure 5: Trends in selected subfields for the Federal Republic of Germany 1973-1979



Science Studies Unit, University Bielefeld, FRG

Source: CHI Inc.

Scientific fields of the type 1: "highly efficient" research

Scientific fields of type 1 are such fields with low publication activity but relatively high citation impact. For the demonstration of this type of research performance we have selected four subfields. 'Biomedical engineering' (cf. figure 4) and 'biophysics' (cf. figure 5) are both subfields with a high citation impact. But as they are numerically small, in the first case between 20 and 40 articles, in the second case less than 20 articles in German journals, they raise a specific methodological problem concerning the reliability of data in such small subfields. The relative citation index which is normalized according to the total amount of publications jumps abruptly if there are some central papers among these few which are cited relatively often. Thus, the validity of a high citation impact is also connected to the total amount of papers establishing the data base. The somewhat larger subfield 'general engineering' also indicates rapid changes concerning it's citation impact. (cf. figure 7). Only 'polymers', (cf. figure 6) is a subfield whose values can be regarded as valid because of the large number of papers.

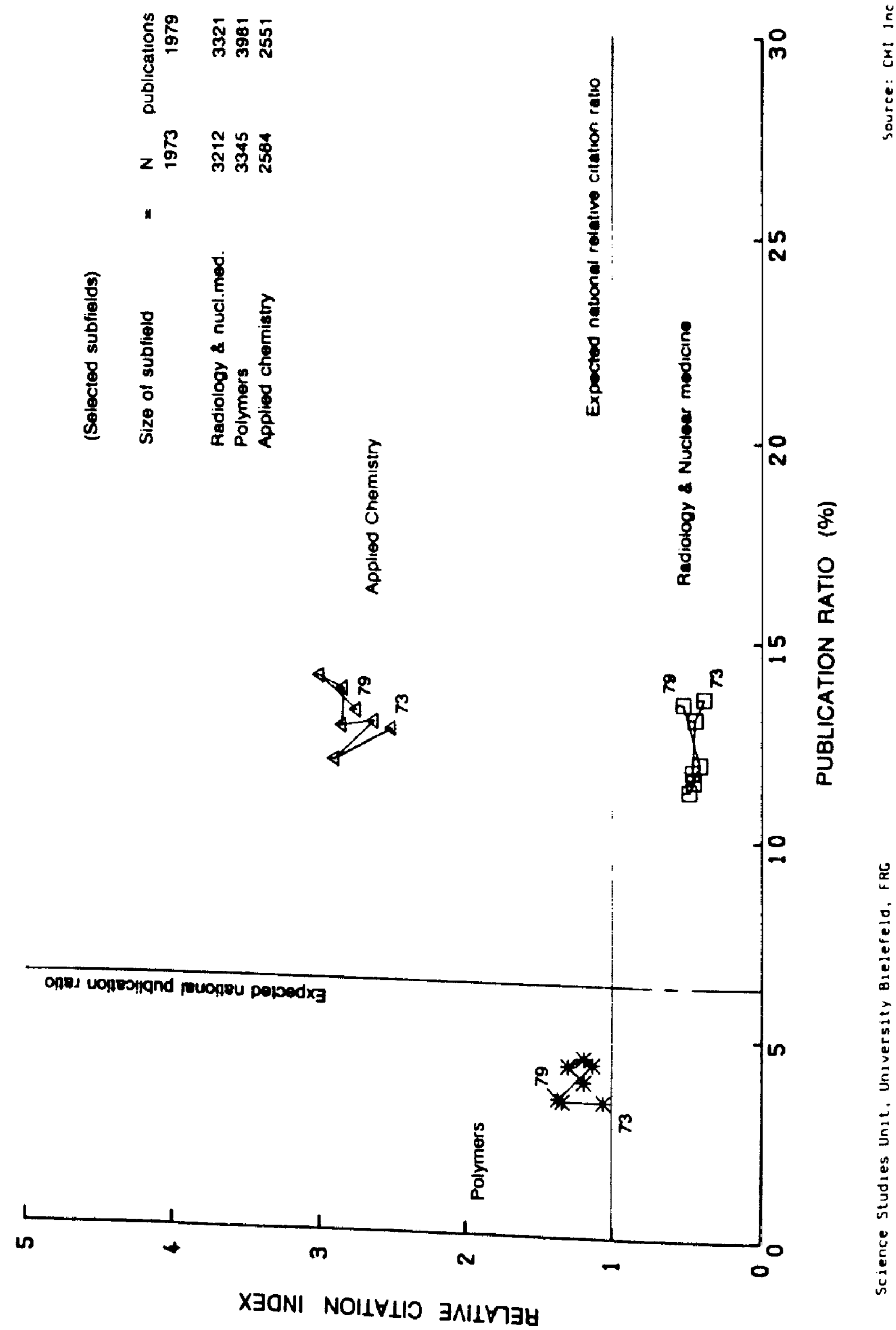
Scientific areas of type 2: "successful" research

On the basis of the criteria of discrimination only 'applied chemistry' (cf. figure 6) can be considered a successful German subfield showing a publication activity constantly above average and having a very high impact factor. In international comparison this subfield has the top position among all German research areas. In this group of prominent German research performance one can also find the subfield 'metals and metallurgy' (cf. figure 7). Two further numerically strong subfields are included to demonstrate a broader spectrum of German research activity: 'solid state physics' (cf. figure 4) and 'botany' (cf. figure 5), both being located in the range of slightly positive values.

Scientific fields of type 3: "marginal" research

No cases of "marginal" research have been selected. A large number of German subfields lie within the matrix field of inactive/ ineffective scientific fields, but the number of those which are outside the "80%-frame" is so small (below 10 German publications) that closer examination does not seem warranted.

Figure 6: Trends in selected subfields for the Federal Republic of Germany 1973-1979



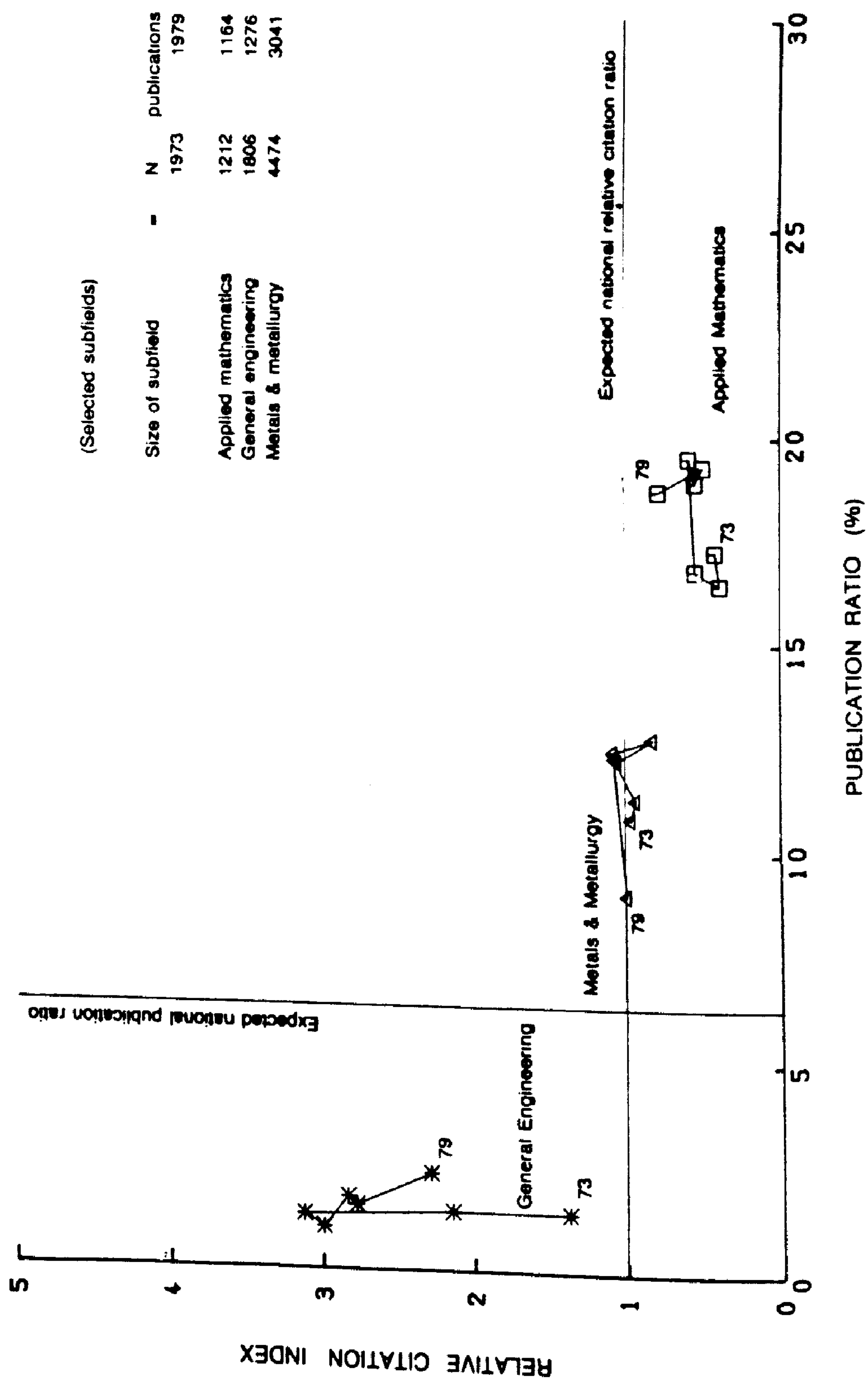
Scientific fields of type 4: "inefficient" research

Among those subfields which have a high publication activity but which are cited relatively seldom 'radiology and nuclear medicine' (cf. figure 6) belong to the subfields with consistently high German publication rates. Similar structures can be determined in 'orthopedics' (cf. figure 4) which has the highest German publication rate among all subfields. Nevertheless, the numerous German contributions have a low international impact (citation index of about 0.5). From the German point of view 'nuclear technology' (cf. figure 5) also belongs to the group of active subfields but the publication curve shows significant oscillations which shed some doubts on the reliability of the data in this area [3]. A considerable spurt in data can also be identified in 'applied mathematics' (cf. figure 7). Since the German publication rate drops exclusively in 1982 (data not integrated in the presentation) it may be assumed that a large portion of the otherwise consistently high publication rate is contained in the SCI data tape of the year 1983 and will be available only after the time series has been updated.

Résumé

In summing up it must be asked whether low citation rates for German publications are to be interpreted as a "weakness" in the "performance" of research in these subfields. Critics of a quantitative approach for measuring research performance refer to problems which are related to the composition of the data - first, that monographs are seldom included and second, the 'bias' towards English journals - which influence the results in a specific manner. No doubt, it seems that the validity of the data is an essential problem. The examination of the list of journals classified on the one hand by its continuous respectively discontinuous presence in the data each year and classified on the other hand by the journal's national publishing address shows that the "fixation of journals" is not as constant as postulated. There are remarkable 'drops' and 'revivals' of journals affecting their presence in the time-series and influencing trends in a significant way. The time-lag of publication and citation counts is another argument which reduces the scope of interpretation of these bibliometric indicators. The outdatedness of some subfields respectively the lack of new special research areas are further aspects which should be taken into account when applying these time-series. From all this follows that they can only represent rough trends, and single figures should not be overinterpreted.

Figure 7: Trends in selected subfields for the Federal Republic of Germany 1973-1979



Science Studies Unit, University Bielefeld, FRG

Source: CHI Inc.

3. Using co-citation analysis in constructing indicators of scientific activity on a national level

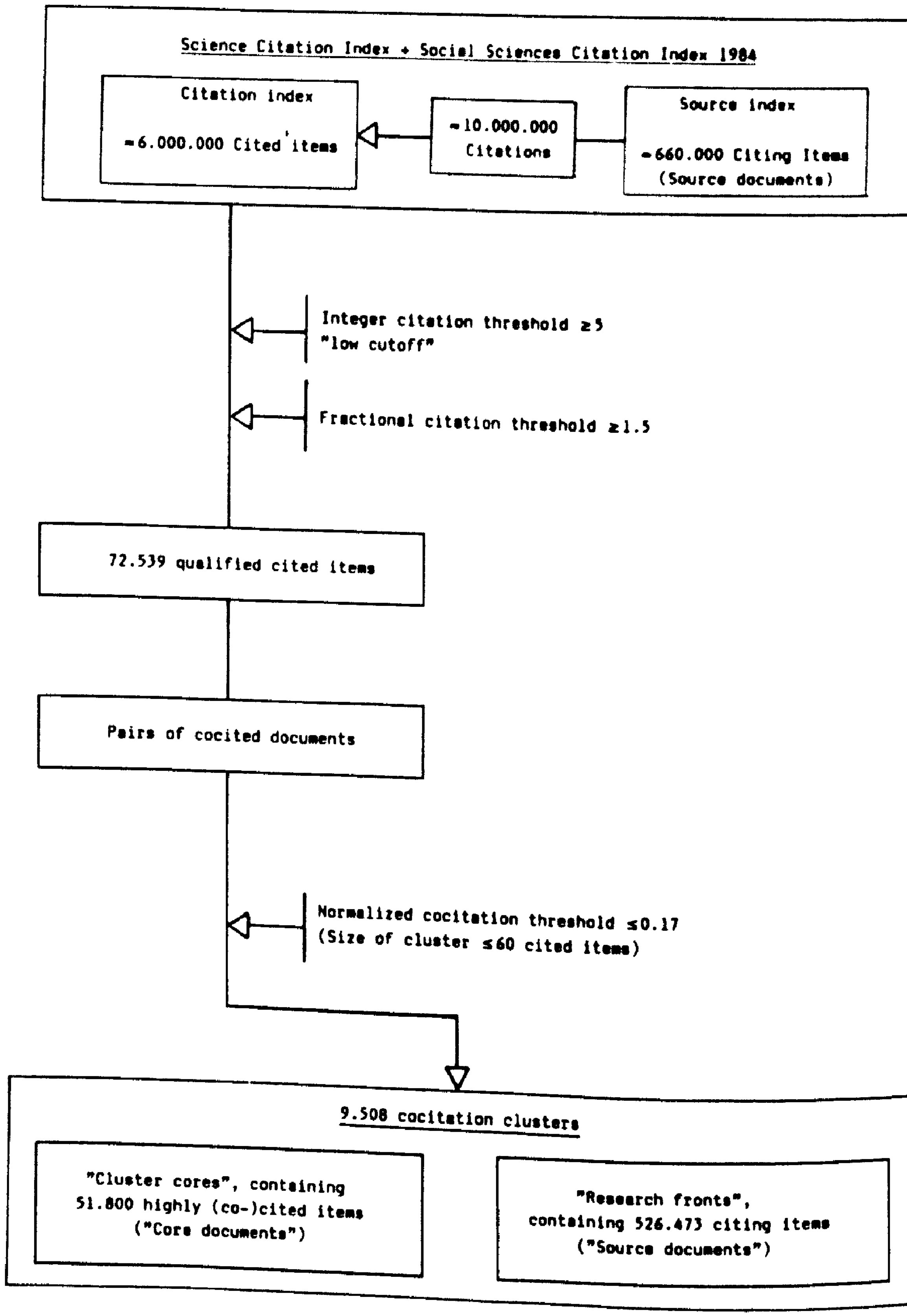
3.1 Methodology and data

Cluster analysis of the Science Citation Index (SCI) using co-citations was introduced as a new bibliometric method by Henry Small and Belver Griffith in 1974. Since then, the method has been continuously developed further [4]. The method applies the technique of cluster analysis to a bibliographic data base, which contains both the current scientific literature for a certain period of time as well as references from these current articles to earlier published papers ("citations"). There is no need for abstracts or summaries in the data base, only bibliographic information is used. Furthermore, the data base does not need to have any thesaurus or controlled vocabulary as descriptor terms. On the other hand, the existence of references (citation data) is necessary. In the case of the Bielefeld study the input was the 1984 segment of the combined Science and Social Science Citation Index (SCI/SSCI) produced by the Institute for Scientific Information. There is no alternative to using ISI's data base, because it is the only existing multidisciplinary science citation index in the world.

Starting with some 660,000 source publications of the 1984 SCI/SSCI files, nearly 10,000,000 citations to approximately 6,000,000 unique earlier published papers have gone into the ISI-model of co-citation cluster analysis (cf. figure 8). In a first step from the 6 million cited documents those which have been cited at least 5 times by the 1984 source papers are selected. The second step is again a selection: only cited documents with a fractional citation count [5] of 1.5 or above are passed to the further steps of the analysis. The introduction of these citation thresholds resulted in a selection of 72,539 from the initial 6 million cited publications, which is not only a reduction of size, but also the selection of "more important" (being highly cited) items against the "less important" ones (hardly or not at all cited).

The next step is running the computer program of the cluster analysis on the selected items. The algorithm of this single-link clustering routine starts from identifying every pair of co-cited items. It then links together those pairs which have one common document and continues in building groups of cited documents which are linked by co-citation and which from now on are called "clusters". A normalized co-citation threshold (i.e. raw co-citation count divided by the square root of the product of the individual citation counts of the cited items of each co-cited pair) of ≥ 0.17 is applied to create clusters. If any of the created cluster exceeds the limit of linking 60

Figure 8: Cluster analysis of cocitations SCI/SSCI 1984



core documents together, the threshold is increased stepwise to generate a cluster which is as large as possible, but not exceeding the size limit of 60 core documents [6]. The output of this "variable level clustering" is a set of 9,508 clusters, consisting of alltogether 51,800 highly cited documents. Again some 20,000 documents are 'lost' by the routine because their co-citation links to other documents are too weak and they remain below the co-citation threshold.

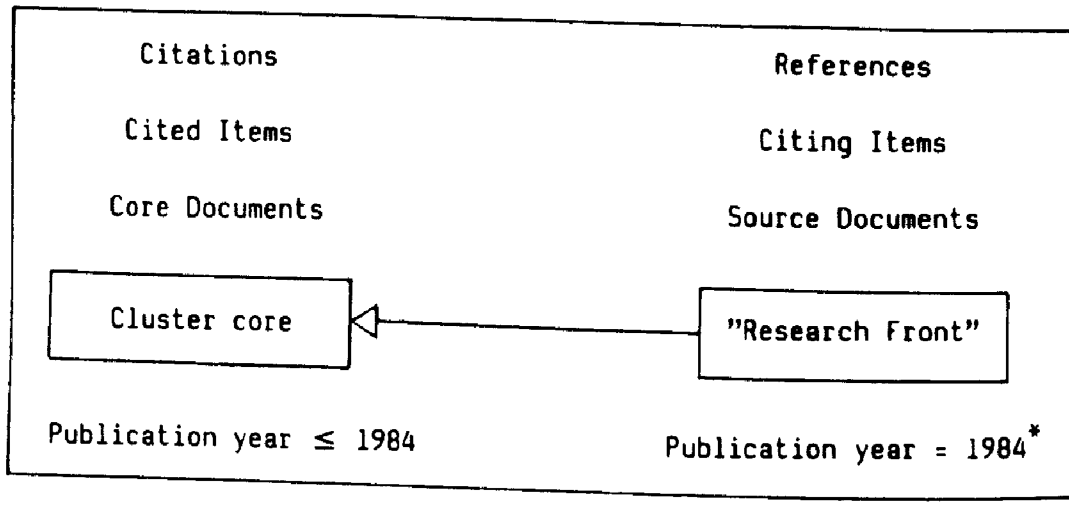
The next step is to retransfer the grouping of cited documents to the "citing" side, i.e. to the current documents of 1984. Thus for each of the 9,508 clusters we have two sets of data (cf. figure 9): 1. the so-called cluster core, containing the highly cited documents (which are linked to each other by a certain strength of co-citation) and 2. the so-called "research front", consisting of the citing documents (each of them citing at least one of the documents in the connected cluster core). Although most of the citing documents are published in 1984, some are from 1983, due to a delay in ISI access to the journals. The publication year of cited documents, on the other hand, may vary from 1984 back to 1900 or even beyond. It is worth noting that for several citing documents there is the possibility of being assigned to more than one "research front" because they are linked to different cluster cores by their references.

For every cluster core and its corresponding "research front" a semi-automatic procedure of "cluster naming" is introduced: a list of all words used within the titles of the current documents is produced, ranked by frequency of appearance in the titles. Using these lists together with the full bibliographic information of the "research front" (current documents) and the linked cluster core an appropiate name is compiled manually.

The output of 9,508 clusters from the cluster analysis is then used as input for a "clustering of clusters", i.e. the co-citation links between clusters lead to the establishment of superclusters. As a result there are 1371 superclusters, each of them incorporating 2 to 60 clusters of the first generation. This procedure of clustering clusters is then iterated twice again, so that it ends up with a hierarchy of co-citation clusters on 4 levels of aggregation. At each level a number of items are 'lost' because of failing the cocitation threshold (i.e. missing cocitation links of necessary strength to any of the other items). To distinguish between the levels of aggregation ISI introduced the C1-C4 prefixes to cluster numbers. Statistics for the outcome of the iterative clustering are as shown in Table 2.

Clusters at C1-level represent very small research areas (a cluster core may consist of only a single pair of co-cited documents!), whereas at higher levels clusters are becoming more and more extensive in size (number of documents) and thematically

Figure 9: Cocitation analysis SCI/SSCI 1984 - Terminology



*): in some few cases 1983 (if there was a delay in journal delivery)

Table 2: Statistics of cluster analysis of cocitations SCI/SSCI 1984

level of aggregation	C1	C2	C3	C4
input	72.539	9.508	1.371	179
clustering items	51.800	6.084	757	110
non-clustering items	20.379	3.424	614	69
output	9.508	1.371	179	21

comprehensive. Because of being created by a somewhat 'artificial aggregation', the "meaning" of those higher-level clusters is still an open question.

In addition to the co-citation analysis a complete ten year West German bibliography complements the data set in the Bielefeld project for purposes of control. It contains all source documents of the SCI from 1975 to 1984 which have at least one author with a corporate address from the Federal Republic of Germany. Some 300,000 documents are included in this file.

The possibility of searching and also manipulating and reprocessing the information electronically was considered absolutely necessary to manage the large quantity and complexity of the data output from the co-citation analysis as well as the bibliography. It would have been simply impossible to manually go through ten-thousands of pages of printouts from the files, which in some cases exceed a million records and more. It was decided to reintegrate the whole output of co-citation analysis (as well as the bibliography) into a complex relational data base, which allows users to have dialogue access to the data through an easy-to-use but also very powerful information storage and retrieval system. Step by step the files are transferred from the mainframe to a UNIX-system and become integrated into a databank which is driven under the ORACLE-software.

Now information is searchable 'online' in a very fast and comfortable manner, using the IBM-standard query language SQL and a set of userfriendly ORACLE interfaces. It is possible for example to ask if the name of certain authors are appearing in any of the 9,508 clusters, the answer appears within seconds on the screen of the terminal. For each of the clusters on the 4 levels of aggregation there is a mass of detailed information, which can be retrieved from the files. Besides the number and title, which of course exist for every cluster the information can be grouped into three main categories: hierarchy data, cluster core data and "research front" data (cf. Figure 10). In the meantime it became possible to access parts of these data also through the DIMDI-online vendor of the SCI. However, certain parts (e.g. cluster cores as such) are not retrievable in that way.
The hierarchy data provide the numbers of other clusters of the same level of aggregation, to which a certain cluster is linked by cocitation. Co-cited clusters are parts of the same "supercluster" on the next level, so the numbers of the superclusters (if existing for that cluster) on all levels are provided as well.

The cluster core data can be divided into two parts: statistical data and the (core) documents themselves. Statistically there is the size of the core (number of cited items in the cluster core) and for purposes

Figure 10: Data from cocitation analysis SCI/SSCI 1984

Level	Item	Format
1	Cluster-no.	I4
1	Cluster-titel	A250
2	Hierarchy data	
3	*Cocited clusters*	I4
3	Supercluster	
4	C2	I4
4	C3	I4
4	C4	I4
2	Cluster core	
3	Statistical data	
4	Number of cited items	I7
4	Number of cited items from 82-84	I7
4	Percent of 82-84 papers of total number of cited items	F5.1
3	*Core documents*	
4	First author	A18
4	Journal	A20
4	Volume	I4
4	Page	I4
4	Publication year	I2
4	Number of received citations	I6
2	"Research front"	
3	Statistical data	
4	Number of source documents	I4
4	Total number of corporate addresses	I5
4	Corporate addresses divided by number of core documents	I2
4	Number of adresses per nation	
5	USA	I4
5	GB	I4
5	D	I4
5	F	I4
5	J	I4
5	Rest	I4
4	National participation in total number of addresses	
5	USA	F5.1
5	GB	F5.1
5	D	F5.1
5	F	F5.1
5	J	F5.1
5	Rest	F5.1
3	*Source documents*	
4	Titel	A100
4	First author	A11
4	*Secondary authors*	A11
4	Language	A2
4	Journal	A14
4	Volume	I4
4	Page	A4
4	Year	I2
4	Number of citations to cluster core	I5
4	*Institutional data*	
5	Name	A114
5	City	A23
5	Province	A18
5	State	A15
5	US-ZIP-Code	I5

Formats: A=alphanumerical, I=integer, F=real;
Digits: maximum number of characters/digits

Note: *italic* elements can contain multiple data
(e.g. several *source documents* within one "research front")

of evaluating the "immediacy" of a cluster, the number of core documents with publication year 1982-84 is available as well as the percentage of these to the total number. For each core document, the following elements are given (in accordance with the SCI data structure): first author, journal, volume, page and year of publication. Additionally there is the number of recieved citations (which in our case will be at least 5 and can reach a peak of 5577).

The "research front" data can again be divided into statistical data on the one hand and the (source) documents themselves on the other. Statistically there is the size of the "front" in terms of number of source documents and number of all corporate addresses. Additionally the ratio of "front" size to core size is given. Then there is a national breakdown of the number of addresses, provided as actual numbers as well as percentage values, indicating the national participation for a "research front" (ISI supplied these data for the five major countries USA, GB, FRG, France, Japan and the rest of the world, but it is possible to calculate the figures from the files for any other desired nation as well). For each source document then, according to the SCI data structure a very detailed set of bibliographic data is available: title, first and all secondary authors, original language, journal, volume, page and year of publication. From the corporate source files there are institutional data for all authors of the source document: name, city, province, country (resp. state for US) and US zip code.

3.2 Some results of co-citation analysis SCI/SSCI 1984

The output from the cluster analysis of co-citations SCI/SSCI 1984 consists in the 9,508 clusters on C1-level and the according superclusters on the higher C2-, C3- and C4-levels. A disciplinary breakdown of C1-clusters (cf. Table 3) shows that over 80% of the clusters are from the natural sciences, only 8% come from the social sciences. The largest part in the natural sciences are the biomedical disciplines, which comprise 30% of the total.

Through the number of corporate addresses at each "research front" it is possible to determine national participation, and statistical measures (as national means) can be calculated for the total (cf. Table 4). E.g. 40,830 out of the total 819,872 (=5%) addresses on C1-level are from West German institutions. This percentage is stable also at the higher levels, although the total counts are continually decreasing due to the algorithm of the cluster analysis. The other nations have also stable mean percentages of participation: USA 47%, GB 7.8%, France 4.8% and Japan 5.4%. The rest of the world counts for 30%.

Table 3: Disciplinary breakdown of 1984 SCI/SSCI Cl-clusters

Area	number of clusters	%
Physical sciences		
1. Biomedicine	2907	30.6
2. Chemistry	1509	15.9
3. Physics	1176	12.4
4. Biology/Biochemistry	1121	11.8
5. Mathematics	491	5.2
6. Geology	330	3.5
7. Ecology	275	2.9
8. Engineering	228	2.4
9. Computer Science	111	1.2
Total	8148	85.7
Social sciences		
1. Sociology	320	3.4
2. Psychology	298	3.1
3. Economics	157	1.7
4. Political Studies	75	0.8
Total	850	8.9
Other	510	5.4

It is also possible to get lists of all "research fronts" at each level for a specific nation, ranked by the national participation percentage in descending (or ascending) order. It is easy to see, at which of the "fronts" this nation is participating strongly resp. weakly (compared to that nation's statistical mean percentage of all institutional addresses over the total of all "research fronts"). This procedure does not establish any kind of "quality" indicator for a nation. It is only a measure of "activity" of the researchers of a particular nation at the various "research fronts" generated by the co-citation analysis. These national rankings are most easily identified at the highest aggregation level C4. The list with the West German ranking order on C4 shows a participation of 9.05% for Germany at the C4-"front" no.18 "Laser, microwave and other studies of small molecules", which is remarkably higher than the German mean (cf. Table 5). The same applies in this case for France, Japan and the "rest of the world", whereas the US and GB remain below their mean values. It should be stressed however, that the clusters at the C4-level are very broad categories (which can be seen in some cases from the cluster names). Because thousands of documents are linked together by the clustering algorithm there may be much variety inside of a cluster. Therefore it is necessary to look at the lower levels, before interpreting the rankings.

On the next lower level C3 national patterns are emerging somewhat clearer (cf. Table 6). At the top of the list with no. 104 and no. 167 two "parts" of the C4-"research front" no. 18 can be found. Additionally, a significant number of "fronts" are listed, which have not been clustered up to the C4-level (because the clusters missed co-citation links to other clusters at their level). These are marked with a "-" in the column "C4", in all other cases the number in that column gives the number of the supercluster on C4-level.

A first glance at this German C3-ranking already shows the predominance of physics and chemistry at the top positions, whereas the first social science "front" appears at rank position 68. This observation can be further systematized: by introducing a rough disciplinary classification it is possible to set up a specific disciplinary profile of all 179 C3-"fronts". (Disciplinary classsification of clusters can be done by counting the journals of the core documents - or of the "front" documents as well.) The distribution of the total number of C3-clusters is as follows (Table 7):

It should be kept in mind that this distribution is "US"-biased, because more than 46% of all corporate addresses in the "research fronts" are from the US. Considering only those 77 "fronts" at which the activity of German researches is higher than the mean (>5.1%), there is a predominance of chemistry and physics and engineering science (Table 8):

Table 4: Overall country participation at SCI/SSCI "research fronts"

Corporate addresses
absolute numbers

Country	C1	C2	C3	C4
USA	385.485	237.238	168.844	135.970
GB	64.360	40.279	28.796	23.335
J	44.355	27.501	20.519	16.483
D	40.830	25.647	18.404	15.044
F	39.021	24.457	17.834	14.738
Rest	245.821	151.854	109.315	88.701
Total	819.872	506.976	363.712	294.272

Corporate addresses
% of total

Nation	C1	C2	C3	C4
USA	47.0	46.8	46.4	46.2
GB	7.8	7.9	7.9	7.9
J	5.4	5.4	5.6	5.6
D	5.0	5.1	5.1	5.1
F	4.8	4.8	4.9	5.0
Rest	30.0	30.0	30.1	30.1
Total	100.0	100.0	100.0	99.9

On the other hand within the 100 "fronts" below the mean of 5.1% there are more clusters for biology and the social sciences. From this comparison of the top against bottom half of the ranked C3-listing there are first hints at where to look for strengths and weaknesses of German science (in the sense of publication activity at "research fronts"). Before going into a detailed evaluation it is, of course, necessary to take care of varying size of several of the "fronts". For very small "research fronts" a few documents can change the national percentages dramatically, whereas for large "fronts" many more documents have to be "moved", until the percentages are changing significantly. Therefore, those "fronts" are especially remarkable, which are of high size (i.e. are including many source papers) and have at the same time a high proportion of German authors.

The results of the co-citation analysis at the C3-level can be summarized as follows: strong publication activity of German research institutions takes place mainly in the disciplinary fields of chemistry and physics/engineering sciences. The German presence at "research fronts" in the social sciences, biology and geosciences on the other hand, is rather weak. In the areas of biomedicine/biochemistry and mathematics/computer science the German activity appears to be "normal", i.e. there are no significant deviations from the over-all mean. It should be repeated however, that clusters of the C3-level are highly aggregated units, the number of documents at the "research fronts" is very high. Within those "fronts" the national participation may vary significantly at the lower levels of aggregation. There will be hardly a homogeneous distribution of all C2- and C1-"fronts" inside such a C3-supercluster. The identification of very small specialities with their high resp. low national participation values become possible this way. The mass of available details for each "research front" (as described in chapter 3.1) hereby allows to arrive at the level of specific institutions and publications at the C1-"fronts".

Clusters and "research fronts" which are generated through the cluster analysis of co-citations are synthetically composed units, built by the clustering algorithm on the base of scientific publication and citation activity in the year 1984, as it is reflected in the actual journal set of SCI and SSCI. One cannot expect to obtain a 100% match of known subdisciplines with the generated "research fronts". It is, on the contrary, one of the main advantages of the method, that the resulting clusters are independent from any such disciplinary categories.

Nevertheless the structure of the generated units is well organized in the way that at the lowest level of aggregation it is possible via the retrieval software to have direct access to 9,508 "research fronts". Thus, for any given research area, through the titles of the clusters

Table 5: All C4-"Research fronts" - national participation (German ranking)

rank	C4	USA	GB	D	F	Japan	other	title
1	14	23.46	21.11	10.56	12.32	6.74	25.81	GENERATION AND ELECTRON-SPIN-RESONANCE AND OTHER CHARACTERIZATION OF RADICALS AND RADICAL-IONS AND THEIR USE IN ORGANIC-SYNTHESIS
2	18	32.10	6.79	9.05	8.30	8.30	35.46	LASER, MICROWAVE AND OTHER STUDIES OF SMALL-MOLECULES
3	16	16.12	5.25	6.88	6.88	9.96	54.89	PHASE-TRANSITIONS AND OTHER PROPERTIES OF VARIOUS SOLIDS
4	2	39.20	8.51	6.73	5.06	4.57	35.94	PHOTOSYNTHESIS, MORPHOLOGY, ENVIRONMENTAL CONDITIONS AND OTHER FACTORS EFFECTING DEVELOPMENT AND GROWTH IN PLANTS
5	7	32.75	8.12	6.36	13.40	4.47	34.91	PROPERTIES OF MOLTON SLAGS AND KINETICS OF DIFFUSION AND FLOW THROUGH POROUS-MEDIA
6	12	39.93	5.75	6.26	5.47	5.55	37.04	TOPICS IN PURE AND APPLIED MATHEMATICS
7	17	46.69	5.91	6.01	8.52	6.75	26.12	STUDIES OF PLASMA PHYSICS IN THE LABORATORY AND ON THE SUN
8	9	58.04	5.86	5.52	3.39	4.75	22.43	DIAGNOSTIC TECHNIQUES AND CLINICAL STUDIES OF TUMORS AND OTHER DISEASES
9	8	36.53	8.03	5.49	10.42	7.39	32.15	THEORETICAL AND EXPERIMENTAL ANALYSIS OF STRESS IN CRYSTALS, METALS AND OTHER MATERIALS
10	20	26.09	8.25	5.39	8.75	4.71	46.80	MOSSBAUER AND OTHER STUDIES OF THE STRUCTURE AND PROPERTIES OF MAGNETIC MATERIALS
11	1	46.12	7.89	5.22	5.81	5.08	29.88	APPLICATIONS AND BASIC PRINCIPLES IN SOCIAL AND NATURAL SCIENCES
12	21	59.89	8.36	4.74	5.85	4.46	16.71	CATHETERIZATION, SHUNTS AND OTHER ASPECTS OF CLINICAL MANAGEMENT OF VARIOUS DISORDERS
13	15	52.45	8.28	4.70	2.86	5.42	26.28	ANTIBIOTIC THERAPY AND OTHER ASPECTS OF MANAGEMENT OF BACTERIAL AND FUNGAL INFECTIONS
14	13	55.02	6.79	4.53	4.45	3.77	25.45	ATMOSPHERIC AND OCEANIC STUDIES
15	5	58.02	10.31	3.19	0.91	2.10	25.47	TOPICS IN OBSTETRICS AND NEONATOLOGY
16	4	38.54	7.68	2.88	9.15	5.51	36.24	EFFECTS OF INSECTICIDES AND OTHER TOXINS ON PLANTS AND ANIMALS
17	19	37.03	7.95	2.70	8.25	7.80	36.28	MORPHOLOGY, ENDOCRINOLOGY AND VIROLOGY OF INSECTS AND OTHER ARTHROPODS
18	6	53.41	10.00	2.64	2.86	5.60	25.49	EFFECTS OF OCCUPATIONAL AND ENVIRONMENTAL SUBSTANCES
19	3	48.37	10.29	2.15	2.09	3.15	33.95	ECOLOGY, TAXONOMY AND BIOLOGY OF ANIMALS AND PLANTS
20	11	51.29	9.41	2.12	2.35	2.12	32.71	GENETIC STUDIES AND APPLICATIONS OF CODED-APERATURE IMAGING
21	10	61.52	10.61	2.05	0.89	2.54	22.38	HEALTH-CARE ISSUES AND TREATMENT OF JOINT DISEASE

the "research fronts" can be displayed easily, including all informational details available in the data base. (For certain parts of the information, this can be done also by using the online version of SCI). The ability of identifying the structures of scientific publications and citations for a given thematic field in this fast and flexible manner is one of the features of the method. Another one is the possibility of getting very detailed profiles for research institutions, showing the "research fronts" at which these institutions are active.

4. Conclusion

A comparison of the results of sections 2 and 3 shows that, due to methodological differences it is not feasible to relate directly the outcomes of the two different procedures to each other. The original intention of extending the status-quo analysis (co-citation data) by a ten year time series (of publication and citation counts) could not be realized, because in most cases it was not possible to match the "fixed" field and subfield categories of the time-series data to the synthetically generated units (cluster cores and "research fronts") of the co-citation analysis.

Nevertheless, there are some hints that the results of both analyses are converging at least at the higher levels of aggregation. An overview of the time-series data as well as the co-citation analysis gives the impression of Germany having its strengths mainly in the disciplines of chemistry and physics, whereas its weaknesses are to be found in clinical medicine and the geosciences. Biochemistry, computer science and to a certain degree also mathematics show no significant deviations from the international means. However the convergence of the results must be handled with great care, mainly because of the very high level of aggregation. The results are of such generality that it is not clear why one would need an extensive data base to obtain them. A successive introduction of the two methods could make more sense: to take the time-series data for identifying broader areas which can be split up into subfields with significantly high or low performance for a certain space of time. The co-citation analysis then provides actual data of national participation at "research fronts" and makes available very detailed information for each of those "fronts". It is possible with co-citation data to arrive at institutional profiles. The main advantage of co-citation analysis however is not its capability to supply disaggregated data. It is rather the possibility of identifying patterns of scientific activity and communication structures without using any of the traditional disciplinary categories.

Table 6: C3-"research fronts" (selection, ranked by German participation)

rank	C3	C4	USA	GB	D	F	Japan	rest	title
1	124	1	23.12	2.76	13.32	8.04	6.03	46.73	DIFFUSION OF MUONS AND OTHER LIGHT PARTICLES IN METALS AND PROPERTIES OF TWO-DIMENSIONAL ELECTRON SYSTEMS
2	45	14	18.81	25.69	12.39	13.76	6.42	22.94	REACTIONS, ELECTRON-SPIN-RESONANCE STUDIES AND OTHER CHARACTERIZATION OF ORGANIC RADICALS AND RADICAL-IONS
3	104	18	26.54	8.35	11.55	8.11	6.63	38.82	HIGH-RESOLUTION MICROWAVE AND OTHER STUDIES OF SYMMETRICAL AND QUASI-SYMMETRICAL SMALL MOLECULES
4	169	-	46.30	1.85	11.11	1.85	5.56	33.33	STUDIES IN DISPERSIVE TRANSPORT
5	79	-	24.39	5.18	10.67	16.77	6.40	36.59	SYNTHESIS AND REACTIONS OF AZIDE DERIVATIVES AND AZO COMPOUNDS
6	166	-	41.79	7.46	10.45	11.94	10.45	17.91	POWER REQUIREMENTS AND OTHER CHARACTERISTICS OF MIXING IMPELLERS
7	151	-	51.97	6.30	10.24	2.36	9.45	19.69	TOPICS IN MAMMALIAN RESPIRATORY FUNCTION AND ENVIRONMENTAL SCIENCE
8	167	18	39.48	4.43	9.96	12.55	15.50	18.08	TECHNICAL ASPECTS AND APPLICATIONS OF LASER-SPECTROSCOPY
9	9	1	34.42	5.97	8.70	8.45	6.15	36.31	PHYSICS OF CRITICAL PHENOMENA AND STUDIES OF AMORPHOUS AND POLYMERIC SYSTEMS
10	134	-	36.16	8.38	8.70	7.42	6.26	33.09	ENZYME DEFICIENCIES AND RETINAL ANOMALIES
					. . .				
68	56	-	62.30	8.74	5.46	0.55	0.00	22.95	ATTITUDES TOWARD PSYCHIATRY AND AUTHORITARIAN, CONSERVATIVE AND RELIGIOUS VALUES
					. . .				
172	136	1	32.41	9.88	0.79	14.62	6.32	35.97	MANAGEMENT AND IMMUNOLOGY OF ALLERGIC REACTIONS AND INFECTIONS
173	40	-	48.28	10.34	0.69	2.07	2.07	36.55	COMPLICATIONS AND MANAGEMENT OF BONE-FRACTURES
174	66	-	65.84	14.91	0.62	0.00	0.62	18.01	URBAN-POLICY AND OTHER CONSIDERATIONS IN PRIMARY HEALTH-CARE STRATEGIES
175	32	1	79.80	7.88	0.49	0.00	0.00	11.82	DEATH, BEREAVEMENT AND POST-TRAUMATIC STRESS DISORDERS
176	74	-	4.06	0.31	0.31	1.25	0.63	93.44	THERMODYNAMIC AND OTHER STUDIES OF ION SOLVATION AND ION CLUSTER FORMATION IN SOLUTION
177	122	-	79.76	5.65	0.30	0.30	0.60	13.39	ROLE OF PSYCHIATRY, CLINICAL PSYCHOLOGY AND OTHER BEHAVIORAL SCIENCES IN COMMUNITY ISSUES AND PUBLIC-HEALTH
178	73	1	84.09	3.74	0.16	0.00	0.00	12.01	SOCIAL AND MEDICAL ASPECTS OF ADOLESCENT DRUG USE
179	133	-	43.59	14.10	0.00	7.69	1.28	33.33	DENTAL PROSTHESES AND RESTORATIVE MATERIALS

For several reasons any evaluation and comparison focussing on individual authors should never be performed by using data of the co-citation analysis. On the one hand the differences between "individual" results of the co-citation analysis and the real individual scientific activity as measured through publication lists are too great to allow an evaluation of single scientists. Scientific publishing activity is on the other hand in most cases the work of teams or institutional units. Even if those groups are influenced by certain individuals, normally a "critical mass" of scientific capacities is needed for holding a position of high research activity with high impact on the scientific community.

It is to be expected that bibliometric indicators of science will not be completely routinized like economic indicators, but, that their implementation will always be bound to the judgement and interpretation of the respective experts. If that prognosis is correct co-citation analysis will become the most powerful tool since it provides the sort of selective and detailed information out of a data pool which no individual or group of experts could adequately oversee.

Notes

* This article is based upon work under German Federal Ministry for Research and Technology (BMFT) grant No. SWF0012 0

1. Originally, the CHI files contain four different types of citation indicators on both tapes. Three of them are constructed on the basis of 'real' citation counts, one on the basis of 'estimated' citation counts.
   The 'real citation count' cumulates all citations in the period observed and classifies them to the year and the country of the cited publication. The cited year is important for the classification of the 'real' citation counts. The cumulative citation count of the standard tape and the aggregated cumulative citation count from the reorganized subfield citation tape should vary only slightly, which is not true in all cases. The normalized relative citation index is also based on 'real' citation counts. On the other hand, the construction of the 'estimated citation count' is rather problematic, because "the citing and the cited countries are assigned to a given citation on a probability basis, based on the portions of the citing and cited journals contributed by each country during the same year" (Data User's Guide, 1985, p.10). For the 'estimated citation count', the citing year is decisive. The 'estimated citation count' not only varies strongly from the 'real citation count', also it's construction does not permit to separate

Table 7: Disciplinary distribution of C3-clusters

	number of clusters	%
biomedicine and biochemistry	75	41.9
other biological sciences	24	13.4
physical science and engineering	35	19.6
chemistry	16	8.9
mathematics and computer science	9	5.0
geosciences	7	3.9
social and behavioral sciences and psychiatry	13	7.3
total	179	100.0

Table 8: Disciplinary distribution of (German) top 77 C3-clusters

	number of clusters	%
biomedicine and biochemistry	31	40.3
other biological sciences	5	6.5
physical science and engineering	21	27.3
chemistry	13	16.5
mathematics and computer science	4	5.2
geosciences	2	2.6
social and behavioral sciences and psychiatry	1	1.3
total	77	100.1

short-term and long-term impact. The 'estimated citation count' has therefore been dropped by CHI in the meantime.

2. The published version of the Science Citation Index includes a statistic, which seperates citations according to the citing and the cited year at the same time. This statistic gives an overview over the general time-lag between publications and the corresponding citations. The specific citation patterns within special research areas may differ from that general pattern.

3. Being irritated by strong oscillations in the performance of German science in various subfields, we asked CHI to deliver some additional information about the classification of journals to the single subfields, the national address of the journals and the year in which the journal is integrated into the data base or, on the contrary, has been dropped. From this special information we can isolate such cases where rapid changes are due to special editions of journals, e.g. special yearbooks, or the omission of these journals.

4. Small, H.G. and B.C. Griffith, 1974; B.C. Griffith, H.G. Small, J.A. Stonehill and S. Dey 1974. In 1985, H. Small, E. Sweeney and E. Greenlee presented some major improvements and reviewed the state of the art of the procedure H.G. Small and E. Sweeney, 1985; H.G. Small, E. Sweeney and E. Greenley, 1985.

5. For the details of "fractional citation counting" see Small, H. and E. Sweeney, 1985, p.393-395.

6. For the details of "variable level clustering" see Small, H. and E. Sweeney, 1985, p.395-397.

7. This data has been supplied by Henry Small from ISI.

References

Data User's Guide to the National Science Foundation's Science Literature Indicators Data Base, Computer Horizons Inc., New Jersey, 1985.

Griffith, B.C., H.G. Small, J.A. Stonehill and S. Dey, The structure of scientific literatures II: Toward a macro- and microstructure for science, Science Studies 4 (1974) 339-365.

Small, H. and B.C. Griffith, The structure of scientific literatures I: Identifying and graphing specialities, Science Studies 4 (1974) 17-40.

Small, H. and E. Sweeney, Clustering the Science Citation Index using co-citations. I. A comparison of methods, Scientometrics 7 (1985) 391-409.

Small, H.G., E. Sweeney and E. Greenley, Clustering the Science Citation Index using co-citations. II. Mapping science, Scientometrics 8 (1985) 321-340.