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The publication output and impact of academic chemistry research in the Netherlands during the 1980s: bibliometric analyses and policy implications [1]

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Abstract

This paper presents a bibliometric assessment of the output and impact of the research activities in the field of chemistry at universities in the Netherlands during the period 1980–1991. It analyses the position of The Netherlands Foundation for Chemical Research (SON), which is a subsidiary of the Netherlands research council NWO. The methodology applied in the study represents a synthesis of 'classical' macro indicator studies on the one hand, and bibliometric analyses of research groups and subfields at the micro- or meso-level on the other. We found that academic chemical research in the Netherlands has gained a high impact compared with a world average, and that the chemists tend to publish in high impact journals as well. The highest impact is achieved by papers that were written in collaboration with scientists from groups outside the Netherlands, indicating that the Dutch chemists play an important role in international scientific networks.

There is a significant correlation between a group's bibliometric impact and the financial support obtained from SON. We discuss several aspects of this correlation in more detail, and draw conclusions with respect to the usefulness of bibliometric analyses and implications for research policy.

1. Introduction

This study relates to the publication output and impact of 656 senior scientists in the field of chemical research in the Netherlands. The time period covered is 1980–1991. The study is based on a quantitative analysis of scientific articles published in journals processed for the Science Citation Index (SCI), and containing at least one corporate address from the Netherlands. The sample of chemists analysed in this study includes all researchers who participated in 283 working groups in 17 SON working communities and who had tenured positions at Dutch institutions in May, 1992. The institutions involved are mainly Dutch universities. On the basis of an analysis to be presented in Section 2 of this article, we will demonstrate that the publication output of our sample of scientists covers, in most chemical subfields, a very large part of the total output originating from Dutch universities. Therefore, one may

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[1] This paper is partly based upon the research report "Bibliometric Profiles of Academic Chemistry Research in the Netherlands. A Bibliometric Study on the Publication Output and Impact during the Time Period 1980–1991 of 656 Senior Scientists Participating in 17 Departments ('Working Communities') of the Netherlands Foundation for Chemical Research (SON)", by H.F. Moed and J.G.M. van der Velde.
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conclude that this study covers adequately the publication output in the field of academic chemical research in the Netherlands.

There is an increasing interest in the assessment of important aspects of scientific activities, such as structure and developments of scientific fields, interaction between science and technology, research performance of nations or research groups, and international scientific collaboration. Economic restraints lead to a sharpening of choices within fields of science and between fields. Politicians, policy makers, and even scientists call for 'accountability' and 'value for money', simply because funds for science have to be weighted against funds for other societal activities. Also within the sciences priorities have to be set.

Traditionally, information on science was primarily supplied by the scientists themselves. This expertise of scientific peers is mainly related to the assessment of the cognitive state-of-the-art of particular fields or research specialities. It is primarily an assessment on the meso- or micro-level. Science policy and R & D management need assessments on a macro-level too, i.e. information of a broader scope. Here *science and technology indicators* come into the picture *not as a replacement of peer expertise, but rather as a support tool.*

During the past decades, science indicators have been applied in many policy-relevant studies (Garfield, 1979; Martin and Irvine, 1983; Moed et al., 1985; Van Raan, 1993). Science indicators are aggregate statistics derived from the scientific literature. A principal assumption underlying the use of science indicators is that scientists publish their research findings in the publicly available literature. Therefore, one may obtain pictures of scientific activities from a quantitative (bibliometric) analysis of scientific texts.

The Netherlands Foundation for Chemical Research (SON) is a subsidiary of the Netherlands research council NWO. The prime objective of the SON foundation is to stimulate advanced innovative fundamental and strategic chemical research at Dutch universities. SON's annual budget of some 28 million guilders amounts to 16% of the total of 175 million guilders of annual government expenditure for academic chemistry research. According to SON data, university chemistry in the Netherlands includes a workforce of 170 professors, 370 senior scientific staff, and 1200 graduate students and post-docs. SON supports about 150 research groups at Dutch universities, financing about 25% of the graduate students and post-docs and 40% of the research equipment. This support spans a broad scientific field, from chemical physics, physical and synthetic chemistry, chemical engineering, biochemistry into molecular biology and biotechnology. SON pursues a national coordinating role for university chemistry research in the Netherlands, both via its support of research programmes and facilities and via its working communities for various subfields and interdisciplinary discussion groups. Frequent 1- and 2-day meetings are organised where smaller groups of senior and junior academics and experts from industry discuss research problems, important developments, and progress. In addition, they promote cooperation.

The foundation's principal task of recognising and selecting high quality research proposals has traditionally been based on various forms of peer review; also for the future, this is foreseen as the principal approach. However, out of curiosity and also because of the regularly appearing criticisms of peer review methods, the foundation decided to initiate a bibliometric study of the productivity and impact of the 283 research groups associated with the foundation.

The objectives of the study were twofold:

1. To conduct a thorough analysis of the publication and citation scores for all the groups that apply for funds as such data may be useful as additional support for funding decisions;
2. To be prepared when influential sponsors (government departments, university boards) draw unwarranted conclusions from overly publicised ratings, often resulting from quick commercial studies. For instance, in 1992 in such a rating a chemical engineering department in the Netherlands turned out to be number two in the world. However, if the definition of chemical engineering had been chosen slightly differently, this department would not have been in the top 25 (Pendlebury, 1992, p. 8).

The main issues addressed in this study are:

1. What is the impact of chemical research in the working communities included in the study?
2. Are there any significant differences in impact

among the various subfields of chemistry as reflected in SON working communities (for instance, nucleic acids research, analytical chemistry, or catalysis)?
3. Are there significant differences in impact among universities at which the various scientists in the sample are appointed?
4. What is the statistical relationship between the level of financial support by SON to working groups (particularly positions for Ph.D. students or 'post-doc' scientists) and the international impact of these working groups?

The structure of this paper is as follows. In Section 2 we define the segment of Dutch chemistry which is covered in the study. We define accurately the sample of chemical scientists included, and compare their publication output to the output in various chemical subfields published by the total population of Dutch scientists.

Section 3 gives a short overview of the data collection and the methodology applied in the study. Essentially, our indicators relate to three different aspects of research performance: *publication output*, *impact*, and *scientific collaboration*. The publication output is measured through the *number of articles* published in journals processed by the Institute for Scientific Information (ISI) for the Science Citation Index (SCI). The impact indicators are based upon the number of times articles by Dutch scientists are cited in other publications processed for the SCI.

Indicators of international scientific collaboration are based upon an analysis of the geographic location of the authors of a paper, as reflected in the authors' addresses given in the heading of the paper.

In Section 4 and Section 5, we present the main bibliometric outcomes at *three* levels of aggregation. The 'overall' results for the sample of chemists as a whole are given in Section 4. In Section 5 we present the outcomes at the level of SON working communities (for instance, nucleic acids research, analytical chemistry or catalysis), and at the level of universities.

The position of the Foundation for Chemical Research is examined in Section 6. Finally, in Section 7 we summarise the main outcomes of our study and discuss their policy implications.

2. Segment of Dutch chemistry covered in the study

2.1. Sample of chemists included in the study

The administration of the Netherlands Foundation for Chemical Research (SON) has compiled data on

Table 1
Publication output in 1991 per category of the sample of SON chemists, compared with the total Netherlands output

Category [a]	No. SON publ. [b]	No. SON univ. publ. [c]	Total NL publ.	Total NL univ. publ. [c]	SON/NL publ. (%)	SON univ./ NL univ./ publ. (%)
Biochem. & mol. biol.	330	300	699	623	47	48
Chem., physical	154	150	265	207	58	73
Chem., organic	131	131	158	147	83	89
Chem., general	130	127	215	178	60	71
Chem., analytical	97	93	227	158	43	59
Phys., at., mol., chem.	84	75	188	156	45	48
Chem., inorg. & nucl.	82	81	93	88	88	92
Microbiology	68	62	276	205	25	30
Biophysics	63	60	119	111	53	54
Polymer science	59	58	105	73	56	80
Crystallography	52	52	95	79	55	66
Chem. engineering	47	47	75	59	63	79

[a] Based upon a classification of scientific journals developed by ISI.

[b] Number of articles published in 1991 in the SCI with a Netherlands address by senior scientists with tenured positions at Dutch institutions (mainly universities) at May, 1992, and who participated in 283 working groups in 17 SON 'working communities'.

[c] Here we counted the number of articles authored by scientists who indicate at least one university department in their addresses.

the names and affiliations of all senior scientists participating in SON working groups, who were active in May, 1992. Since these data are used by SON in the daily practice of running the foundation, they are highly reliable. Senior scientists were defined as scientists with a tenured position in one of the institutions involved. Senior scientists (for example, university professors) who have been active in the period 1980–1991 but who retired before May, 1992, were *not* included in the study.

Our set does not contain *all* senior chemical scientists who were active in 1992 in the Netherlands, but only those who participated in SON working groups. The overwhelming majority of these scientists are from Dutch universities. In fact, the sample includes almost all senior chemists with appointments at Dutch universities in May, 1992. Our sample will be labelled as 'SON chemists' throughout this report.

The 656 chemists participate in 283 SON working groups. A working group normally consists of one or two group leaders, senior scientists, and a number of junior scientists who work for their Ph.D. and who are supervised by a group leader or one of the other senior scientists. A working group will be referred to as a group throughout this paper. These working groups are aggregated in 17 SON working communities, covering various subfields in chemical research. The SON chemists are active in 14 institutions: 11 universities and three research institutes, [2] with more than 90% working at the universities.

It should be noted that scientists may move from one institution to another. In this study, however, we link scientists to institutions on the basis of their affiliations in May, 1992.

2.2. Publication output of the sample of chemists compared with the total output in chemical research in the Netherlands

In this section we analyse the publication output of the chemists in our sample and compare their output to the total Dutch publication output in chemical research. The publication output is defined as the number of articles with a 'Netherlands' address published in journals processed for the Science Citation Index (SCI). As article types we have included normal articles, letters, notes, reviews, and proceedings papers since these types are usually considered as fully fledged research articles. We use a classification of scientific journals into 'journal categories' developed by the ISI. In fact, the ISI has assigned each journal processed to one or more categories which correspond roughly to scientific subfields. This classification based on journal categories is designed to facilitate literature searchers, and does not coincide with the groupings of scientists into working communities. Below, we count the number of Dutch articles per category. If a journal is assigned to two categories rather than one, we apply a so-called fractional counting scheme. A paper in such a journal will be assigned half to each category. For more details related to the publication database that we utilised and to the ISI categories, refer to Section 3.

The *first* column in Table 1 gives the name of the *journal categories*. We included the 12 categories in which the SON chemists have the highest publication output in 1991. The total number of papers by the SON chemists in these 12 categories constitutes about 70% of the total output of the SON chemists in 1991. The *second* column in Table 1 presents the numbers of articles published in the year 1991 in each category by the scientists in our sample. The category *biochemistry and molecular biology* ranks first with 330 papers published in 1991. The category *chemistry general* contains general journals such as the *Journal of the American Chemical Society* and *Receuil des Traveaux Chimiques des Pays-Bas*.

The *third* column in Table 1 gives the number of papers authored by SON chemists and containing at

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[2] The working communities are: *analytical chemistry, bio-energetics, bio-organic chemistry, catalysis, coordination chemistry and homogeneous catalysis, physical-organic chemistry, lipids and bio-membranes, liquids and interfaces, macromolecules, molecular genetics, molecular spectroscopy nucleic acids, organic synthesis, process technology, protein research, quantum-theoretical chemistry, solid state chemistry and materials science.* The universities involved are (in alphabetical order of their abbreviations): The Erasmus University at Rotterdam (EUR); The Catholic University at Nijmegen (KUN); The Agricultural University at Wageningen (LUW); The University of Gronigen (RUG); The University of Leiden (RUL); The University of Utrecht (RUU); The Delft University of Technology (TUD); The Eindhoven University of Technology (TUE); The University of Twente (UT); The University of Amsterdam (UVA); and The Free University at Amsterdam (VUA).
The research institutes involved are the following: The FOM Institute for Atomic and Molecular Physics in Amsterdam (AMOLF); The Netherlands Cancer Institute in Amsterdam (NKI); and The Netherlands Organisation for Applied Research (TNO).

least one address indicating a university department or group. It should be noted that if a paper is the result of a *collaboration* between a university scientist and an author from a company or another type of organisation (so that it contains both a university and a non-university address) such a paper is considered in this table as a university paper.

The total number of Dutch publications in 1991 is presented in the *fourth* column of Table 1. In the *fifth* column we give the number of Dutch publications originating from *universities*. The *sixth* column shows the percentage of all SON papers compared with the total Dutch output (both from universities and other research organisations). Finally, the last column in this table gives the relative contribution of our SON *university* chemists to the total Dutch *university* output in each category.

Table 1 indicates that even in industrially highly important fields such as polymer science and chemical engineering the major part of the international publications originates from universities and in particular from SON groups. This illustrates the role of university/SON research as an important window for Dutch industries on international scientific developments.

Roughly speaking, in the typical chemical categories (*organic* and *inorganic & nuclear chemistry*; *polymer science*; and *chemical engineering*) the SON university output constitutes about 80 to 90% of the total Dutch university output. An exception is the category *analytical chemistry*, in which only 59% of all Dutch university papers is (co)authored by the university scientists in our sample. In categories with strong connections to other disciplines (*biophysics*; *biochemistry and molecular biology*; *atomic, molecular & chemical physics*; and *microbiology*) this percentage is around 50 or lower. *Physical chemistry* (66%) and *crystallography* (59%) have relatively strong links to other disciplines as well (particularly physics).

For the categories showing strong links with other disciplines it is not surprising that the percentages of university papers in our SON sample relative to the total Dutch university output is rather low. Many scientists who are active in these categories may not view themselves primarily as chemists, and consequently, will not participate in any working community of the Netherlands Foundation for Chemical Research (SON), or apply for financial support from this Foundation.

With respect to most of the typical chemical categories we found percentages of university papers in our sample of 80 to 90. One should take into account that, similar to our comments related to categories showing strong links with other disciplines, several papers written in these categories by university scientists but not included in our SON sample may be written by authors who do not view themselves primarily as chemists, and for whom the work described in these papers constitutes a 'side line' rather than a 'main line' of research. In addition, senior scientists who retired before May, 1992, are not included, although they may still have been active in 1991 or 1990. If these scientists have published in 1991 articles not co-authored by any of the scientists included in our sample, their articles will not play a role in our study. This will particularly be so for articles authored only by such a 'retiring' scientist and one or more Ph.D. students, but not by any other senior scientist in the group. [3]

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[3] In order to give at least a rough estimate of the number of articles missed through the 'retirement phenomenon' described above we adopt the following line of reasoning. We assume that a scientist retiring in a specific year will remain active as an author only during the first 2 years after his retirement. Consequently, only scientists who retired in the years 1989, 1990, or 1991 may have published articles in 1991. Next, we assume that the overall percentage of scientists retiring in a specific year is about 3% of the total population active in that year. If we assume that retiring scientists publish on average as many papers as any other scientist in our sample, the total number of articles published in 1991 by scientists retiring during 1989–1991 may constitute some 9% of the total output in 1991 as reflected in our data. We conclude that the 'retirement phenomenon' may at least account for a large part of the discrepancies of 10 to 20% between SON and total university output in the chemical, specialised categories mentioned above.

A second factor to be considered is that articles authored only by scientists who never had tenured positions at a university are not included either (for instance, papers authored only by Ph.D. students but not by any permanent staff member). However, according to our experiences in other bibliometric studies in the field of chemistry, it is 'common practice' in a chemical research group that the vast majority of articles published by Ph.D. students or other temporary staff members are co-authored by senior scientists (particularly supervisors with tenured positions), and therefore will be included in our study.

It should be noted that the figures in Table 1 relate to the year 1991, which is actually the most recent year in our bibliometric analysis. Since scientists who retired before the month May, 1992, are not included in our study, it is to be expected that these percentages will decline as one goes back into the past. In fact, this phenomenon constitutes an important reason to focus in the bibliometric study on the more recent period 1986–1991 rather than on the total time period 1980–1991.

3. Data collection and methodology

3.1. Data collection

In this study we have utilised a large bibliometric database of scientific publications by Dutch scientists. This database contains all scientific articles, published during the period 1980–1991 in journals processed by the Institute for Scientific Information (ISI) for the Science Citation Index (SCI), the Social Science Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI), and containing at least one corporate address from the Netherlands. Moreover, it contains information on all scientific publications which have cited any of these Netherlands articles during the period 1980–1991. The database includes also citation data on all journals processed for the SCI, SSCI, or A&HCI. A detailed description of this database is given in Moed et al. (1995).

For each scientist in our set we generated lists of publications extracted from our Netherlands publication database. These lists were sent to the scientists involved in order to check their completeness and correctness (verification round). About 90% of all scientists responded to our request to check their publication lists. All additions and corrections indicated by these scientists were entered in our database. As a result, we obtained reliable publication data for at least 90% of all authors in our set.

3.2. Output and impact indicators

We calculated the following 11 indicators. These are listed in Table 2. For a detailed description refer to Moed et al. (1995). The *first* statistic gives the total number of papers published by a working group during the entire period (*P*). We considered only *normal articles*, *letters*, *notes*, *reviews*, and *proceedings papers*. Meeting abstracts, corrections, and editorials are *not* included, since these types are not considered as full research articles. In a few cases a paper is published in a journal for which no citation data are available, or that is not assigned to an ISI journal category. These papers are not considered in the calculation of the indicators presented in this table. The next two columns give the total number of citations received (*C*), and the average number of citations per publications (*CPP*). In these figures self-citations are included. We applied a variable citation window. For instance, with respect to articles published in 1980, we counted citations received during the period 1980–1991, while for articles from 1990, citations were counted during 1990–1991.

A self-citation to a paper is a citation given in a publication of which at least one author (either first

Table 2
Indicators of scientific collaboration during the time period 1986–1991

Type of collaboration	*P*(%)	*C*	*CPP*	*CPPex*	*%Pnc*	*CPP/ JCSm*	*CPP/ FCSm*	*JCSm/ FCSm*	*%SELFCIT*
No collaboration	5275 (53%)	32499	6.2	4.2	25.8	1.08	1.27	1.17	31.5
Collaboration within the Netherlands	2588 (26%)	16680	6.5	4.3	26.0	1.12	1.37	1.22	34.1
International collaboration	2180 (22%)	19672	9.0	6.0	23.0	1.28	1.71	1.33	33.1

P, the number of articles published.
C, the number of citations received.
CPP, the average number of citations per article.
CPPex, the average number of citations per article, self-citations not included.
%Pnc, the percentage of articles not cited during the time period considered.
CPP/JCSm, the average number of citations per article, divided by the mean citation rate of all papers in the journals in which the articles are published.
CPP/FCSm, the average number of citations received, divided by the world citation average in the subfields (journal categories) in which the scientists are active.
JCSm/FCSm, the mean citation rate of all papers in the journals in which the scientists have published, divided by the world citation average in the subfields (journal categories) in which the scientists are active.
%SELFCIT, the percentage of self-citations.

author or co-author) is also an author of the cited paper (either first author or co-author). The *fourth* indicator is the average number of citations per publication calculated while self-citations are not included (*CPPex*). The percentage of self-citations (relative to the total number of citations received) is presented in the last column of Table 2.

The next indicator is the percentage of articles not cited during the time period considered (*%Pnc*) when self-citations are included. The *sixth* indicator gives the mean citation rate of the journals in which the group has published (*JCSm*, the mean journal citation score), taking into account both the type of paper (e.g. normal article, review, and so on), as well as the specific years in which the group's papers were published. To give an example, the number of citations received during the period 1985–1991 by a *letter* published by a group in 1985 in journal *X* is compared with the average number of citations received during the same period (1985–1991) by all *letters* published in the same journal (*X*) in the same year (1985). Generally, a group publishes its papers in several journals rather than one. Therefore, we calculated a weighted average *JCS* indicated as *JSCm*, with the weights determined by the number of papers published in each journal.

The *seventh* indicator is the mean citation rate of the subfields (journals categories) in which a working group is active (*FCSm*, the mean field citation score). Our definition of subfields is based on a classification of scientific journals into *categories* developed by the ISI. Although this classification is far from perfect, it is at present the only classification available to us. Table 1 shows the most important journal categories of the articles in our SON set. In calculating *FCSm*, we used the same procedures as the one we applied in the calculation of *JCSm*, with journals replaced by subfields. In most cases, a group is active in more than one subfield (i.e. journal category). In those cases, we calculate a weighed average value, the weights being determined by the total number of papers the group has published in each subfield.

The next indicators compare the average number of citations to a group's oeuvre (*CPP*) to the corresponding journal and field mean citation scores (*JCSm* and *FCSm*, respectively), by calculating the ratio for both. If the ratio *CPP/FCSm* is above 1.0, this means that the group's oeuvre is cited more frequently than an 'average' publication in the subfield(s) in which the group is active. *FCSm* constitutes a *world average* in a specific (combination of) subfield(s). *In this way, one may obtain an indication of the international position of a research group, in terms of its impact compared with a 'world' average.* This 'world' average is calculated for the total population of articles published in ISI journals assigned to a particular subfield or journal category. As a general rule, about 80% of these papers are authored by scientists from the United States, Canada, Western Europe, and Japan. Therefore, this 'world' average is dominated by the Western world. If the ratio *CPP/JCSm* is above 1.0, the mean impact of a group's papers exceeds the mean impact of all articles published in the journals in which the particular group has published its papers (the group's journal packet). Finally, if *JCSm/FCSm* is above 1.0, the mean citation score of the journal packet in which the group has published exceeds the mean citation score of all papers published in the subfield(s) to which the journals belong. In this case, one can conclude that the group publishes in journals with a high impact. It should be noted that the three last mentioned indicators are dependent upon each other. The value of each one of these follows directly from the values of the other two indicators.

3.3. Indicators of scientific collaboration

The indicators of scientific collaboration are based on an analysis of all addresses in papers published by a group. We identified first all papers authored by scientists from one group only. To these papers we assigned the collaboration type '*no collaboration*'. With respect to the remaining papers we established (on the basis of the addresses) whether authors participated from other groups within the Netherlands collaboration (*within the Netherlands*), and finally whether scientists are involved from other groups outside the Netherlands (collaboration type *international*). If a paper by a group is the result of a collaboration with *both* another *Dutch* group and a group *outside* the Netherlands, it is marked with collaboration type *international*.

The purpose of this indicator is to show how frequently a group has co-published papers with other groups, and how the impact of papers resulting from national or international collaboration compares with the impact of publications authored by scientists from one research group only.

3.4. Coverage of the Science Citation Index

As mentioned in Section 3.1 we conducted a 'verification round' in which the scientists involved were requested to check lists of publications extracted from our Netherlands publication database containing ISI publications only. In addition, we conducted a survey in which the scientists could give an estimate of the number of publications published in other sources: international journals not covered by the ISI databases, national journals, proceedings of international conferences, books (thematic collections of papers or monographs), research reports, and patents.

On the basis of the estimates provided by the scientists themselves we calculated for the time period 1988–1991 the following indicators. First, we calculated the share of the SCI-publications (*P*) in the total number of journals articles (*Pjtot*): the indicator *P/Pjtot* (%). Additionally, we calculated the percentage of journal articles (*Pjtot*) in relation to the total number of submitted publications: the indicator *Pjtot/Ptot* (%).

4. Overall results

4.1. Publication output and impact

Table 3 gives the results with respect to the indicators presented in Section 3.2. These indicators are calculated for *two* time periods: the total period 1980–1991, and the more recent period 1986–1991.

The total number of articles in our database, published by SON chemists during the time period 1980–1991 amounts to 17 080. The total number of citations to the papers during the same time period amounts to 207 841. The average number of citations per article (*CPP*) is 12.2.

A *first* indication of the impact of the articles published by SON chemists can be obtained by comparing the average citation rate of their papers (*CPP*) to the average citation rate of all articles in the journals in which SON chemists have published (*JCSm*), or to the world citation average in the subfields in which SON chemists are active (*FCSm*).

These results indicate that the papers by the SON chemists have a high impact compared with the average impact of all papers in the journals in which they have published (*CPP/JCSm* = 1.16 during 1980–1991, and 1.14 for the time period 1986–1991), and an even higher impact compared with the world citation average in the subfields in which they

Table 3
Indicators of publication output and impact

Indicator	Symbol	Period	
		1980–1991	1986–1991
No. publications in SCI	*P*	17080	10043
Total no. citations received	*C*	207841	68851
Citations per publication	*CPP*	12.2	6.9
Citations per publication, self-citations not included	*CPPex*	8.7	4.6
% Publications not cited	*%Pnc*	16.6	25.3
Mean citation rate journal packet	*JCSm*	10.5	6.0
Mean citation rate subfield(s)	*FCSm*	8.4	4.9
Citations per publication, compared with citation rate of journal packet	*CPP / JCSm*	1.16	1.14
Citations per publication, compared with citation rates of subfield(s)	*CPP / FCSm*	1.44	1.40
Citation rate journal packet, compared with citation rate of subfield(s)	*JCSm / FCSm*	1.24	1.22
Percentage self-citations	*%SELFCIT*	28.7	32.6

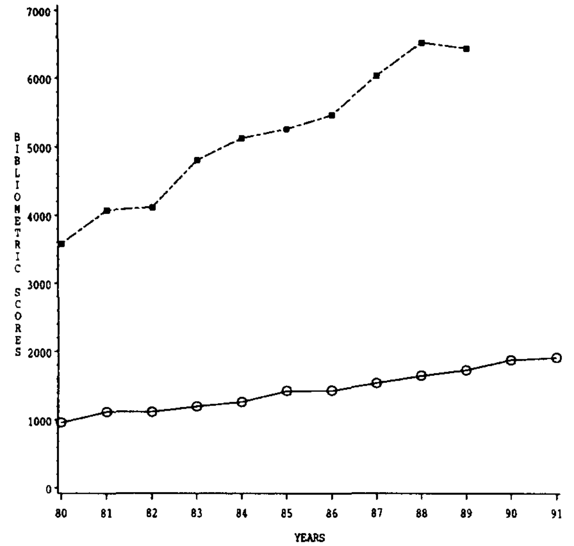

Fig. 1. Trends in the numbers of publications and short-term citations for all SON chemists aggregated. Self citations not included. Solid line, publications; dashed line, short term citations.

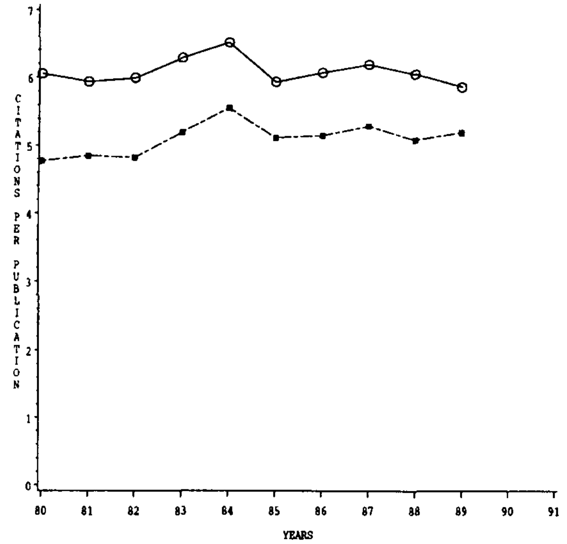

Fig. 2. Trends in the average short-term impact and journal impact of all articles by the SON chemists. Self citations included. Solid line, citations per publication group oeuvre; dashed line, citations per publication journal packet.

are active (*CPP*/*FCSm* = 1.44 during 1980–1991 and 1.40 during 1986–1991). According to a statistical test developed by Glänzel,[4] the difference between the citation-per-publication ratio (*CPP*) of our SON chemists and the world- or journal-packet citation average (*JCSm* or *FCSm*) is significant at a confidence level of 95%. Moreover the SON chemists publish in scientific journals with a relatively high impact (*JCSm*/*FCSm* = 1.24 during 1980–1991 and 1.22 during 1986–1991).

The *next* analysis is a trend analysis presented in Figs. 1 and 2. Fig. 1 shows that the annual number of articles published (*P*) increases steadily during the period, from 960 papers in 1980 to 1916 in 1991. The number of citations received during the first 3 years after publication date (*Cex*) increases as well, from 5777 citations to papers published in 1980, to 10151 citations to papers from 1989 (self-citations not included). Since citations are counted during the first *3* years after publication date (the publication year included), and since the last year covered by our database is 1991, the publication year 1989 is the most recent year for which the 3-year citation window can be applied. The publication output of our sample of SON chemists increases by a factor of two. In order to give an adequate interpretation of this result, one should keep in mind that several scientists in our sample were junior scientists during the beginning of the time period, and became senior researchers or even group leaders in later years, while senior scientists or group leaders who retired before May, 1992, are *not* included in the sample. Consequently, the publication output of scientists who *started* their career during the period 1980–1991 is included in the trend figures, while the output of those who *ended* their careers during this period is not.

Fig. 2 shows the trend in the average number of citations per publication (*CPP*) published by SON chemists, compared with the average citation rate of all articles in the journals in which they have published (*JCSm*). The curve for *CPP* (solid line) is

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[4] In this study we applied a statistical test developed by W. Glänzel in order to establish whether the average impact of a group's publication oeuvre (*CPP*) differs significantly from the average impact of all papers in the group's journal packet (*JCSm*) or from the world citation average (*FCSm*) in the subfield(s) in which the group is active. For further details concerning the comparison of citation averages and the construction of expected mean citation rates refer to Schubert and Glänzel (1983) and to Glänzel (1992).

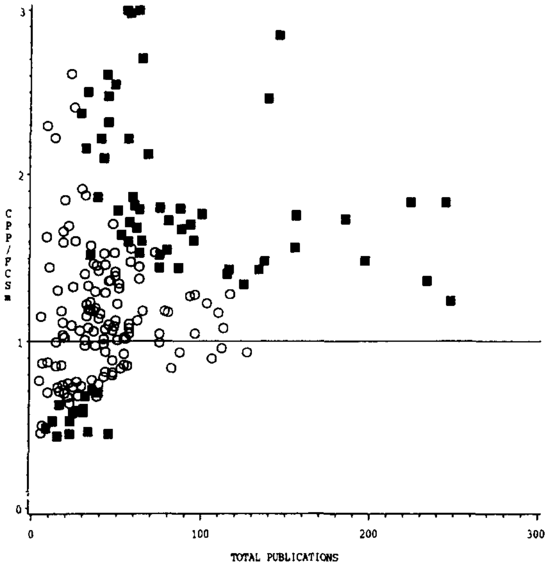

Fig. 3. Impact compared with world citation average per working group (time period 1986–1991). Black coloured squares above (below) the horizonal reference line represent groups for which the impact (*CPP*) is significantly above (below) world average (*FCSm*).

above that for *JCSm* (dashed line), reflecting the overall high impact of the papers by SON chemists. This outcome is consistent with the results presented in Table 3. Focusing on the ratio *CPP/JCSm*, there seems to be a slight decrease of this ratio during the time period considered. However, this decrease seems to be mainly due to an increase in the value of *JCSm*. This indicates that the impact of the journals in which SON chemists publish increases slightly over time.

In a third analysis, Fig. 3 shows the number of papers published during 1986–1991 (horizontal axis) plotted against the relative impact measure in which the average citation rate of papers published by a group is compared with the world average citation rate in the subfield(s) in which this group is active (*CPP/FCSm*). Groups (represented by circles or squares) located on the horizontal reference line (*CPP/FCSm* = 1.0) have an impact which is equal to the world citation average in the subfield(s) in which they are active. Circles or squares above this reference line represent working groups with an impact above world average. The world average citation rate is constructed in such a way that, for instance, the average citation rate of a working group active in *biochemistry* is compared with the world citation average in *biochemistry*, and the citation rate of a working group in *analytical chemistry* is compared with the world citation average in *analytical chemistry*. We applied the statistical test developed by Glänzel. Black coloured squares positioned above the reference line indicate groups for which the average impact (*CPP*) is significantly *higher* than the world citation average in the subfields in which the group is active (*FCSm*). Black coloured squares below the reference line indicate groups with a average impact which is significantly *lower* than the world citation average. The confidence level applied is 95%. Open circles represent groups for which *CPP/FCSm* is not significantly different from 1.0.

Fig. 3 shows first of all that the number of groups with an impact above world average by far exceeds the number of groups below world average. This confirms the general impression based upon the analyses presented above that the publication oeuvres of the SON chemists involved in the study generally have a high impact. A second interesting feature of Fig. 3 is that the groups with the highest number of papers generally have a high impact. Since the number of papers published by a group depends, at least partly, upon the size of the group, which in turn depends upon the degree of success in obtaining funds for research by the group leaders, Fig. 3 provides a first indication that the working groups being most successful in obtaining funds have a high impact at the international research front. A detailed analysis of the statistical relationship between impact of groups and the level of support from SON to these groups will be presented in Section 6.

4.2. International collaboration

Table 2 presents the results of the analysis of international collaboration. The table shows that 53% of all articles in our sample were published by authors who indicate only one institutional address in the heading of their articles. The authors of these papers are from the same research group, and therefore, no collaboration was involved with other research groups. Twenty-six percent of the articles originate from a collaboration between two or more groups located in the Netherlands. Finally, 22% of the papers is the result of a collaboration between Dutch groups and one or more groups from abroad (*international collaboration*).

It is interesting to analyse the *impact* of the articles as a function of the type of *collaboration*. All three 'relative' impact indicators (both the average impact of the papers compared with the impact of the journal packet (*CPP/JCSm*) or with the world citation average in the subfields to which the articles are assigned (*CPP/FCSm*) as well as the impact of the journal packet compared with the world citation average (*JCSm/FCSm*)) show the same pattern. They obtain the highest values for papers resulting from international collaboration, and the lowest for articles from which no collaboration is apparent in the addresses given in their headings. This pattern has been observed in several other bibliometric studies (see for instance Narin and Withlow, 1990).

Focusing on the impact compared with the world citation average (*CPP/FCSm*), and taking the overall value of 1.4 presented for all Dutch chemistry articles in Section 4.1 as a 'national' reference level, we observe that the impact of articles with no collaboration involved is below this level ($CPP/FCSm = 1.27$). Articles resulting from national collaboration have an impact which is very near to this level ($CPP/FCSm = 1.37$), while the impact of papers co-published with foreign groups is considerably higher ($CPP/FCSm = 1.71$).

Our findings are consistent with the general conclusion reached in Section 4.1 according to which the citation analysis indicates a strong international position of Dutch academic chemistry. Science becomes more and more a multi-national enterprise. Dutch academic chemists play an important role in international scientific networks and gain a substantial part of their impact from their activities in these networks.

In order to obtain a more detailed picture of international collaboration, we calculated for each individual working group the numbers of articles published during the period 1986–1991 in collaboration with groups outside the Netherlands. We found that 88% of the groups have published at least one paper with foreign groups and 48% at least nine such papers. We conclude that a considerable number of working groups participates in international collaborations, as reflected in the addresses in the headings of their articles.

Table 4
Publications subdivided by type of publication [a]

Publications types	% Publications
Publications in ISI/SON database (*P*)	70
ISI publications not in ISI/SON database	4
Publications in non-ISI international journals	2
Publications in national journals (non-ISI)	1
Publications in proceedings	8
Publications in books	3
Research reports	8
Patents	1
Other types of publications	3
All types	100

[a] Results are based on a survey among all scientists in our sample with a response rate of 66%. Data relate to the time period 1988–1991.

4.3. The coverage of the Science Citation Index

As outlined in Section 3.4, we conducted a survey among the scientists in our sample in which we asked them to give an estimate of the numbers of publications published in sources other than scientific journals covered by the ISI. Four-hundred and thirty-four chemists responded to our request. In fact, the response rate of our survey was 66%. Table 4 presents an quantitative analysis of the responses.

We found that the publications in our ISI publication database on SON chemists constitute 70% of the *total* publication output, including *all* types of publications. Four percent of the total output consisted of articles published in journals processed (at least during some years) for the ISI database, but *not* included in our publication database on SON chemists.

Table 5
Indicators on journal coverage [a]

	%
ISI/SON publications relative to total number of publications in journals (*P / Pjtot*)	91
Publications in journals relative to the total number of publications (all types, *Pjtot / Ptot*)	77

[a] Results are based on a survey among all scientists in our sample with a response rate of 66%. Data relate to time period 1988–1991.

Table 6
Bibliometric indicators per working community for the time period 1986–1991

Working community	*P*	*C*	*CPP*	*CPPex*	*%Pnc*	*CPP/ JCSm* [a]	*CPP/ FCSm* [a]	*JCSm/ FCSm*	*%SELFCIT*
Analytical chemistry	647	2827	4.4	2.9	25.7	1.17 *	1.45 *	1.24	34.8
Bio-energetics	599	4797	8.0	5.1	19.0	1.08	1.05	0.97	36.6
Bio-organic chemistry	1124	8757	7.8	5.1	21.8	1.22 *	1.46 *	1.20	34.5
Catalysis	633	2614	4.1	2.6	30.0	1.06	1.28 *	1.21	28.1
Coordination chem. & homogeneous catalysis	837	4012	4.8	2.7	23.7	1.10 *	1.51 *	1.38	44.4
Lipids and biomembranes	991	8805	8.9	5.9	21.1	1.20 *	1.22 *	1.02	34.2
Liquids and interfaces	585	3219	5.5	3.7	24.8	1.23 *	1.55 *	1.26	32.1
Macromolecules	723	3252	4.5	2.7	28.5	1.29 *	1.41 *	1.09	40.9
Molecular spectroscopy	427	2675	6.3	4.4	24.4	1.00	1.15	1.15	30.1
Molecular genetics	513	5384	10.5	7.3	17.2	1.07	1.55 *	1.46	30.7
Nucleic acids	1262	16587	13.1	10.4	20.3	1.12 *	1.73 *	1.54	21.2
Organic synthesis	912	3823	4.2	2.2	26.2	0.99	1.31 *	1.33	47.7
Physical-organic chemistry	1123	6161	5.5	3.2	26.4	1.11 *	1.40 *	1.27	42.7
Protein research	1046	10614	10.2	7.1	19.5	1.15 *	1.31 *	1.14	30.4
Process technology	526	1679	3.2	2.0	35.2	1.28 *	1.21 *	0.95	37.6
Quantum theoretical chem.	293	1761	6.0	3.4	24.9	1.17 *	1.49 *	1.27	42.9
Solid state chem. & material science	1098	5722	5.2	3.2	31.3	1.43 *	1.68 *	1.17	39.3

[a] An asterix indicates that the ratio is significantly above 1.0 at a confidence level of 95%.

This set of articles can be subdivided into the following subsets.

1. Articles published in ISI journals which do not contain a corporate address from the Netherlands.
2. Articles published in journals that were not processed by the ISI in all years. For instance, a new journal will be included by the ISI after 2 or 3 years. Thus, the articles published during these first years in this journal are not in our database.
3. Articles published in ISI journals with a Netherlands address that we could not find in our database, due to 'unexpected' differences in spelling of author names, volume numbers, or starting page numbers.

Articles published in *journals* not processed by the ISI but nevertheless indicated by the scientists themselves as '*international*' constitute 2% of the total output, and articles in *national journals* 1%. For publications in *proceedings* of international conferences, *books* (both thematic collections of papers and monographs), *research reports*, and *patents*, the percentages are 8, 3, 8, and 1, respectively. Finally, *other types* of publications contain 3% of the total output.

In Table 5 we calculated two relevant indicators based upon the data presented in Table 4. The first measures the percentage of articles in our ISI/SON file, and actually included in our analyses, relative to the total number of articles in scientific journals. This percentage amounts to 91%, which is rather high. It indicates that our publication file covers the total journal output by the SON chemists very well. The second indicator measures the relative importance of journals as communication media for the chemists in our sample. In fact, the percentage of journal papers (relative to the total output) amounts to 77%. We conclude that journals are by far the most important written communication media for SON chemists, and that our ISI/Netherlands database covers their journal output adequately.

5. Results at the level of SON working communities and universities

The results per working community are presented in Table 6, and relate to the time period 1986–1991. [5]

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[5] It should be noted 'double countings' do occur in this part of the analysis. If a chemist is active in two working groups rather than one, all his/her papers are assigned to each of the two working groups. In addition, if these working groups are included in different working communities, these papers are included in the statistics of both working communities. The number of scientists participating in more than one working community is about 10%.

This means that we counted citations, received during the period 1986–1991 by all articles published during the same time period. The working communities are listed in alphabetical order.

The indicator *CPP/JCSm* compares the average impact of papers published by a working community (*CPP*) to the average impact of all articles published in the journals in which the community has published (its journal packet). Table 6 shows that 11 working communities have a ratio which is significantly higher than 1. This means that their average impact is significantly higher than the average impact of all papers in its journal packet. The exceptions are *bio-energetics*, *catalysis*, *molecular genetics*, *molecular spectroscopy*, *organic synthesis*, and *quantum theoretical chemistry*. But for most of these communities the ratio *CPP/JCSm* is above 1.

A limitation of the indicator *CPP/JCSm* is that it does not take into account the level of the journal packet. Some groups may publish in high impact journals, and others in average or low impact journals. In both cases the citation rate of their papers are compared with a standard defined by the journal packets in which they have published. In order to overcome this limitation, we calculated the indicator *CPP/FCSm*, in which we compare the average impact of a group's articles to the world citation average in the subfields (defined through journal categories) in which the group is active.

Table 6 indicates that almost all working communities but two have an impact per article which is significantly higher than the world citation average in their subfields. The only exceptions are *bio-energetics* and *molecular spectroscopy*, but even for these two the ratio *CPP/FCSm* is above 1.0. Consequently, if one adopts the world citation average as a standard, there are no 'weak' chemical working communities in the Netherlands. The overall strong position of Dutch academic chemistry (in terms of impact compared with a world average), observed in Section 4, appears to be maintained in almost all chemical subdisciplines and is reflected in SON working communities.

Focusing on *JCSm/FCSm*, Table 6 shows that the observation in Section 4 that the SON chemists in our sample publish in journals with a high impact is also valid for almost each working community separately.

With respect to universities, we obtained the following results. [6] Focusing on the average impact compared with the impact of the journal packet (*CPP/JCSm*), four universities have on average an impact which is significantly higher than the impact of their journal packets. However, none of the universities shows a ratio *CPP/JCSm* below 1.0.

Considering the average impact compared with the citation average in the subfields in which each university is active (*CCP/FCSm*), we observe that all universities except two have an impact which is significantly higher than the subfield average. But even for these two this ratio is above 1.0.

Regarding the impact of the journals in which the scientists from the various universities have published, we notice that this journal impact is above the world citation average for all universities. Therefore, we conclude that the conclusion drawn in Section 4 that the SON chemists in our sample publish in journals with a high impact is valid for almost each individual university as well.

6. The position of the Netherlands Foundation for Chemical Research (SON)

In this section we analyse the statistical relationship between the level of financial support by SON to working groups (particularly the allocation of research positions for Ph.D. students or post-doc scientists) and the international impact of these groups as reflected in citations.

In this part of the study, results will be presented that can be useful as tools in an assessment of the allocation policy of SON during the second half of the 1980s. It should be emphasised, however, that our method gives only a *partial* view on the SON allocation policy. It takes into account two aspects only – although certainly not the most uninteresting

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[6] We emphasise that articles are assigned to universities on the basis of the institutional affiliations of their authors in May, 1992. If a scientist moves in 1991 from university A to university B, his or her total publication output is assigned to university B, even if a large part related to research conducted at (and financed by) university A. A more detailed comparison among universities, taking into account this migration phenomenon goes beyond the scope of this study.

ones: numbers of positions allocated by SON on the one hand, and impact as measured through citations, compared with a world citation average, on the other.

The general question posed in this section is whether there are any indications that SON has supported, generally, research groups with a high impact more strongly than groups with a low impact, or whether the groups supported most strongly by SON have on average a higher impact than those groups receiving less support.

On the basis of data provided by SON, we calculated for each group the average number of positions obtained from SON per year during the time period 1986–1990. The number of working groups involved in this analysis amounts to 180.[7] The minimum value of the average number of positions per year in our sample is 0, the maximum value amounts to 7.

We subdivided all groups into five classes according to the number of SON positions obtained, distributing the groups as evenly as possible among the classes. The results of this operation are presented in Table 7.

Table 7
Categorisation of the variable 'number of positions financed by SON'

Class	No. groups	Range (min–max) no. SON positions
Very low	24	0.0–0.2
Low	42	0.3–1.0
Average	54	1.1–2.0
High	33	2.1–3.0
Very high	27	3.1–7.0

With respect to the *impact*, we calculated for each group the indicator *CPP/FCSm*, indicating the impact compared with the world citation average. Applying the statistical test, we determined for each group whether its average citation rate (*CPP*) is significantly higher or lower than the world average citation rate in the subfields in which the group is active (*FCSm*).

The Spearman rank-correlation coefficient between the number of SON positions obtained and the impact compared with world average (*CPP/FCSm*) amounts to 0.26, and is found to be significant at the probability level of 99%. Consequently, there is a tendency in our set that the groups having received the highest number of positions financed by SON during the period 1986–1990, have also gained the highest impact during this period.

Using the categorisation of the variables 'number of positions financed by SON' and 'impact compared with the world citation average' described

Table 8
Relationship between the number of SON positions and impact: categorical data [a]

Number SON positions obtained [b]	Impact compared with world average [c]		
	Low	Average	High
Very low	3	19	2
Low	6	30	6
Average	4	33	17
High	2	22	9
Very high	0	13	14

[a] Number of working groups in the sample: 180.
[b] Number of positions for Ph.D. students or post-docs financed by the foundation SON during 1986–1990.
[c] Impact analysis relates to the time period 1986–1991. The impact of a group is considered high (low) if its citation per publication ratio is significantly higher (lower) than the world average citation rate in the subfields in which the group is active.

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[7] Three methodological issues should be clarified. The first is that university professors may be active in two (or even more) working communities rather than one. Formally, such a person will be the leader of two working groups, one in each working community. He or she may obtain positions for Ph.D. students from both SON working communities (Ph.D. positions are always allocated by SON to a working group leader). On the other hand, the two working groups contain in many cases the same, or almost the same, scientists. In this case we considered the two working groups as one single group, aggregating both the SON positions obtained, and the articles published and citations received.
A second methodological point is that several working groups were established only at the end of the time period 1986–1990, or even in 1991 or 1992. Evidently, such groups have not obtained SON positions during the entire period 1986–1990, but at most only during a part of it. Since it was considered inappropriate to compare working groups which exist during the entire period 1986–1990 with groups existing only during a part of this period, we deleted all these 'new' working groups from our sample.
The third methodological point is that we deleted all working groups of the Netherlands Organization for Applied Research (TNO) as well, since the policy is that these groups do not receive any research positions financed by SON.
As a result of the operations described above, we obtained a final set of 180 research groups.

above, we calculated a cross-table presented in Table 8. This part of our analysis has merely a descriptive nature.

Inspecting Table 8 one observes first of all that the number of groups having a high impact exceeds the number of low impact groups in the classes representing an average or above average number of SON positions obtained. This is consistent with the general picture presented in Section 4, according to which the impact of the groups in Dutch academic chemistry on average is high. Perhaps the most significant result in Table 8 is that in the class of research groups with a very high number of SON positions obtained, *none* of the groups has a *low* impact. With respect to research groups with a high number of SON positions, only two groups (6%) have a low impact. Among the groups with high impact, two groups (4%) have a very low number of SON positions, while for six groups (12%) the number of SON positions obtained is low.

Fig. 4 gives a scatter plot for all groups included in the analyses presented in this section. The total number of articles published during the period 1986–1991 (horizontal axis) is plotted against the impact compared with the world average during the same period (vertical axis). *Open circles* represent groups with a *very low* or a *low* number of SON positions obtained. *Circles with crosses* indicate groups with an *average* level of SON support, while *black coloured squares* represent groups with a *high* or a *very high* number of SON positions.

Table 9
Relationship between the number of SON positions and impact: variance analysis [a]

Number SON positions [b] obtained	Mean log *CPP / FCSm*	SD	*CPP / FCSm* [c]
Very low	−0.04	0.72	0.96
Low	0.04	0.40	1.04
Average	0.18	0.40	1.20
High	0.20	0.38	1.22
Very high	0.37	0.40	1.45

[a] Number of research groups in the sample: 180.

[b] Number of positions for Ph.D. students or post-docs financed by SON during 1986–1990.

[c] Gives the value exp (mean log(*CPP / FCSm*)) which may differ from the overall mean *CPP / FCSm* for all papers in a class.

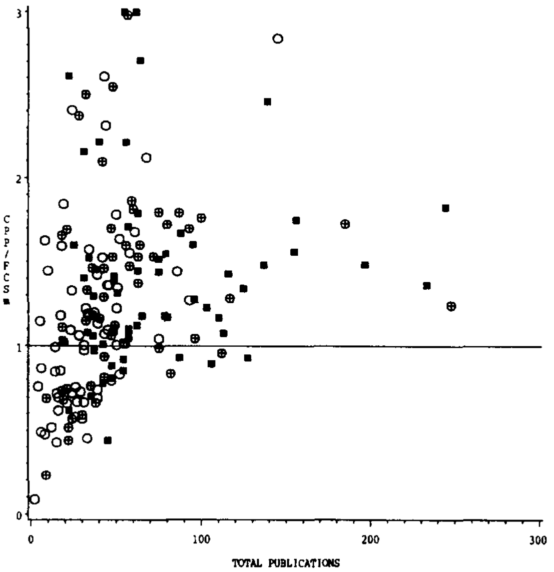

Fig. 4. Impact versus number of SON positions. Open circles represent groups with a very low or low number of SON positions. Circles with crosses indicate groups with an average level of SON positions. Black coloured squares represent groups with a high or very high number of SON positions obtained.

As a next analysis we determined for each research group the natural logarithmic value of the ratio *CPP/FCSm*. Per class of SON support we calculated the mean values and the standard deviations of this variable log(*CPP/FCSm*). The results are given in Table 9. This table shows that the mean (log(*CPP/FCSm*)) of research groups in a class increases as the level of SON support rises. [8]

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[8] We applied an ANOVA variance analysis with log(*CPP / FCSm*) as the dependent variable, and tested whether the sample means in the various classes of SON support were equal. The null-hypothesis that the sample means are equal could be rejected at the probability level of $P = 0.05$. Consequently, significant differences exist in the means of the variable log(*CPP / FCSm*) among the various classes. We compared the classes pairwise and tested for each pair whether there were significant differences between the means, applying a Tukey test at the probability level of $P = 0.05$. We found significant differences in impact between the class containing research groups with a *very low* or a low number of SON positions on the one hand, and the class with a *very high* number of SON positions on the other. For none of the other pairs of classes could significant differences in mean impact be detected.

We conclude that during the time period 1986–1990 there is a fair agreement between the level of SON support to groups on the one hand (measured through the number of positions for Ph.D. students and post-doc scientists) and the impact level of the groups compared with the world citation average on the other. We found a significantly positive rank correlation coefficient between the two variables. In addition, there are very few groups with a high or very high level of SON support that have gained a low impact compared with the world citation average. Conversely, a small part of the groups with a high impact has obtained a low number of SON positions, or no SON positions at all. Groups with a very low or a low level of SON support have an impact which is significantly lower than that of groups receiving a very high number of SON positions.

7. Discussion, conclusions, and policy implications

This study presents a bibliometric approach to the assessment of research performance. It focuses on the past performance during the time period 1980–1991 of senior scientists participating in working communities of the Netherlands Foundation for Chemical Research (SON). A large number of these scientists have tenured positions at Dutch universities.

But the study is also directed towards the future, since it analyses the performance of senior scientists who are active in 1992, disregarding the activities of those who retired or migrated from academic chemical research to other fields during the time period under consideration. The sample of scientists analysed in this study can therefore be considered to have the task to shape academic chemical research in the future.

Using a classification of scientific journals into subfields, we showed that our sample of SON chemists accounts for an overwhelming part (between 80 and 90%) of the total Dutch scientific output originating in 1991 from universities, in most of the chemical subdisciplines, particularly *organic* and *inorganic & nuclear chemistry, polymer science*, and *chemical engineering*. The SON chemists appeared to be active in subfields showing strong links with other disciplines as well, mainly in *biochemistry and molecular biology, biophysics, atomic, molecular & chemical physics*, and *microbiology*. Evidently, their contribution to the total Dutch university output in these subfields is lower than their share in the typical chemical subfields.

We concluded that for the total set of scientists in our study the scientific journal is the principal medium of written communication, and that the Science Citation Index (SCI) covers the Dutch academic output in journals very well. Therefore, we conclude that the SCI constitutes an appropriate monitor of research performance. It should be noted, however, that differences exist in publication practices among the various subfields covered in this study. Other bibliometric studies have shown that in subfields with a more applied or technical nature, scientific journals may have a less dominant position than in basic subfields. In fact, proceedings of international conferences are often very important in applied science. Moreover, patents rather than scientific publications may be relevant forms of output in a performance analysis. Even though this study relates almost exclusively to academic research, the SCI may provide only a partial view on the scientific output particularly in applied subfields such as chemical engineering.

We constructed several impact indicators based upon the number of times that articles are cited in the serial literature covered by the Science Citation Index. *Impact* and *quality of scientific* research are by no means identical concepts. Quality of research is a multi-dimensional concept, and impact is one of its components. Essentially, citations measure the quantity of response to a research work. On the one hand, a piece of research is not 'good' merely because many scientists respond to it by citing it in their papers. On the other hand, in many studies significant positive correlations were found between citations to a piece of research and the perceptions of experts on the significance and quality of that work.

Our bibliometric analyses presented in Section 4 indicate that during the time period 1980–1991 academic chemical research in the Netherlands has gained a high impact compared with the world average, and that the chemists in our sample tend to publish in high impact journals as well. We did not detect any significant changes in impact during the time period under consideration. Since the scientists involved in our analyses are the ones who have the task to shape the future of academic chemical research, our results give a positive picture of the future as well. We found that the highest impact is achieved by papers that were written in collaboration with scientists from groups outside the Netherlands.

Fig. 3 shows that the publication output and impact is not evenly distributed among all research groups involved. But interestingly, when we aggregated the groups at the level of either working communities or universities, we observed that almost all working communities and universities have gained an impact which is significantly above world average. In other words, the 'top groups' gaining the highest impact are to a considerable extent evenly distributed among working communities or universities. Our findings indicate that there are no 'weak' working communities or universities in Dutch academic chemistry during the time period 1980–1991. On the contrary, most of the working communities or universities can be qualified as 'strong' in terms of their impact.

Recently, several publications appeared in the journal *Science Watch* (published by the Institute for Scientific Information) in which impact indicators are calculated for universities or even research departments in the field of chemistry. For instance, in vol. 3, no. 3 of *Science Watch* (April, 1992), rankings are published on the top 25 universities in the subfield (i.e. journal category) organic chemistry and analytical, inorganic, and nuclear chemistry. Publications were assigned to universities on the basis of an analysis of the addresses of the contributing authors. From a detailed analysis of our data we obtained very strong indications that the ISI made several severe errors in their assignment of papers to universities. The ISI did not take into account all variations under which the name of a university appears in the addresses. For instance, the ISI seems to have missed an important variation in the name of the University of Leiden. As a consequence, the number of papers assigned to this university in the field analytical, inorganic, and nuclear chemistry is almost a factor of 2 too low.

We compared our findings at the macro-level presented in Section 4 with those obtained by Schubert et al. (1989). These authors have presented numerous data tables on publication output and impact for many countries and subfields. Their study relates to the time period 1981–1985. Applying their definition of the main field chemistry (which includes the journal categories: analytical chemistry; applied chemistry; electrochemistry; inorganic and nuclear chemistry; organic chemistry; physical chemistry; and polymer science) they found for all papers from the Netherlands a ratio 'observed versus expected citation rate' of 1.12. This ratio is rather similar to the indicator *CPP/JCSm* calculated in our study. Moreover, according to Schubert et al. (1989) the ratio of the Dutch observed citation rate and the overall mean citation rate in the main field chemistry, a measure which is similar to our indicator *CPP/FCSm*, amounts to 1.44.

These results obtained by Schubert et al. (1989) are remarkably consistent with those presented in our study, particularly if one takes into account that the methods applied in the two studies are quite different from one another. For instance, our study deals mainly with university scientists, while the publication by Schubert et al. (1989) considers the output from all types of institutions. While the Schubert study relates to the time period 1981–1985, our study relates to the period 1980–1991 or 1986–1991. Moreover, the journal category biochemistry and molecular biology is not included in their main field 'chemistry' while our sample of SON chemists contains many biochemists.

In Section 6 we examined some aspects of the statistical relationship between the impact of groups and the number of positions for Ph.D. students or post-doc scientists obtained by these groups from SON. We considered the time period 1986–1990. We found a positive (rank) correlation between these two variables in an appropriate sample of 180 research groups, which appeared to be significant at a confidence level of 99%. Moreover, there were very few groups in our sample with a high level of SON support but gaining a low impact compared with the world citation average. Conversely, only a small part of the groups with an impact significantly above world average obtained a low number of SON positions or no SON positions at all. These groups with a high impact and a low level SON support are mostly active in fields in-between chemistry and neighbouring fields such as physics or the life-sciences and they obtain their support from foundations in these fields. In fact, groups with a (very) low level of SON support have an impact which is significantly lower than that of groups obtaining the highest number of research positions from SON.

Clearly, there is a significant correlation between the bibliometric impact of a group and the financial support obtained from the research council foundation SON. However, discrepancies exist, as one should expect. Essentially, there are two types of causes for the limited number of observed discrepancies between the bibliometric impact and the financial support from SON.

1. The future is unknown, not an extrapolation of past performance. Funding decisions are based on proposals for research still to be performed. SON's policy is aimed at funding high quality research and high quality implies an essential element of risk. A basket of ambitious research proposals will inevitably also result in a few non-flyers.
2. Bibliometric indicators are not perfect. This paper presents a useful way of handling the differences in publication behaviour in various subfields of chemistry, but one should still realise that quality in, for example, chemical engineering is to a much lesser degree determinable from bibliometrics that it is in biochemistry. Also, for policy reasons we would like to concentrate on short-term citations, while the real impact of a paper can only be assessed over a longer period.

In conclusion, this study has led to gratifying outcomes such as the good international standing of chemical research in the Netherlands and the significant correlation between bibliometric impact and funding which had been based on peer review. Other interesting results include the detailed data on individual groups, the comparison of various subfields of chemistry, the observed strong relation between impact and national and international collaboration, and the high percentage of Dutch papers coming from university research, also in industrially hot areas such as chemical engineering, polymers, and catalysis, highlighting the importance of academia to industry. In order to draw firm conclusions on such topics one will usually also need evidence from other sources, but clearly a careful bibliometric analysis can provide valuable insight or raise pointed questions in many science policy matters.

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