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International visibility

Science as an international enterprise

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This paper discusses different phenomena concerning the 'internationality' of science. International visibility is enhanced by the impact of research results, which can be stimulated by changing the publication strategy towards higher impact journals. There is a strong positive correlation between international co-publication and high impact as measured by citation analysis. Political and cultural factors strongly influence international collaboration. Patterns of scientific collaboration often strikingly reflect political situations.

There are also 'science-internal', or field-dependent, factors. Often 'external' and 'internal' factors are strongly related, for instance, social sciences and humanities are more nationally and culturally oriented than the basic natural sciences. A specific bibliometric method of structuring 'maps' of research fields may provide further insight into 'internationality' and related factors in the development of science.

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ALL TYPES OF RESEARCH institutes in most places in the world are collaborating more and more. This increase has been in evidence for many years, it is a long-term and gradual aspect of science (Hicks and Katz, 1996). The same is true for a specific facet of collaboration, namely international collaboration. During the period 1981–1991, out of a total of 400,000 UK publications, the proportion based on international collaboration increased from 14% to 23%, representing an annual growth-rate of nearly 1%.

We should, however, not consider international collaboration as the indicator of scientific 'internationality'. It is only one aspect of a broader pattern of scientific activity. There are several characteristics of general scientific publication behaviour that are important indicators of internationality. Regardless of participating in international co-operation, the sole fact of publishing in an internationally visible journal is the most important aspect of 'internationality'. In other words, it is the transition from a domestic or national outlook to an inter- or transnational orientation (Zitt *et al*, 1997). Thus, we have two different phenomena in 'internationality': the strategy to become more visible internationally, and international collaboration in the formal sense.

This paper gives an overview of important aspects of the state-of-the-art in research on the 'internationality of science' from a primarily bibliometric point of view.

Change of publication behaviour

First let us discuss the strategy to become more visible internationally. Increasingly, international activity is a very general pattern of 'the global village': almost

Table 1. Number of SCI-covered journals in French

1982	1993
52	31

Source: OST (1996)

Table 2. Relative number of SCI-covered publications in different languages (%)

	1982	1993
English	89.2	94.4
Russian	5.1	2.4
German	3.0	1.5
French	1.7	1.1
Japanese	0.4	0.4
Spanish	0.2	0.1

Source: OST (1996)

everything on this planet is becoming more and more international. For instance, Hicks and Katz (1996) show that the number of airline passengers carried from the UK increased from 1981 to 1991 by 87%, and the number of international telephone calls from the UK by 138%. Internationality is evidently a broader-context phenomenon, certainly not confined to science.

In the same broader context it is understandable that scientists strive to increase their international visibility. Changing publication behaviour from nationally oriented media to international journals is a major means to achieve this goal. It is also a necessity: in order to benefit from world-wide scientific developments, the scientist has to contribute actively to these developments.

Apart from this 'broader-context' phenomenon, it is evident that science itself is not confined to national boundaries, it is global *per se*. For a very long time science, and particularly natural science, has been a 'promoter' of international contacts and exchange. But again, the same is true for other human enterprises such as trade and art.

The publication strategy towards more international visibility through international journals can be specified in three 'sub-strategies' (Zitt *et al*, 1997). The first is the choice of those international journals which are covered by the *Science Citation Index* (SCI, and sister indexes for other fields of science). It is nowadays a 'fact of life', whether we like it or not, that the SCI sets a standard for, or at least provides a powerful symbol of, international visibility.

The second step is the change of publication activity from non-English to English-language SCI journals. This is a small step, after the first, as the majority of SCI-covered journals are in English: nowadays the *lingua franca* of science is English. This is clearly illustrated by Tables 1 and 2 which give data on the change in the number of SCI-covered journals and, more specifically, the (relative) number of SCI-covered publications in French and in other major languages (for more details see OST (1996)).

In many developing countries, and in countries with a relatively strong but originally more nationally oriented research system such as Spain, we see this type of publication behaviour change. It is also partially the case for highly developed countries such as Germany and France, since their languages are no longer the *lingua franca* of science.

The third step, which is important but certainly not easy as it is research-quality related, is the change of publication activity towards the 'high-impact' SCI-covered journals.

These three strategies can be seen particularly in the natural sciences and medicine. In the social sciences and the humanities, we see that the 'shift' toward more international visibility along these steps is relatively new. It is characteristic for almost all countries, except for the UK and the USA, simply because the language of these countries is, by definition, international. This is also the reason why the SCI is undoubtedly Anglo-Saxon biased in terms of journal coverage. Be that as it may, the SCI nowadays functions as a standard in international visibility.

Now that we have an outline of this change of publication strategy toward international visibility in qualitative terms, it is important to look at the data and see what we can find empirically. We analysed all publications covered by the *Science Citation Index* and the *Social Science Citation Index* (SSCI) for the period 1976 to 1994 or almost 20 years (a total of 11,000,000!) Using the addresses in these publications, we were able to study for all countries the change of publication numbers as a function of time during this period.

We selected most European Union (EU) countries, the USA, Canada, Australia, Japan and other major Asian countries, including the rapidly developing 'Tigers'. Table 3 shows the relative numbers, indexing the figures for 1979 as 100. Table A1 in the appendix shows the absolute numbers.

If we take the world-wide growth as a reference value (1979: 100; 1995: 146.3) we immediately see striking features. First, as can be expected, the USA heavily dominates the global pattern. The breakdown of the Soviet Union is dramatically demonstrated. Very striking is the rise of China, and here we clearly show the role of the SCI (and the SSCI) as a 'monitor' on internationality. The increase of South Korea is even stronger. Next we see the other Asian Tigers: Taiwan, Singapore, Hong Kong, and, on a lower but still significantly increasing level, Japan and Malaysia. In the western world, we notice the remarkable increase of Spain, and to a lesser extent Italy. We emphasise that the above features will be the result of the interaction of two intertwined processes: a strengthening of the national research system and a stronger orientation toward internationality.

We also notice that India is falling behind. If the present developments continue, China will outvie India in a few years as the second scientific power in Asia, after Japan.

As most SCI journals are generally regarded as core journals of science which are a 'must' in libraries in the different fields of science, we can state that

Table 3. Relative publication levels by country, 1979–1995

Country	Indexed growth per year (1979=100)																
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Australia	100	105.2	110.1	107.4	114.9	120.4	121.5	123.6	125.2	129.9	133.7	144.4	151.1	157.5	168.4	182.0	185.9
Austria	100	104.8	101.5	100.1	108.6	108.9	115.6	117.5	113.7	124.1	132.3	140.4	146.0	162.1	162.7	175.5	186.9
Belgium	100	103.9	109.6	115.3	116.1	126.1	125.4	125.2	133.2	134.5	146.3	152.0	158.6	168.9	174.9	197.2	205.1
Canada	100	100.1	98.5	102.2	111.1	111.1	117.6	123.2	126.4	131.7	142.2	151.5	155.0	161.9	163.5	169.2	167.1
Denmark	100	99.6	103.9	107.2	111.9	113.4	117.8	121.9	119.0	126.3	128.4	134.7	141.1	156.8	160.4	176.8	172.8
France	100	102.9	105.0	104.9	108.2	112.8	118.0	121.4	125.5	130.2	135.2	140.8	148.2	156.0	163.2	174.3	175.3
Germany	100	98.8	103.9	104.0	107.8	110.4	115.7	116.6	119.6	121.3	127.2	134.4	136.5	136.6	143.2	150.5	153.2
Hong Kong	100	103.5	110.8	129.0	130.1	176.4	191.3	214.4	246.9	252.3	312.7	329.8	337.1	394.3	475.9	572.1	718.4
India	100	101.0	101.6	97.9	98.6	99.3	94.3	98.8	101.5	102.9	107.2	106.4	109.7	109.0	111.4	113.7	107.2
Israel	100	104.7	109.7	117.2	125.0	130.0	134.0	136.0	138.7	141.2	144.7	147.9	151.3	157.7	172.5	176.0	180.7
Italy	100	107.0	114.7	122.1	134.7	144.4	149.5	152.5	159.8	178.0	191.4	201.9	220.3	238.9	252.2	275.3	284.6
Japan	100	117.7	124.1	124.7	129.4	141.2	151.7	158.8	169.1	176.4	188.8	197.6	212.5	223.7	236.1	252.8	252.7
Malaysia	100	96.2	85.7	99.7	97.2	91.3	92.3	95.1	116.4	118.1	123.0	140.4	149.5	144.6	173.2	206.3	228.6
People's Republic of China	100	182.2	347.0	541.7	624.3	705.2	747.4	928.9	1146.5	1366.3	1532.6	1717.8	1769.8	1937.2	2095.2	2263.3	2655.2
Singapore	100	90.5	109.5	130.2	177.2	230.2	267.2	298.9	327.0	355.6	415.9	478.3	515.3	649.7	803.7	925.4	1077.8
South Korea	100	114.3	190.0	222.9	301.4	354.3	452.9	527.9	673.6	828.6	1047.1	1284.3	1580.0	1799.3	2423.6	3107.9	4157.1
Spain	100	116.8	120.2	137.1	159.4	179.3	201.8	232.2	252.6	275.8	297.4	323.5	358.5	420.1	461.2	491.6	523.9
Sweden	100	102.0	105.8	116.0	121.9	132.3	136.5	138.1	140.0	149.1	150.4	158.3	165.1	168.0	177.9	190.7	194.9
Switzerland	100	99.2	100.0	101.7	109.5	108.1	112.9	112.9	115.6	117.0	123.1	135.3	142.3	153.9	163.2	176.9	171.9
Taiwan	100	115.8	115.2	121.3	149.0	177.4	229.9	267.2	347.9	426.2	504.6	627.1	773.3	958.8	1119.7	1375.1	1499.3
Thailand	100	107.1	106.2	110.5	132.8	129.4	129.4	122.9	116.4	133.1	134.2	151.1	152.5	162.7	176.6	203.4	191.2
The Netherlands	100	102.4	110.7	116.2	132.7	141.6	148.8	153.7	160.4	175.0	187.2	203.6	209.0	227.7	241.8	255.5	259.9
UK	100	100.6	105.6	105.5	110.3	116.2	120.8	118.6	123.2	123.9	127.0	133.7	139.9	145.6	151.8	160.8	167.0
USA	100	100.8	103.7	105.8	111.7	115.1	116.6	116.3	117.6	120.0	125.0	131.5	136.6	137.0	140.0	143.9	144.3
USSR	100	101.5	109.5	109.8	102.9	124.6	124.1	119.6	118.3	122.4	127.3	131.2	127.4	109.7	99.5	102.0	89.8
World	100	100.7	103.4	104.1	110.9	116.5	118.2	117.7	119.7	122.3	126.2	130.7	134.5	135.8	139.3	146.8	146.3

Note: Figures include articles, notes, reviews and letters
USSR includes new republics

The 'final step' in acquiring international visibility is publishing in the top journals: this is not a matter of course, since high impact means highly cited, and thus aspects of research quality are involved

publication behaviour as observed through the SCI significantly reflects global patterns of international communication.

Reinforcement by impact of research results

The 'final step' in acquiring international visibility is publishing in the top journals. We stress again that this is not a matter of course. High impact means highly cited, and thus aspects of research quality are involved. Although the correlation is not perfect, in a first and good approximation we can say that most top journals are the highly cited or 'high impact' journals. Generally, research of higher quality is published in the high-impact journals. We say 'generally', since quality and number of citations are by no means 'automatically' related.

First indications of the role of the different countries in top journals can be obtained by looking at the extent to which a country is cited for all its scientific work on a world-wide scale. We show some first results as published by Braun *et al* (1995) in Table 4, for the combination of mathematics, engineering, chemistry and physics. China had a 1.04% world share of all publications in the period 1989–1993, but only a 0.29% world share in citations. In the table we see the data for a number of other countries. It is clear that, although developing countries, particularly the Asian Tigers, show impressive increases of publication in international (SCI) journals, it is much more difficult for them to make the third step in their publication strategy successfully.

As already discussed, this third step is indeed the most problematic, since research quality and not productivity is a prerequisite. The citation data in Table 4 clearly show that global research impact is strongly concentrated in the western countries. So far, Japan is the only serious competitor outside the western world. This does not mean, of course, that outside the western world and Japan there are no places of research quality. We just indicate the dominant patterns. Although science nowadays is characterised by strong international developments all over the world, the dominant position of the western world and Japan remains and is strengthening rather than diminishing.

The immediate consequences of this are that most other aspects of 'international visibility' or

Table 4. World-wide share in publications ('output') and citations ('impact') of selected countries (1989–1993) for a set of major fields

	Publications (%)	Citations (%)
USA	33.8	49.9
UK	8.1	8.7
Germany	6.3	6.4
France	4.8	4.6
The Netherlands	2.0	2.3
Spain	1.6	0.9
Japan	7.9	6.8
PR China	1.0	0.3
South Korea	0.3	0.1
India	1.9	0.6
(Former) USSR	5.9	1.1

Source: Braun *et al* (1995)

'internationality' in general, such as leading conferences, major 'big science' research facilities, and influential programmes on scientific and technological co-operation, will also be predominantly based in the western world and Japan. Other countries participate more and more, but mainly in a dependent position. Thus, it remains to be seen whether internationalisation in science will lead to more homogeneity in research profiles and performance, or that co-operative work will accentuate country differences (Miquel and Okubo, 1994).

Returning to the issue of language, we present Table 5, which gives data on the relationship between impact of scientific publications (SCI-covered) and language (for more details see OST (1996)).

International collaboration: co-publication

So far we have discussed the strategy to increase the international visibility of an institute's or country's research work. We have argued that this general characteristic is already a major aspect of the 'internationalisation' of science, regardless of collaboration. Now we look at the phenomenon of international scientific collaboration. This is the type of 'internationality' usually considered in science policy discussions.

Collaboration is possible in many ways:

Table 5. Relative impact of publications in a specific language

	1982	1992
English	1.1	1.1
German	0.5	0.3
French	0.3	0.2
Spanish	0.2	0.1
Japanese	0.2	0.1
Russian	0.2	0.1

Note: Impact all languages = 1.0
Source: OST (1996)

Distinguishing between 'tourists' (attending conferences), 'motivated' researchers (contributing papers), and 'attractive' researchers (giving invited papers), we find the latter are by far the most productive internationally

- exchange of researchers and students;
- joint research facilities and work meetings;
- organisation of international conferences;
- division of tasks in a larger and broadly defined research programme; or, almost the opposite,
- close co-operation in a well-defined project.

All these types of collaboration may range in a wide spectrum between typical individual and informal relations on one hand, and very formal, politically dominated relations on the other.

This whole spectrum of collaboration yields internationally co-authored publications, or co-publications. Such co-publications also function as symbols or evidence of collaboration. From this it is clear that an analysis of co-publications will never provide a complete picture of international scientific collaborations (Moed *et al*, 1991), but at least it gives an interesting representation of important aspects of international collaboration, such as the results in terms of concrete output.

Pioneering work on international collaboration was done by Narin's group in the USA in the 1970s. Based on these experiences, Frame and Carpenter (1979) formulated the following 'rules':

- the more basic the field, the more international collaboration;
- the larger the national research system, the smaller the international collaboration;
- 'external' factors play a major role in international collaboration.

These rules are still valid after almost 25 years.

In the work of Narin and Whitlow (1990) followed by Moed *et al* (1992) the main results on EU 'international visibility' can be summarised as follows. Between 1977 and 1990 the share of EU countries in world-wide science (in a set of selected fields) stayed stable at about 28%. The proportion of EU papers with international (outside EU) co-publication, however, increased steadily from 9.4% in 1977 through 14.6% in 1985 to 21.9% in 1990. In recent years the annual growth of such papers is about 2%. More recently, 'intra-EU' and EU–non-EU co-publication increased at about the same rate. In many cases, no significant differences were found between 'targeted' (that is, EU-stimulated) and control fields.

Recent data produced by the French Observatoire des Sciences et des Techniques (OST, 1996) largely confirm the first two rules: smaller countries (in scientific terms) are relatively more active in international collaboration, and the basic natural and life sciences show a higher degree of international collaboration than other fields. The first observation is quite obvious as smaller countries usually have a smaller science base and thus are forced to collaborate more internationally.

What about the third rule: how does international collaboration correlate with the 'external' factors? First, on a macro scale, we find that political situations may influence scientific collaboration strongly. Nagtegaal and de Bruin (1994) found that international co-operation in science between the western world and the third world often follows neo-colonial patterns (that is, strong ties remain after decolonisation). They argue, for instance, that Africa south of the Sahara is the scientific backyard of western Europe.

Fascinating correspondences between political trends and bibliometric data on international collaboration were found by de Bruin *et al* (1991) for the Gulf Region. Clearly, for the western powers scientific co-operation is part of their 'vested interests'. Thus, co-operation patterns may be both cause and effect of political developments. De Bruin *et al* applied bibliometric techniques based on the mapping of co-publication patterns. Their scientific collaboration maps illustrate how closely scientific collaboration in the Gulf Region followed the political developments in the period 1980–1989.

Across all these external influences, such as geopolitical and cultural aspects, there are 'science-internal' factors. In their study on scientific collaboration of Norwegian scientists, Kyvik and Larsen (1994) noticed considerable differences between scientific fields. They found for all fields a relatively strong correlation between frequency of international contacts, active (invited) conference participation, and international publishing. In the humanities and the social sciences, the difference in degree of international publishing between 'locals' and 'cosmopolitans' is larger than in other fields. Thus, there are not only differences between fields of science, but even within a field there may be 'community-specific' differences.

Often these 'community-specific' differences are related to cultural aspects and differences in ideas about 'how to practise science'. Humanities and social sciences are less cosmopolitan. Perhaps it has to do with language problems given the essay style of humanities and social science papers, as opposed to natural sciences, medicine and technology. In the humanities and social sciences there seems to be a relative absence of the drive to go abroad, which may indicate a stronger culturally-bound attitude than in the natural sciences and medicine, which are more 'universal'.

Kyvik and Larsen found that a research stay abroad is important for strengthening international collaboration in the humanities and social science as well. For the 'cosmopolitans', these authors make a distinction between 'tourists' (just attending conferences), 'motivated' researchers (contributing papers), and 'attractive' researchers (invited papers). Attractive researchers are considerably more internationally productive than motivated, who, in their turn, are more so than 'tourists'. This illustrates nicely how science-internal, cultural, and 'broader-context' aspects are interconnected.

We may also look at this complex network of interrelated factors via another specific facet: accessibility. International visibility is closely related to accessibility of the global science system. Most countries have access to various science networks, which often consist of different sub-networks, again dominated by geopolitical and cultural influences. For instance, in the EU, programmes to stimulate European international co-operation have been active since the mid-1980s (Lewison *et al*, 1993).

Even within the western world there are different patterns following the lines of, for instance, related languages (Okubo *et al*, 1992). Thus, although English, or, more specifically, 'broken' English, is the scientific *lingua franca*, aspects such as common or related languages may influence scientific collaboration considerably.

Mapping co-publication patterns, as discussed earlier for the Gulf Region, yields insight into the role of countries in international networks, their national intensities of international collaboration and their 'affinities' to other countries (Luukkonen *et al*, 1993). These are important indicators: joint research as such is not sufficient to strengthen the scientific potential of a country or institute. The position in the network is crucial (Leclerc and Cagné, 1994).

Recent work shows that there are no major differences between universities of various size with respect to international collaboration. Universities, regardless of size, play an important role as nodes of scientific networks (Melin and Persson, 1997).

International collaboration serves several purposes. In 'Big Science', sharing of very expensive infrastructure is a central motive. It is a matter of economic necessity. Without international collaboration this type of research is for most countries impossible. A time-honoured aim is the idealistic approach: in the role of international collaboration the sharing of ideas, the bringing together of people from different countries is emphasised.

As indicated earlier, it is not clear yet how 'internationality' of science will work out. Certainly, and fortunately, the idealistic aim remains, implicitly or explicitly, as a basic principle. We must, however, accept that, while science as such is indeed a powerful driving force, it will never be the dominant force. This dominant force is a combination of science-external factors, such as socio-political (common history, language), economic and geo-political (common frontier, common defence and/or trade organisations), or budgetary (common facilities) ones.

Another factor is probably related to a typical 'psychological' characteristic of human beings: the propensity to set out and to take a look elsewhere. As Griffith and Miller stated somewhat sarcastically:

> "individual scientists may be reluctant, at one extreme, to travel seventy-five feet to utilise another person's store of knowledge, but at the other extreme, would willingly travel hundreds or thousands of miles to communicate with other persons in other circumstances." (as quoted by Katz, 1994)

General patterns of co-publication

The general picture now is that western Europe makes the core network, with the USA in a very central position. Japan remains in a somewhat remote position (but slightly improving). Sweden is a bridge to a Scandinavian sub-cluster, while Poland plays this role for the eastern European countries. Switzerland takes a special central position in physics due to CERN (European Organisation for Nuclear Research).

Parallel to its strongly increasing publication activity, China now has, despite its late start, many more collaborative papers with most Asian and western countries, except than UK, than India. As far as differences in scientific fields are concerned, both India and China collaborate with the USA much more in physics than in other fields, followed by clinical medicine (Arunachalam *et al*, 1994). Generally speaking, physics (including astronomy) is probably the most international field (Braun *et al*, 1992).

As discussed earlier, science-internal and 'field-dependent' factors play their role alongside the external factors. In terms of broad disciplines of science (such as natural sciences, humanities, social sciences) there is a kind of hierarchy in internationality, but also within these broad disciplines we find some fields are more internationally oriented than others. Mostly this has to do with the first rule mentioned earlier: differences between the more basic- and the more application-oriented fields. These differences can be accentuated further by the structure and level of a national research system as a whole. Bordons *et al* (1996) found for medical fields in Spain an increasing "degree of internationality" for gastroenterology, cardiovasacular systems and neurosciences in that order. Indeed, this hierarchy is clearly related to the basic–applied dichotomy.

A clear illustration of field-dependent differences in international co-publication, on a higher aggregation level, is given by Tijssen *et al* (1996) as shown in Table 6.

We have already mentioned the stimulation of international collaboration by specific programmes. A recent analysis of more than thousand publications resulting from a EU programme for the stimulation

Table 6. Differences between major fields of science in international co-publication and changes over time, The Netherlands

Major field	1983/84	1993/94
Natural sciences	13	21
Engineering sciences	8	15
Medical sciences	9	15
Agricultural sciences	10	11
Social sciences	6	10
Humanities	2	3

Note: Figures indicate the percentage of internationally co-authored publications in the total number of publications
Source: Tijssen *et al* (1996)

of biotechnological research revealed that these publications are three times as 'international' as other EU biotechnology papers, and 25% of single-country papers do depend in fact on foreign co-authors or acknowledge transnational support. Citations by other EU member states show that the programme results have been effectively disseminated within the EU.

Some collaboration linkages are somewhat unexpected such as Germany–Italy and UK–Spain. For the Netherlands, the linkages with Belgium and Germany are surprisingly low, whereas generally they are relatively high. This suggests that specific EU programmes may stimulate new collaboration linkages within the Union. Publications resulting from this EU programme are cited about 1.2 times more than other EU biotechnology papers. This higher impact does not indicate automatically a higher quality of research; it could be the result of active 'advertisement' by the scientists managing the projects (Lewison, 1994). We discuss the relation between international co-publication and impact in more detail in the next section.

Impact of collaborative research results

Narin and Whitlow (1990) found that, generally, internationally co-authored papers are cited more than single-country papers. We may call this the 'fourth rule' of international collaboration. Although some authors (Herbertz, 1995) have different opinions based on their empirical work, we have strong evidence that generally the internationally co-authored publications are indeed the ones with the higher impact. To illustrate this, we discuss recent work of our group on astronomy research in The Netherlands.

Table 7 presents the results of our analysis of international collaboration for astronomy in The Netherlands (publications: 1980-1991; citations: 1980-1993, for more details see van Raan and van Leeuwen 1995a). These results are based on a bibliometric analysis of 2,090 publications and 35,780 citations in a period of about ten years.

The table shows that 33% of all Dutch astronomy articles have been published by authors with only one institutional address in the heading of their articles, no collaboration was involved with other research groups. About 8% of the articles originate from a collaboration between two or more groups located in the Netherlands. The majority however (almost 60%) are the result of a collaboration between Dutch groups and one or more groups from abroad: this is research in international collaboration.

It is interesting to analyse impact as a function of the type of collaboration. We here use the relative impact indicator, which is the average impact of Netherlands astronomy papers compared to the world average (CPP/FCSm). For a detailed discussion of this and related indicators, we refer to Moed *et al* (1995) and to the recent review paper of van Raan (1996).

The table shows that papers in international collaboration obtain the highest value. The overall value for all Dutch astronomy articles (more than 2,000 in ten years) is 1.44, so we observe that the impact of papers co-published with foreign groups is by far the highest (CPP/FCSm=1.67). Thus, international collaboration indeed contributes to a considerable extent to the international impact of Dutch astronomy. These findings are consistent with the general conclusion of the strong international position of Dutch astronomy. Dutch academic astronomers play an important role in international scientific networks and gain a

Table 7. Bibliometric indicators of output and impact for different types of scientific collaboration, astronomy, The Netherlands, 1980–1993

Type of collaboration	P(%)	C	CPP	CPPex	%Pnc	CPP/FCSm	%Self cit
No collaboration	691 (33)	9515	13.77	11.69	11.87	1.12	15.09
National collaboration	173 (8)	2014	11.64	9.34	6.94	1.07	19.76
International collaboration	1226 (59)	24251	19.78	15.50	6.77	1.67	21.64

Notes: Indicators given are:
P: number of articles (normal articles, letters, notes and reviews) published in journals covered by the SCI
C: number of citations recorded in SCI journals to all articles involved, self-citations included
CPP(ex): average number of citations per publication, self citations in(ex)cluded
%Pnc: percentage of articles not cited during the time period considered
FCSm: average citation rate of all articles in the (sub)fields in which the institute is active (that is, world citation average based on the institute's research (sub)fields). Subfields are defined by means of SCI journal categories
CPP/FCSm: impact of an institute's publications, compared to the world citation average in the subfields in which the institute is active
%Selfcit : percentage of self-citations; a self-citation is a citation in which the citing and the cited paper have at least one author (any co-author) in common

A study of three European environmental research institutes showed that, for those in Italy and Denmark, international co-publication had the highest impact: in Germany the differences in impact between the various types of collaboration was less marked

substantial part of their impact from their activities within them.

A similar analysis of the relationship between international collaboration and impact was part of our study, commissioned by the European Commission, on the research performance of three European environmental research institutes (van Raan and van Leeuwen, 1995b). For the European Commission Joint Research Centre (JRC, at Ispra, Italy) we again find that publications in international collaboration have the highest impact. However, papers in international collaboration are the smallest category. Also the international co-publications of NERI (Denmark) show the highest impact.

For the third research institute, GSF (near Munich), we see a different picture. As might be expected, for a large organisation, such as GSF, and a scientifically large country, such as Germany, the differences in impact between the various types of collaboration are less pronounced. In the study by Herbertz (1995) German institutes were also involved. More empirical work is necessary to analyse the relationship between international co-publication and impact, particularly possible differences between countries of different size.

Bibliometric mapping of internationality

Finally, we discuss a bibliometric method to create maps of scientific fields, with the location of 'actors'. Such strategic maps show us the strong internationality of scientific research, regardless of collaboration. They could, in fact, serve as tools for finding international research partners, or for stimulating international collaboration. We limit ourselves to the main points and refer for a more detailed discussion to Tijssen and van Raan (1994).

Each year about a million scientific articles are published world-wide. The number of papers in a research field is many tens of thousands per year for a large field such as materials science, and a few

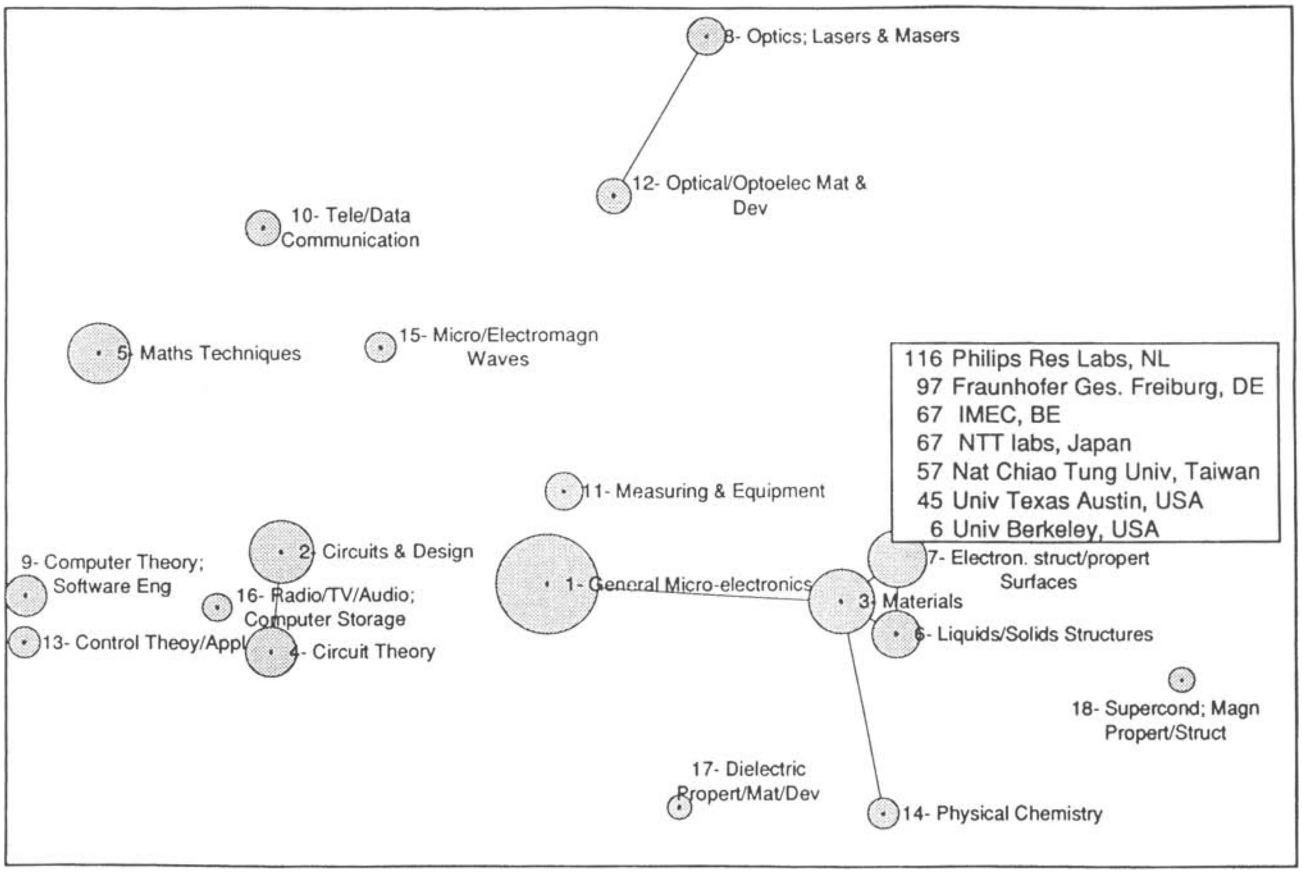

Figure 1. Bibliometric map of micro-electronics, 1992–1994

Note: As an example we labelled subfield 7 with the most active actors
Noyons *et al* (1995)

thousand for a more specific field like microelectronics. These figures give an impression of the enormous size of scientific output nowadays. How can we keep track of all these developments? Are there cognitive structures hidden in this mass of published knowledge, at a meta-level?

Suppose each research field can be characterised by a list of the most important, say 100, keywords. Each publication can be characterised by a subset from the total list of keywords. For all publications we compare their keyword lists pairwise. In other words, all these publications constitute a gigantic network in which most of them are linked by one of more common keywords ('co-words') or common classification codes ('co-classification'). The more keywords (or codes, in general) two publications have in common, the more these publications are related (keyword- or code-similarity) and thus belong to the same research area or research speciality.

In mathematical terms, publications are represented as vectors in a high-dimensional word- (or code-) space. In this space they group together in close relationship, or take very distant positions when they are not related to each other. We developed mathematical techniques (co-classification analysis for macro-level structures, and co-word analysis for details) to unravel these publication networks and to map the underlying structures.

These structures can be regarded as the cognitive, or intellectual structure of science. They are not the result of any pre-arranged classification system. Nobody prescribed these structures. They emerge entirely from the internal relations of the whole universe of publications together. In other words, what we make visible by our mathematical methods is the self-organised structure of science. For a detailed, general description of our method see Noyons and van Raan (1997).

In Figure 1, we show the result of mapping the underlying patterns in about a thousand publications (years 1992–1994) in micro-electronics research. This map (Noyons *et al*, 1995) represents the 'coarse' structure and can be regarded as an overview map of the field. It clearly shows the major subfields in their mutual relationships. The closer these clusters are, the more related the subfields, represented by these clusters. For all subfields, detailed maps have been made, with the help of co-word analysis.

This bibliometric cartography has interesting potential. First, as shown in the figure, it puts into visual form the cognitive landscape of a scientific field. Second, by making these maps for a series of years, we are able to observe trends and changes in structure. Thus we gain insight into the dynamics of scientific development.

Third, we also put the position of major actors (with number of publications) on the map, as illustrated in the figure for one of the micro-electronics subfields — electronic structures and properties of surfaces. Immediately we observe the 'internationality' of this subfield. Industrial and academic research institutes from the Netherlands (Philips, Eindhoven), Germany (Fraunhofer Institute, Freiburg), Belgium (IMEC, Leuven), Japan (NTT), National Chiao Tung University (Taiwan), USA (University of Texas at Austin; University of California at Berkeley) dominate this field of research, at least in terms of scientific productivity. Similar observations can be made for the other subfields (Noyons *et al*, 1995).

With the help of these maps we can analyse whether there are also typically 'national' or 'regional' research areas. If so, it is interesting to investigate whether they are related to typical national facilities, national circumstances, or 'culturally bound' topics.

Further examples of bibliometric mapping can be found in our institute's world-wide web home page at http://sahara.fsw.leidenuniv.nl/cwts/cwtshome.html.

Concluding remarks

We have discussed several phenomena concerning internationality of science. First, the use of international, and particularly Science Citation Index covered, journals to become more visible. Second, the shift to English as the *lingua franca* of science. As a third step, international visibility is enhanced by the impact of research results, which can be stimulated by changing the publication strategy toward higher impact journals. This, however, is not a free choice but related to the quality of the research work.

Alongside these strategies to become more internationally visible, we discussed internationality of science in terms of international collaboration, often resulting in co-publication We showed that there is a strong positive correlation between international co-publication and high impact as measured by citation analysis.

International scientific collaboration is strongly influenced by political and cultural factors. Patterns of scientific collaboration often strikingly reflect political situations. These 'external' factors are also related to science-internal (for instance, field-dependent) factors. For instance, social sciences and humanities are, by their nature, more nationally and culturally oriented than the basic natural sciences.

Finally, we showed how specific bibliometric methods of structuring 'maps' of research fields may provide further insight into internationality in the development of science.

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Appendix 1

Table A1. Absolute numbers of publications of selected countries, 1979–1995

Country	Number of indexed publications																	1979–1995
	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	average % social science
Australia	10599	11149	11666	11386	12178	12763	12874	13096	13272	13766	14168	15306	16013	16694	17850	19294	19707	12.6
Austria	2983	3127	3029	2986	3240	3247	3448	3505	3391	3703	3948	4189	4355	4834	4854	5235	5574	6.2
Belgium	4206	4370	4608	4848	4884	5302	5273	5264	5602	5657	6152	6395	6672	7105	7358	8293	8626	5.8
Canada	21519	21546	21205	21988	23898	23898	25314	26516	27199	28335	30610	32596	33363	34844	35182	36402	35954	12.6
Danmark	3859	3845	4011	4135	4317	4376	4544	4706	4593	4875	4954	5200	5446	6052	6188	6824	6669	5.5
France	24622	25345	25856	25827	26649	27773	29051	29881	30898	32067	33285	34670	36494	38404	40182	42913	43166	3.6
Germany	36252	35800	37660	37689	39072	40009	41947	42282	43343	43982	46125	48721	49496	49521	51907	54551	55538	5.3
Hong Kong	369	382	409	476	480	651	706	791	911	931	1154	1217	1244	1455	1756	2111	2651	12.8
India	14229	14373	14457	13932	14035	14131	13424	14053	14449	14636	15249	15142	15603	15514	15844	16173	15249	3.3
Israel	4942	5172	5421	5792	6179	6425	6624	6723	6853	6979	7152	7307	7478	7796	8526	8700	8928	12.2
Italy	9243	9894	10604	11290	12446	13343	13814	14091	14768	16450	17687	18664	20361	22086	23307	25447	26304	3.4
Japan	23748	27941	29472	29612	30735	33535	36028	37720	40164	41903	44844	46922	50467	53125	56074	60039	60011	1.8
Malaysia	287	276	246	286	279	262	265	273	334	339	353	403	429	415	497	592	656	9.2
People's Republic of China	460	838	1596	2492	2872	3244	3438	4273	5274	6285	7050	7902	8141	8911	9638	10411	12214	2.0
Singapore	189	171	207	246	335	435	505	565	618	672	786	904	974	1228	1519	1749	2037	9.9
South Korea	140	160	266	312	422	496	634	739	943	1160	1466	1798	2212	2519	3393	4351	5820	4.2
Spain	3206	3745	3855	4395	5109	5749	6469	7444	8098	8842	9535	10373	11495	13468	14785	15761	16795	2.8
Sweden	6959	7100	7365	8074	8486	9207	9502	9611	9742	10378	10463	11018	11489	11691	12382	13268	13562	6.4
Switzerland	6936	6879	6935	7056	7596	7500	7828	7829	8019	8118	8536	9383	9872	10673	11318	12267	11926	5.0
Taiwan	461	534	531	559	687	818	1060	1232	1604	1965	2326	2891	3565	4420	5162	6339	6912	4.4
Thailand	354	379	376	391	470	458	458	435	412	471	475	535	540	576	625	720	677	8.4
The Netherlands	6881	7043	7615	7996	9129	9746	10241	10576	11038	12045	12878	14013	14378	15669	16640	17578	17883	7.8
UK	37037	37265	39101	39062	40849	43047	44723	43944	45620	45877	47024	49528	51809	53920	56204	59545	61845	12.0
USA	189604	191067	196705	200585	211801	218224	221018	220588	222913	227456	236931	249268	259003	259801	265376	272933	273667	16.3
USSR	32005	32470	35044	35151	32926	39874	39720	38274	37871	39177	40753	41978	40766	35125	31855	32659	28747	3.2
World	514094	517522	531545	535221	570248	599060	607706	605065	615609	628689	648820	671968	691705	698381	715910	754760	752171	11.3

Notes: Figures include articles, notes, reviews and letters covered by SCI and SSCI
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