The Steady Growth of Scientific Publication and the Declining Coverage Provided by Science Citation Index

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Abstract

The growth rate of scientific publication has been studied from 1907 to 2007 using available data from a number of databases, including the expanded version of the Science Citation Index (SCIE). Traditional scientific publishing, that is publication in peer-reviewed journals, is still increasing although there are big differences between fields. There are no indications that the growth rate has decreased in the last fifty years. At the same time publication using new channels, for example conference proceedings, open archives and home pages, is growing fast. The growth rate for SCIE is smaller than for comparable databases. This means that SCIE is covering a decreasing part of the traditional scientific literature. There are also clear indications that the coverage of SCIE is especially low in some of the scientific areas with the highest growth rate, including computer science and engineering sciences. The role of conference proceedings, open access archives and publications published on the net is increasing, especially in scientific fields with high growth rates, but this is only partially reflected in the databases. It is therefore problematic that SCIE has been used and is used as the dominant source for science indicators based on publication and citation numbers.

Introduction

In 1963 Derek J. de Solla Price used the number of records in abstract journals for the period from 1907 to 1960 to study the growth rate of science. He found a doubling time of 15 years (corresponding to an annual growth rate of 4.7 per cent). Price underlined the obvious fact that this growth rate sooner or later would decline although there were no indications for it.

Since Price's pioneering investigations, Research and Development (R&D) statistics and science indicators have become necessary and important tools in the science of science, research policy and research administration. Publication numbers have been used as measures of the output of research, especially academic research and university research. The basis for the measurement of publication numbers are databases for scientific publications. The databases also give the basis for measurements of citations, used as indicators of the quality of publications.

In the present study we investigate the growth rate of scientific publication from 1907 to 2006, based on information from several different databases for scientific publications and on growth data recorded in the literature. The data give information about changes in the growth rate of science and permit a discussion about the internal and external causes of the observed changes. The data have also been used to establish the coverage provided over time by the different databases. The dominating databases used in R&D statistics are the Science Citation Index Expanded (SCIE), the Social Science Citation Index (SSCI) and the Web of Science (WoS), all from Thomson Reuters, USA (Thomson Reuters, 2008a). Therefore special attention has been paid to the coverage of these databases.

Methodology

The data from the databases used were either obtained directly from the publishers or from the net. For *Chemical Abstracts*, data were available from 1907 to 2007, covering both the total number of records and separate values for *Papers*, *Patents* and *Books*. Conference Proceedings are included under the heading papers.

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For *Compendex*, the total number of records from 1870 to 2007 were obtained on the net using the year in question as the search term and restricting the search to the same year. Compendex covers not only scientific publications in engineering but also other engineering publications.

For *CSA* (Cambridge Scientific Abstracts) data including values for *All Types*, *Journals*, *Peer Reviewed Journals* and *Conference Proceedings* were available from 1960 to 2007 for Technology and from 1977 to 2007 for Natural Science.

For *Inspec* and the sections of Inspec, *Physics*, *Computers/Control Engineering*, *Electrical-/Electronical Engineering*, and *Manufacturing and Production Engineering*, data were available from 1969 to 2007 for All Records, Journal Articles, Conference Articles and Conference Proceedings.

For *LNCS*, Lecture Notes in Computer Science, data were available for All Records from 1940 to 2007.

For *MathSciNet*, data were available from 1907 to 2007 for All Records, Journals, Proceedings and Books.

For *Physics Abstracts*, data were available from 1909 to 1969 for All Records.

For *PubMed Medline*, data were available from 1959 to 2007 for All Records

For *SCIE*, data were available from 1955 to 2007 for All Records and from 1980 to 2007 also for Anonymous Source Items, Authored Source Items, Total Source Items, Articles, Meeting Abstracts, Notes, News Items, Letters, Editorial Material, Reviews, Corrections, Discussions, Book Reviews, Biographical Items, Chronologies, Bibliographies, and Reprints.

In our analysis we have used the numbers of total records, including both authored and anonymous source items. We have compared “Papers” with “Journals”, “Journal Papers”, “Journal Articles” and “Articles+Letters+Notes+Reviews”. We have not used the distinction between “Journals” and “Peer Reviewed Journals”, since the change of status of a journal does not provide information about publication activity. Thus, in all Figures and Tables we are using data given in the databases for all journal publications, also when data for peer-reviewed journals have been available. We have compared “Conference Proceedings” with “Conference Contributions”, “Conference Articles + Conference Proceedings” and “Meeting Abstracts”. Alas, we have not been able to obtain representative data for Arts and Humanities. Our data for Social Sciences are restricted and permit only few conclusions.

Data for the number of journals covered by SCI/SCIE have been obtained from the Web of Science.Exponential growth has been studied using semilogarithmic display of time series. Linear regression has been used to calculate annual growth rates with standard errors and doubling times. Double-sided tests have been used to calculate P-values for the difference between time series for different databases.

Results

Figure 1 gives a semilogarithmic presentation of the cumulative number of the total number of abstracts, the number of abstracts of papers and the number of abstracts of patents in Chemical Abstracts from 1907-2007, the total number of records in Compendex from 1907-2007, the total number of abstracts, the abstracts from journals and the abstracts of proceedings in MathSciNet from 1907-2007, the number of abstracts in Physics Abstracts (All Records) from 1909-1969 and the number of Abstracts (All Records) in Inspec Physics from 1969 to 2007. The straight lines indicate a doubling time of 15 years. The graphs representing the total number of abstracts and covering the period from 1907 to 1960 are similar to the classical figure with data from Chemical Abstracts, Biological Abstracts, Physics Abstracts and Mathematical Reviews, published in 1963 by Derek J. de Solla Price in *Little Science, Big Science*. Price interpreted the steep beginning of the curves as “an initial expansion to a stable growth rate” but of course the correct mathematical description is that for a curve giving cumulative values for exponential growth the slope decreases continually from an initial value larger than two to a limit value larger than 1 (1 + the annual growth rate in per cent divided by 100). The use of cumulative values makes it impossible to use the data for regression analysis. Price concluded from his data that the doubling period for science was about 15 years (corresponding to an annual growth rate of 4.73 per cent). The effects of the two world wars are barely visible on the curves. Price mentioned a small decline in the growth rate during World War II, but this can only be observed for Chemical Abstracts and Physics Abstracts (Price, 1963, pages 10 and 17).

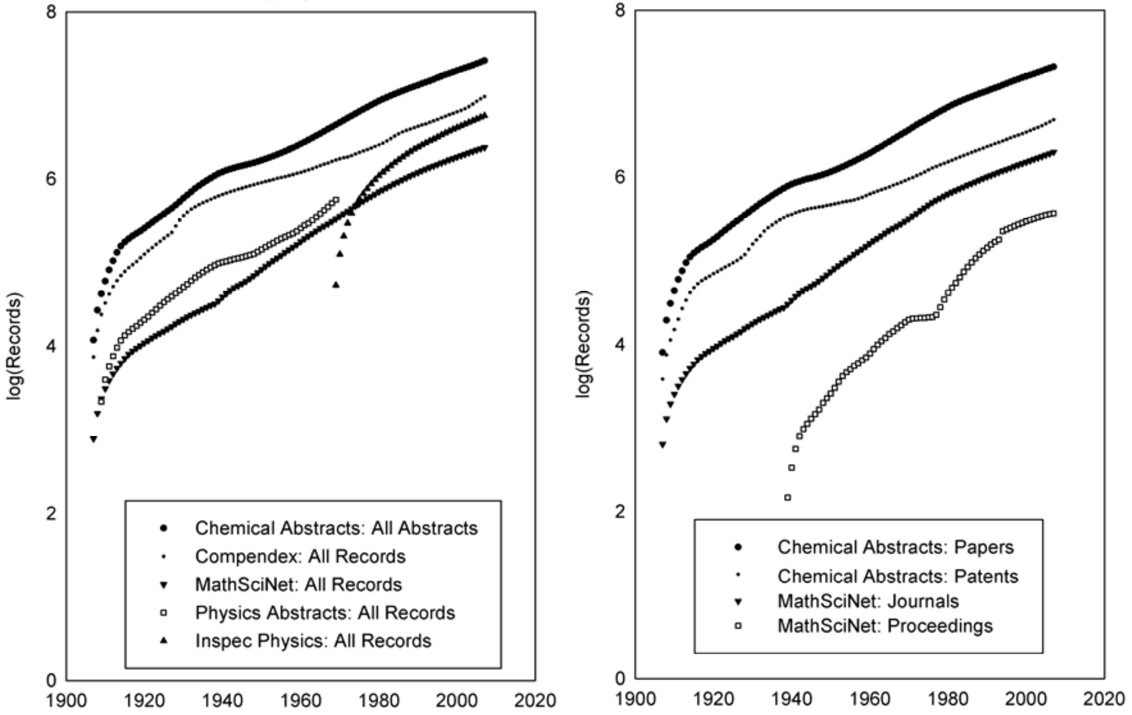

Figure 1. Cumulative Number of Records for nine databases 1907-2007 (semilogarithmic scale).

In Figure 2 the same numbers are presented. However, this figure records the numbers of abstracts for each year instead of the cumulative numbers. Again, the data are represented on a semilogarithmic scale. For Chemistry the negative effect of the two world wars and the extremely fast growth after the wars is clearly visible. Also the stagnation in the 1930s caused by the economic crisis from 1929 is clearly visible. In the period from 1974 to 1990 there is also a clear decline in the growth rate. This is followed by an increase in the period from 1990 to 2007 but the high values from before 1974 have not been reached again.

The data for Physics Abstracts show three periods, 1920-1930, 1930-1939, and 1945-1969, corresponding to the periods found for Chemical Abstracts. The data from Inspec Physics show a stable growth from 1971 to 2007 but the rate is much slower than that recorded in Physics Abstracts in the preceding period. This slowdown corresponds to that found for chemistry. For mathematics there is a very high growth rate immediately after the end of World War II. The growth rate is still high up to the 1980s. At the end of the 1980s the growth rate has fallen to a very low level. In contrast to the slowdown in mathematics, physics and chemistry, for the Compendex database covering engineering sciences a completely different growth is observed. During World War I a smaller decline is observed than for the other databases. A strong decline is observed from the beginning of the economic crisis in 1930 followed by a long period of stagnation until the late fifties. The slowdown in the seventies and eighties is absent in the data for Compendex. It is remarkable that the growth of the Compendex data is very similar to the growth of the patent data in Chemical Abstracts.

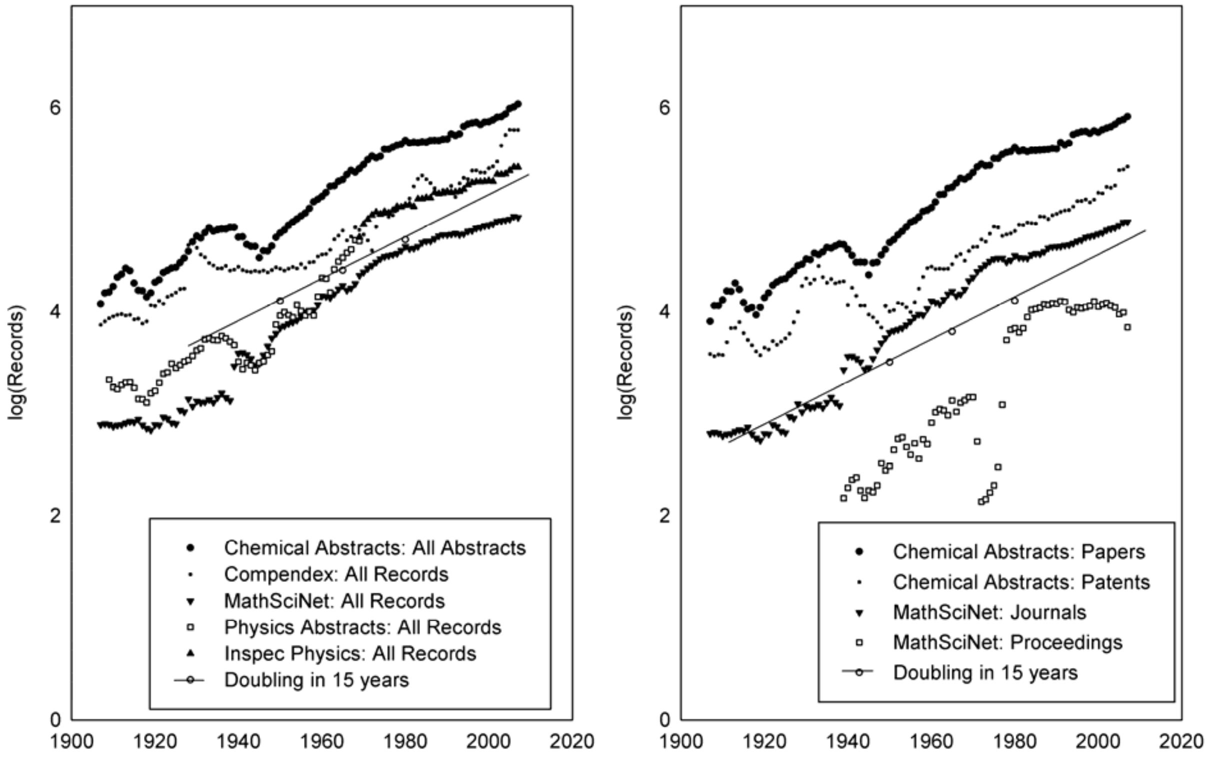

Figure 2. Number of Records for nine databases 1907-2007 (semilogarithmic scale).

The growth rates and doubling times for the different periods are displayed in Table 1.

Table 1. Annual growth rates and doubling times for databases covering long time spans.

Period	Growth rate, %	Doubling time, years	Growth rate, %	Doubling time, years	Growth rate, %	Doubling time, years
	Chemical Abstracts					
	All Records		Journal Articles		Patents	
1907-2007	4.5	15.6				
1907-1960	3.6	20	3.8	19	2.8	25
1907-1914	3.4	21	11.1	6.6	13.1	5.6
1920-1930	5.8	12	8.4	8.6	16.4	4.6
1930-1939	2.5	28	4.3	17	-1.2	-
1945-1974	8.4	8.6	8.8	8.2	7.4	9.8
1974-1990	1.8	39	1.7	42	2.7	26
1990-2007	4.2	17	2.8	25	6.2	12
	Compendex					
	All Records					
1907-2007	3.9	18				
	MathSciNet					
	All Records		Journal Articles		Conf. Proceedings	
1907-2007	5.9	12			-	-
1907-1960	6.1	12	6.3	11	-	-
1950-1984	6.3	11	5.9	12	6.9	10
1950-2007	3.3	20	4.3	16	7.7	9.3
1984-2007	2.6	27	3.3	22	-0.7	-
	Physics Abstracts					
	All Records					
1909-1960	3.8	18				
	Inspec Physics					
	All Records		Journal Articles		Conf. Proceedings	
1974-2004	3.0	23	2.1	33	6.4	11

Figure 3 displays the graphs for All Records from 1970 to 2007 for Chemical Abstracts, Compendex, CSA Technical Science, CSA Natural Science, Inspec All Sources, Inspec Physics, Inspec Electrical/Electronical Engineering, Inspec Computers/Control Engineering, Inspec Manufacturing and Production Engineering, LNCS, MathSciNet, Medline and SCIE.

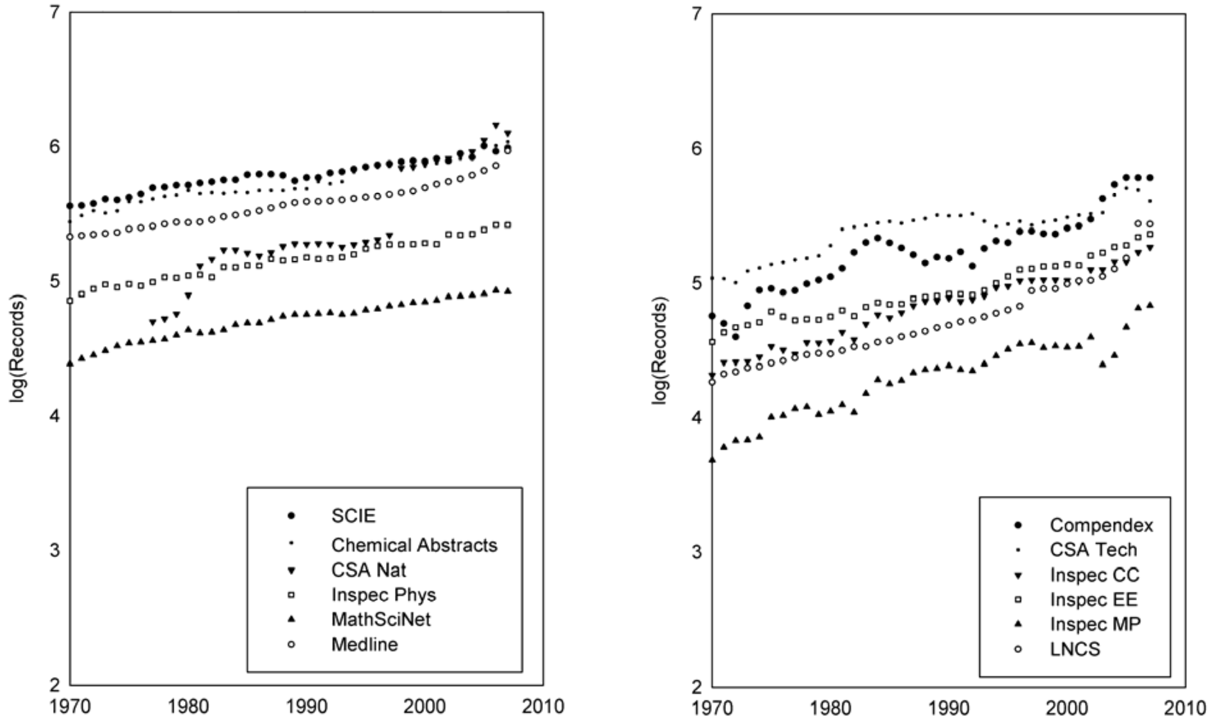

Figure 3. Number of Records for thirteen databases 1970-2007.

In Table 2 we present data for All Records from 1997 to 2006 derived from all the databases used, except Inspec Manufacturing and Production Engineering.

Table 2. Growth rate 1997-2006 for All Records in databases.

	Slope (semilogarithmic scale)	Standard error	P-values declining the hypothesis "No difference between the database and SCIE" (double-sided test)	Annual growth rate, %	Doubling time, years	Rank
Chemical Abstracts	0.01849	0.00225	0.044	4.3	16	8
Compendex	0.05487	0.00731	< 0.01	13.5	5.5	1
CSA, Natural Science. Only 1998-2004.				4.7	15	7
CSA, Technology	0.03131	0.00434	< 0.01	7.5	9.6	2
Inspec All Sources	0.02118	0.00308	0.017	5.0	14	6
Inspec Computers & Control Engineering	0.02318	0.00375	0.011	5.5	13	5
Inspec Electrical & Electronical Engineering.	0.02598	0.00279	< 0.01	6.2	12	3
Inspec Physics	0.01636	0.00223	0.17	3.8	18	10
LNCS. Only 1997-2005.	0.01787	0.00167	0.041	4.2	17	9
MathSciNet	0.01207	0.00062	0.90	2.8	25	11
PubMed Medline	0.02366	0.00115	< 0.01	5.6	13	4
Science Citation Index	0.01176	0.00248	-	2.7	26	12

Table 3 records the number of All Records, Journal Articles and Conference Contributions in 2004 for the databases investigated. The table also reports the shares of All Records for Journal Articles and for Conference Proceedings.

Table 3. Numbers in databases in 2004 of All Records, Journal Articles and Conference Contributions and the shares for Journal Articles and Conference Contributions.

Database	All Records	Journal Articles		Conference Contributions	
		Numbers	% of All Records	Numbers	% of All Records
Chemical Abstracts	865,066	685,796	68.2	-	-
CSA, Technology	452,744	374,333	82.7	86,401	19.1
CSA, Natural Science	917,780	844,273	92.0	14,960	1.6
Compendex	541,192	-	-	-	-
Inspec All Sources	421,865	256,339	60.8	162,540	38.5
Inspec Computers & Control Engineering	144,786	68,895	47.6	74,447	51.4
Inspec Electrical & Electronical Engineering	186,421	90,969	48.8	93,944	50.4
Inspec Physics	225,293	162,426	72.1	61,359	27.2
MathSciNet	78,829	66,761	85.0	11,046	14.0
PubMedMedline	614,126	-	-	-	-
Science Citation Index	835,126	593,797	71.1	129,516	15.5

Discussion

Analysis and interpretation of our results

Figures 1 and 2 and Table 1 corroborate Price's work based on Biological Abstracts, Chemical Abstracts, Mathematical Reviews and Physics Abstracts although our analysis indicates a slightly lower growth rate for the period up to 1960 than that given by Price (4.7 per cent per year, doubling time 15 years). The data for Chemical Abstracts also indicate that the growth in publication numbers has continued until 2007. However, the growth rate has not been stable. The growth in numbers of Journal Articles has declined significantly since 1974. The data for Physics Abstracts reflect the dramatic increase in growth from the end of World War II.

Table 2 indicates annual growth rates between 2.1 and 6.1 per cent per year for the period 1997-2006 for All Records. There are two possible explanations for this wide range. The first is that some of the databases increase or decrease coverage in their field. The second is that publication activity is growing with different rates in different fields.

SCIE has the lowest growth rate for All Records and for Articles. Table 3 gives the number of All Records, Journal Articles and Conference Contributions for 2004 for the databases studied. Because of overlapping between the databases, the numbers cannot be added. However, it is remarkable that the number of records in Science Citation Index is lower than the numbers in Chemical Abstracts and in CSA, Cambridge Scientific Abstracts, Natural Science, and only slightly higher than the numbers in Medline. It has been estimated that in 2006 about 1,350,000 articles were published in peer-reviewed journals (Björk et al, 2008).

All in all, the data suggests that the coverage in Science Citation Index is lower than in other databases and decreasing over time. It is also indicated that the coverage in Science Citation Index is lower in high growth disciplines and in conference contributions than in well established fields like chemistry and physics. However, it must be remarked that Science Citation Index has never aimed at complete coverage.

The growth rate of scientific publication and the growth rate of science

It is a common assumption that publications are *the* output of research. This is a simplistic understanding of the role of publication in science. Publication can just as well be seen as a (vital) part of the research process itself. Publications and citations constitute the scientific discourse (Ziman, 1968, Mabe & Amin, 2002, Crespi & Geuna 2008, Larsen et al., 2008). Nevertheless, the numbers of scientific publications and the growth rate for scientific publication are generally considered important science output indicators. The major producers of science indicators, the European Commission (EC), National Science Board/National Science Foundation (NSB/NSF, USA) and OECD all report publication numbers as output indicators (European Commission, 2007, National Science Board, 2008, OECD, 2008). All base their data on SCI/SCIE, as do in fact virtually all others using publication number statistics.

The number of scientific journals

This question has been taken up by Mabe and Amin (2001). Based on *Ulrich's International Periodicals Directory on CD-ROM*, they give a graphical representation of the numbers of unrefereed academic journals, refereed academic journals and active, refereed academic journals from 1900 to 1996. The number of unrefereed academic journals is about 165,000 in 1996. The numbers for refereed academic journals and active, refereed academic journals are about 11,000 and 10,500 in 1995. The lower limit for growth rate for active, refereed journals is given as 3.3 per cent per year for the period 1978-1996. In a subsequent publication (Mabe & Amin, 2002) it is stated that there are about 14,000 peer-reviewed learned journals listed in Ulrich's Periodicals Database. No information is given about the year for which the value of 14,000 is valid. Even if it is the year of the publication, 2002, 3.3 per cent annual growth from 1995 to 2002 gives only 13,179 journals but no explanation is given for this discrepancy.

However, in a third publication (Mabe, 2003) it is reported that the number of active, refereed academic/scholarly serials comes to 14,694 for 2001. This number is based on a search using *Ulrich's International Periodicals Directory on CD-ROM*, Summer 2001 Edition. It is stated that this number is noticeable lower than estimates given by other workers but almost certainly represents a more realistic number. In this publication an annual growth rate of 3.25 per cent is given for the period from 1970 to the present time. On the other hand van Dalen and Klamer (2005) reported that according to Ulrich's International Serials Database in 2004 about 250,000 journals were being published, of which 21,000 were refereed.

According to Björk et al. (2008) the number of peer-reviewed journals was 23,750 in the winter of 2007. This figure was based on a search of Ulrich's database.

Scopus in 2008 covers 15,800 peer-reviewed journals from more than 4,000 international publishers.

To conclude, the number of serious scientific journals today most likely is about 24,000. This number includes all fields, that is all aspects of Natural Science, Social Science and Arts and Humanities. There is no reason to believe that the number includes conference proceedings, yearbooks and similar publications. The number is of course important in considerations about the coverage of the various databases. For comparison SCIE covered 6,650 journals and SSCI 1,950 journals in 2008 (Björk et al., 2008).

Citations and differences in citations recorded by different search systems

Until a few years ago, when citation information was needed the single most comprehensive source was the Web of Science including SCIE and SSCI but recently two alternatives have become available. Scopus was developed by Elsevier and launched in 2004 (Reed Elsevier, 2008). In 2008 Scopus covers references in 15,800 peer-reviewed journals. Google Scholar records all scientific publications made available on the net by publishers (Google, 2008). A publication is recorded when the whole text is freely available but also if only a complete abstract is available. The data comes from other sources as well, for example freely available full text from preprint servers or personal websites.

It has repeatedly been reported that more citations are found using Google Scholar than by using the two other sources and also that there is only a limited overlap between the citations found through Google Scholar and those found using the Web of Science (Meho, 2006; Meho & Yang, 2006; Bar-Ilan, 2008; Kousha & Thelwall, 2008; Vaughan & Shaw, 2008, and references therein).

According to Mabe (2003) the ISI journal set represents about 95% of all journal citations found in the ISI database. This indicates that citations found in SCIE and SSCI are primarily based on the journals covered by these databases.

Bias in source selection and language barriers

When SCIE and later SSCI were established it was the ambition to cover the most important part of the scientific literature but not to attempt complete coverage. This is based on the assumption that the significant scientific literature appears in a small core of journals in agreement with Bradford's Law (Garfield, 1979). Journals were chosen by advisory boards of experts and by large scale citation analysis. The principle for selecting journals has been the same during the whole existence of the citation indexes. New journals are included in the databases if they are cited significantly by the journals already in the indexes and journals in the indexes are removed if their numbers of citations in the other journals in the indexes are declining below a certain threshold. A recent publication provides a detailed description of the procedure for selecting journals for the citation indexes (Testa, 2008a).

From soon after the inception of SCIE it has been criticized for being biased toward papers in the English language and those from the United States (Shelton et al., 2009). As an example, MacRoberts and MacRoberts (1989) noted that SCIE and SSCI covered only a part of the scientific literature. English language journals and western science were over-represented; whereas small countries, non-western countries, and journals published in non-Roman scripts were under-represented. For example, coverage of Soviet and Japanese journals was poor. As part of a response to such criticism Thomson Reuters has recently taken an initiative to increase the coverage of regional journals (Testa, 2008b).

Conference proceedings

Table 3 corroborates the result, that the importance of conference contributions differs between fields (Butler, 2008). Thomson Reuters has covered conference proceedings from 1990 in ISI Proceedings with two sections, Science and Technology and Social Sciences and Humanities. However, these proceedings were not integrated into WoS until 2008. Therefore, the proceedings recorded have not been used in scientometric studies based on SCIE and SSCI. In 2008 Thomson Reuters launched Conference Proceedings Citation Index with two editions; Science & Technology and Social Science, fully integrated into WoS and with coverage back to 1990 (Thomson Reuters, 2008b). However, if scientometric studies continue to be based solely on SCIE and SSCI, the low coverage of conference proceedings there will still cause problems.

Fast- and slow-growing disciplines

There are indications that many of the traditional disciplines, including chemistry, mathematics and physics, are among the slowly growing disciplines, whereas there are high growth rates for new disciplines, including engineering sciences and computer science. Engineering sciences and computer science are disciplines where conference proceedings are important or even dominant.

Do the ISI journals represent a closed network?

Because of the importance of the visibility obtained by publishing in journals covered by SCIE and SSCI and because of the use of the counting values in many assessment exercises and evaluations, it has been important for individual scientists, research groups, institutions and countries to publish in the journals covered by this database. It is a reasonable conjecture that SCI has had great influence on the publishing behaviour among scientists and in science. But the journals in SCIE constitute a closed set. It is not easy for a new journal to gain entry. One way to do so is to publish papers bringing references to the journals already included. It is important to publish in English since English speaking authors and authors for whom English is the working language only rarely cite literature in other languages. It is best to get inside but it is not easy.

Is the growth rate of science declining?

In 1963 Price concluded that the annual growth rate of science measured by number of publications was about 4.7 per cent (Price, 1963). The annual growth rates of 3.7 per cent for Chemical Abstracts for the period 1907-1960 and of 4.0 per cent for Physics Abstracts for the period 1909-1960 given in Table 1 are slightly lower. What has happened since then? Table 4 shows a slower growth rate in the period 1997 to 2006 according to SCIE, MathSciNet and Physics Abstracts. A tentative conclusion is that old, well established disciplines including mathematics and physics have slower growth rates than new disciplines including computer science and engineering sciences but that the overall growth rate for science is still at least 4.7 per cent per year. However, the new publication channels, conference contributions, open archives and publications available on the net, for example in home pages, must be taken into account.

Conclusion

Traditional scientific publishing, that is publication in peer-reviewed journals, is still increasing although there are big differences between fields. There are no indications that the growth rate has decreased in the last fifty years. At the same time, publication using new channels, for example conference proceedings, open archives and home pages, is growing fast.

The growth rate for SCIE is smaller than for comparable databases. This means that SCIE is covering a decreasing part of the traditional scientific literature. There are also clear indications that the coverage of SCIE is especially low in some of the scientific areas with the highest growth rate, including computer science and engineering sciences.

The role of conference proceedings, open access archives and publications published on the net is increasing, especially in scientific fields with high growth rates, but this is only partially reflected in the databases.

It is therefore problematic that SCIE has been used and is still used as the dominant source for science indicators based on publication and citation numbers.

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