FROM IMPACT FACTOR TO EIGENFACTOR

An introduction to journal impact measures

Introduction

Journal "impact measures" are statistics reflecting the prominence and influence of scientific journals within the framework of documented scholarly communication. The basic idea from the viewpoint of information science is that citations express the use of information (cf. Cronin, 1981). In particular, according to Linda C. Smith (1989) "*citations are signposts left behind after information has been utilized*", furthermore citations give "*a formalised account of the information use and can be taken as a strong indicator of reception at this level*" (Glänzel and Schoepflin, 1995).

Sociology of science provided a somewhat different view of citation impact. According to this view communication in science is also characterised by the position scientists hold in the community. Merton (1988) interpreted citation as a reward system. This view had partially serious consequences for the application of journal impact measures to science policy and research management.

Besides "impact measures" or, in other words, " , related measures based on citation given or received by journals have been defined for various purposes. *Ageing measures* reflect the obsolescence of information published in scientific journals. The *Mean Response Time* (Schubert and Glänzel, 1996) measures the reception speed of a journals based on the year when the first citation if given to the individual articles published in the journal in a given year. The *Price Index* (Price, 1970) measures the "hardness" of science on the basis of the distribution of the items of a journal's reference list over time.

The Journal Impact Factor – History

The ISI *Impact Factor* (IF) simply relates the citations a journal has received in a given year to the number of papers it has published in the preceding two years. The IF was first used as a measure for comparing journal impact independently of "size" and to help select journals for ISI's *Science Citation Index* (SCI) (cf. Garfield and Sher, 1963). It goes back to the assumption by Gross and Gross (1927) in chemistry that most frequently cited journals are most relevant to the field and thus the most valuable journals for a library to purchase.

Eugene Garfield soon recognised the power of the IF for journal evaluation and considered it also a journal performance indicator (see Garfield, 1972).

Nowadays, the ISI impact factor has probably become the most frequently used bibliometric measure worldwide, and has obtained a very strong 'market' position. It actually represents a paradigm in bibliometrics and information science.

Todorov and *Glänzel* (1987) have characterised this measure as follows.

> "*Journal citation indicators are commonly used as general measures for various journal characteristics and research impact by different participants in the publication, dissemination, and evaluation process of scientific knowledge. … Many librarians, information scientists and, sociologists of science already consider journal citation analysis as a practical alternative to subjective judgement. Authors may take citation measures from JCR and use them as possible indicators of journal characteristics. Lists of ranked SCI journals may help potential and real users to identify sources with significant contributions. Editors and publishers may relate high citation impact to a successful editorial practice and policy. That is why we are trying*

in this paper to review and comment on some citation-based measures for scientific journals which are available and applied as evaluative indicators."

The strengths of the Impact Factor lies above all in its comprehensibility, stability and its fast availability since it is annually published for a large range of scholarly journals along with other ISI products. This is contrasted by flaws that have provoked critical and controversial discussions about its correctness and use.

In their state-of-the-art report, Glänzel and Moed (2002) have summarised several flaws.

1. There is no normalisation for reference practices and traditions in the different fields and disciplines (*Pinski* and *Narin*, 1976).
2. "There is no distinction in regard to the nature and merits of the citing journals" (*Tomer*, 1986).
   ⇒ Introduction of *Eigenfactor* and *Influence Factor* scores to overcome this problem.
3. There is a bias in favour of journals with large papers, e.g. review journals tend to have higher impact factors (*Pinski* and *Narin*, 1976).
4. Citation frequency is subject to age bias (*Asai*, 1981, *Rousseau*, 1988, *Glänzel* and *Schoepflin*, 1995, Moed et al., 1998).
5. There is no indication of the deviations from this statistic (see, for instance, *Schubert* and *Glänzel*, 1983).
6. The average time for a journal article from publication to peak in citations is not always two years, or as *Garfield* (1986) writes "if we change the two-year based period used to calculate impact, some type of journals are found to have higher impacts". (cf. also *Glänzel* and *Schoepflin*, 1995, *Moed* et al., 1998)
   ⇒ Introduction of the 5-year IF to provide at least a synchronous solution.
7. One single measure might not be sufficient to describe citation patterns of scientific journals (e.g., Glänzel, 2009).
8. The concept of citable document is not operationalised adequately. As a result, journal impact factors published in ISI's Journal Citation Reports are inaccurate for a number of journals (*Moed* and *van Leeuwen*, 1995, 1996).
9. In the calculation of JCR impact factors, errors are made due to incorrect identification of (cited) journals, for instance for the journal *Angewandte Chemie* – International Edition (*Braun* and *Glänzel*, 1995, *van Leeuwen* et al, 1997).
   ⇒ Solved for some journals.

The Journal Impact Factor and related measures – Definition, calculation and statistical properties

The Impact Factor is part of the *Journal Citation Reports* (JCR). Two editions are provided by Thomson Reuters, the Science Edition and the Social Sciences Edition. Both editions overlap since several journals are assigned to both the sciences and social sciences and several *Subject Categories* are defined for both editions with possibly somewhat different journal profile.

There is no JCR edition for the arts and humanities. Consequently journal impact measures are not calculated for journals covered by the AHCI (except for those that are covered by the SCIE or SSCI as well.)

From the statistical viewpoint, the Impact Factor (standard Impact Factor and Five-Year Impact Factor) as well as the Immediacy Index are mean values. They are defined as mean citation rates

(1) $$\frac{c_n}{\sum_{i=j}^{k} p_i},$$

where p_i is the number of papers of document type *article* (including note and proceedings paper) or *review* published in the journal in year i and c_n the number of citations received by the papers in year n.

For the standard Impact Factor we have $j = n-2$; $k = n-1$,

for the Five-Year Impact Factor we have $j = n-5$; $k = n-1$,

for the Immediacy Index, we have $j = k = n$.

Note that journal indicators are *synchronous* (retrospective) measures, that is, the citation year is fixed and relates backwards to variable publication windows in the past (cf. above definition).

All indicators used in the JCR are based on calculations made on *reference lists* of all papers published in citing and cited journals. Journal identification in the reference lists is made on the basis of thesauri built for *source titles* and the *publication year*. In the SCIE and SSCI, citations are determined through paper-by-paper match of the source paper and the items in the reference list of citing papers. Any attempt of reconstructing the Impact Factor by calculations made on the basis of the two citation databases will therefore fail.

A further problem arises from this procedure. The denominator of Eq. (1) is based on *citable* items, that is, on articles and reviews. In the numerator all citations are taken into consideration. This might result in distortions of several journals' IF as has shown, e.g., by Moed et al. (1999) using the example of the journal *The Lancet*. The following example taken from Glänzel and Moed (2002) illustrates the role of the document type *letter* as significant conveyor of original scientific information (see also Peritz, 1991).

The use of reference lists for IF calculation is sensitive to double-counting due to lacking disambiguation, as has shown by Braun and Glänzel (1995) and *van Leeuwen* et al. (1997) for the journal Angewandte Chemie – International Edition. This error has been corrected by ISI/TR.

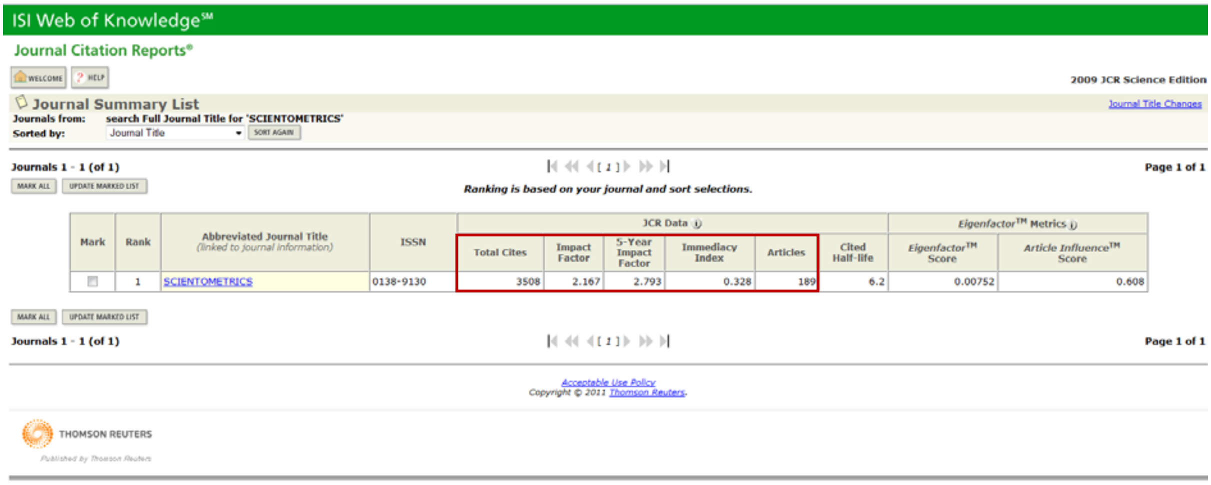
"3-year impact measure" for selected journals by document types (*Source*: Glänzel and Moed, 2002)

Journal	Mean Citation Rate			
	Total	Articles	Reviews	Letters
SCIENCE	32.86	42.30	145.35	0.41
NATURE	32.88	49.73	96.07	3.93
LANCET	5.25	17.55	14.68	1.99
CELL	75.68	74.82	78.63	75.64
ANGEW CHEM INT ED	11.01	9.37	32.03	19.00
J ACQ IMMUN DEFIC SYND HUM R	4.05	4.64	39.00	1.04
INT J RAD ONCOL BIOL PHY	3.52	4.15	35.00	0.37
J PHYS CONDENS MATTER	2.72	2.47	9.57	3.99

In what follows, we will restrict further example to the original JCR version of the impact factor. The first figure gives an overview of journal impact measures provided by this database. Impact measures can whether be viewed for individual journals or journals grouped by one or more subject categories or even for all journals covered by one of the JCR editions. Subject assignment of TR products is made on the basis of journal assignment. Each individual journal is assigned to one or more subject categories. The Science Edition comprises 173 subject categories in total. By contrast, the Social Sciences edition of the JCR covers 55 categories.

For each journal the following measures are shown (impact measures are indicated here by a red frame).

Journal impact measures as presented in the 2009 JCR (*Source*: Thomson Reuters – Web of Knowledge, 2011)



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2009 JCR Science Edition

Journal Summary List

Journal Title Changes

Journals from: search Full Journal Title for 'SCIENTOMETRICS'

Sorted by: Journal Title SORT AGAIN

Journals 1 - 1 (of 1)

MARK ALL UPDATE MARKED LIST

Ranking is based on your journal and sort selections.

Page 1 of 1

Mark	Rank	Abbreviated Journal Title (linked to journal information)	ISSN	JCR Data						Eigenfactor™ Metrics	
				Total Cites	Impact Factor	5-Year Impact Factor	Immediacy Index	Articles	Cited Half-life	Eigenfactor™ Score	Article Influence™ Score
☐	1	SCIENTOMETRICS	0138-9130	3508	2.167	2.793	0.328	189	6.2	0.00752	0.608

MARK ALL UPDATE MARKED LIST

Journals 1 - 1 (of 1)

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Comparison and ranking of Impact Factors

The JCR offers the opportunity of ranking journals by impact measures within their subject category. Citation indicators are very sensitive to subject specific communication behaviour. Cross-field comparison or even cross-filed ranking of journals would therefore result in invalid conclusions and should not be done at any cost.

A further problem is the use of the Impact Factor results from interdisciplinarity and multiple assignments of journals to Subject Categories. The journal *Bioinformatics* is assigned to three subject categories with different communication and citation behaviour.

Example: The journal *Bioinformatics* in different subject categories with IF = 4.926 (2009)

Rank	Subject Category
2	mathematical & computational biology
9	biochemical research methods
14	biotechnology & applied microbiology

The JCR also provides similar indicators at subject level. These measures are called *Aggregate Impact Factor* (AIF) and *Aggregate Immediacy Index* (AII). The AAI values of the above three categories amount to 2.945 in mathematical & computational biology, to 3.387 in biochemical research methods and to 3.028 in biotechnology & applied microbiology. The following example shows further subject impact values covering the full range of subject citation impact. For all categories the median impact factor is determined. Note that the IFs are means values with different standard deviation originated from journals of different size with different; therefore the mean IF is not an appropriated reference standard for the impact factors of journals in the corresponding category.

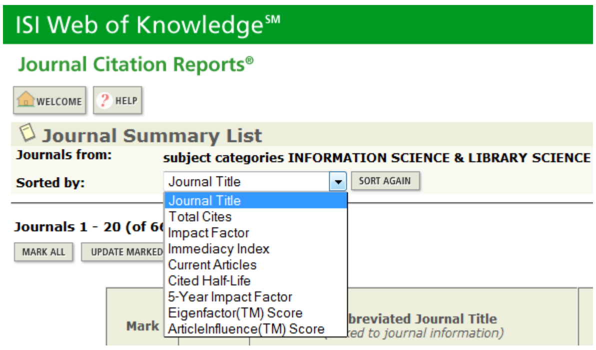
The median IFs in these fields follow the general trend set by the AIF category impact measure.

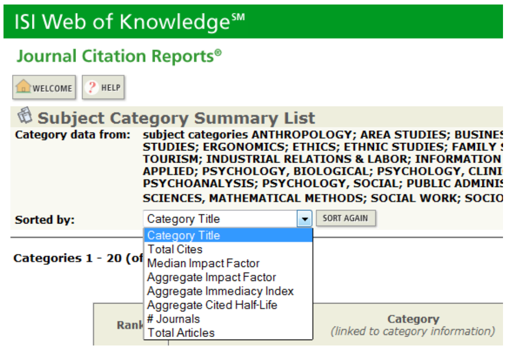
Example: Aggregate Impact Factors of selected subject categories

Rank	Subject Category	Median IF	AIF
2	cell & tissue engineering	3.263	6.475
3	cell biology	3.308	5.825
17	neurosciences	2.766	3.864
29	biochemical research methods	2.347	3.387
30	psychiatry	2.197	3.374
31	physics, particles & fields	2.034	3.264
57	chemistry, analytical	1.776	2.638
63	energy & fuels	1.395	2.550
93	oceanography	1.151	1.895
129	acoustics	0.840	1.454
130	computer science, cybernetics	1.194	1.439
131	crystallography	1.451	1.433
132	fisheries	1.227	1.427
148	statistics & probability	0.940	1.213
149	entomology	0.891	1.212
150	materials science, ceramics	0.434	1.207
167	mathematics	0.633	0.777
171	engineering, aerospace	0.508	0.650
172	engineering, petroleum	0.404	0.494
173	engineering, marine	0.280	0.121

In general, life sciences have the highest citation impact, followed by physics, and chemistry, computer science, mathematics and engineering have the lowest citation impact.

Presentation of journal and category measures in the JCR (*Source*: Thomson Reuters – Web of Knowledge, 2011)





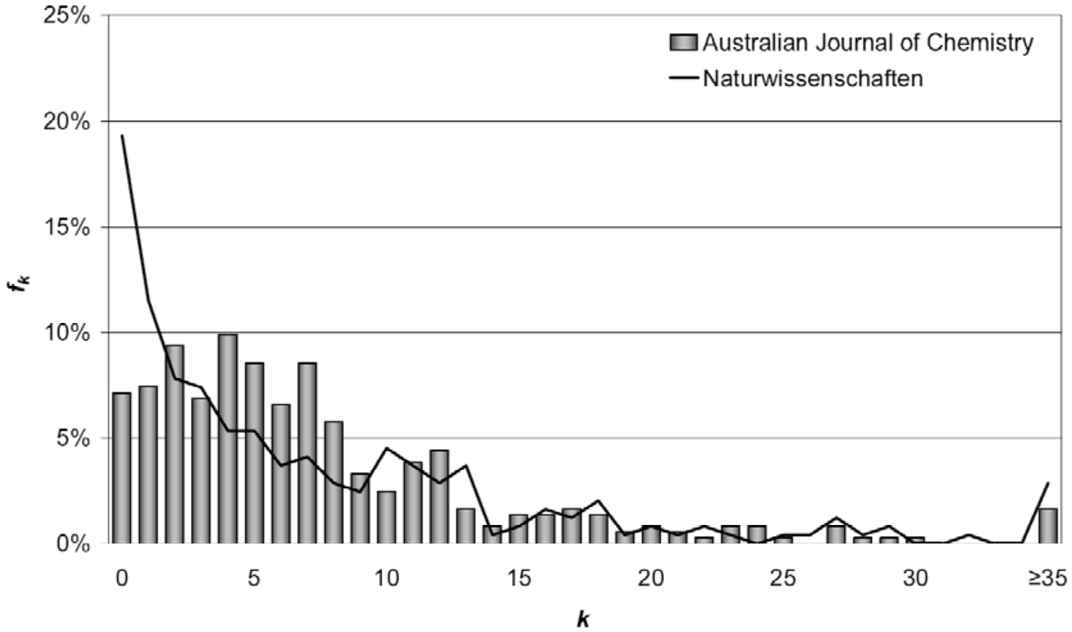
Statistical properties

The citation distributions underlying the IF-type measures are integer-valued discrete and often 'skewed'. Nevertheless, these measures have the following important property (cf. Schubert and Glänzel, 1983, Glänzerl and Moed, 2002). The sample mean, say $\overline{x}$, i.e. in our case the IF-type measure in question, follows the normal distribution $N(m, \sigma)$ where m is the expectation of the underlying (discrete) distribution and σ depends only on the standard deviation of the underlying distribution and the sample size, provided the underlying distribution belongs to the domain of attraction of the normal distribution. Many discrete distributions meet this condition (e.g., the negative binomial, the geometric, the Poisson distribution, the log series distribution, all Paretian distributions with exponent > 2).

The law of large numbers implies that $E(\bar{x}) = m$ and $D(\bar{x}) = \sigma = d/\sqrt{n}$, where *d* is the standard deviation of the underlying integer-valued discrete citation distribution and *n* the sample size. Furthermore, $\bar{x}$ is an unbiased estimator of *m*. As a result of this property, kind of a confidence interval for journal impact measures can be calculated in order to facilitate ranking or the comparison of impact measures of different journals within the same discipline.

Although the above statistics help decide whether the deviation of two IFs may be considered significant or not, one single measure is not sufficient to fully describe the citation patters of a journal. The following example shows two journals (*Naturwissenschaften* and *Australian Journal of Chemistry*) with differently shaped citation distributions but similar mean citation rate. IF measures can therefore only partially describe journal impact.

Frequency distribution of citations over papers published in *Naturwissenschaften* and *Australian Journal of Chemistry* in 1980 (citation window: 1980-1990; *Source*: Glänzel, 2009)



Some critical comments on policy applications

Merton's interpretation of the citation and his idea of citation as part of the reward system of science have paved the way for present-day interpretation and application of journal impact measures. According to the sociologists' view communication in science is not merely linked to cognitive processes (cf. information science), but also characterised by the position scientists hold in the community (cf. Kaplan, 1965, Merton, 1973, 1988).

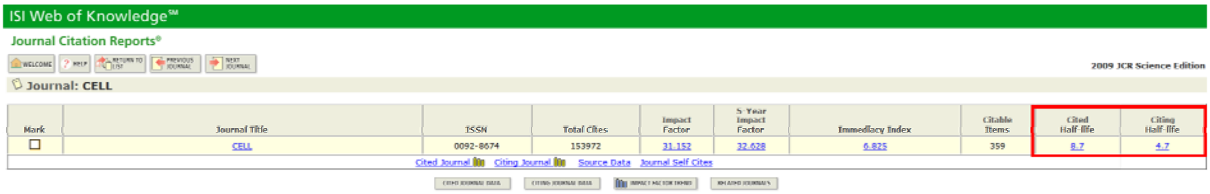
Ever since, the Impact Factor evolved to an evaluation tool. Nowadays it plays an important part in the evaluation of research groups and individuals. The IF seems to have become the common currency of scientific quality in research evaluation (Neuberger and Counsell, 2002) and has already influence on scientists' funding and carrier.

According to van Raan, the Impact Factor is the "poor man's" tool for citation analysis (cf. Adam, 2002).

Half-life – A measure of ageing and obsolescence

Journal half-life is an obsolescence indicator. Historically it is adopted from physics, where it characterises the speed of radioactive decay. It is identical with the median of the decay process. Although life-time distributions of references and citations do not follow the exponential model of physics, the median is a good indicator of ageing of information. The citing and cited half-life is actually defined as the time period beginning with the publication year in which half the citations are given or received, respectively, that is, half of the citations in the category are to/from articles published within the citing/cited half-life. For the cited half-life a synchronous solution is chosen since the citation year is fixed and the corresponding cited source year is moving. The JCR provides these indicators in the JCR for journals and subject categories along with the IF data. The measures are provided both numerically (here indicated by a red frame) and graphically for a 10-year cited period. If the half-life is greater than 10 years, the corresponding indicators value is put >10.0.

Journal impact measures for the journal *Cell* as presented in the 2009 JCR (*Source*: Thomson Reuters – Web of Knowledge, 2011)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2009 JCR Science Edition

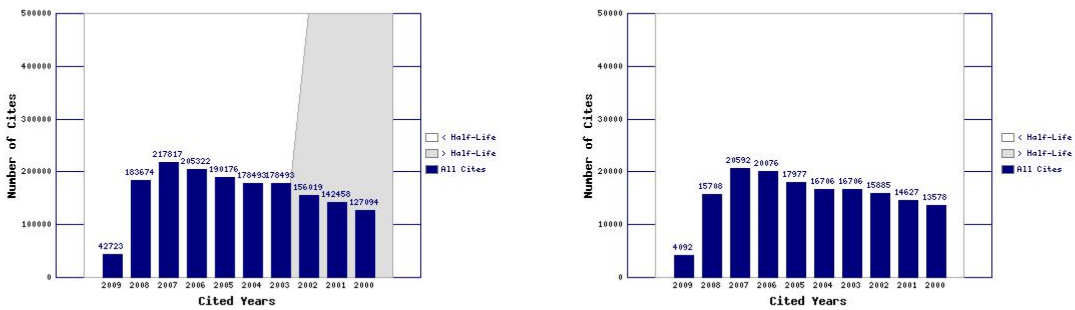
Journal: CELL

Mark	Journal Title	ISSN	Total Cites	Impact Factor	5-Year Impact Factor	Immediacy Index	Citable Items	Cited Half-life	Citing Half-life
☐	CELL	0092-8674	153972	31.152	32.628	6.825	359	8.7	4.7

Cited Journal Citing Journal Source Data Journal Self Cites

In the JCR graphs (for both cited and citing half-life) the indicator value is indicated by white and grey zones, respectively, provided this is less than 10 years. For journals, distinction between (journal) self-citations and foreign citations is made. Below the graphic presentation is shown using the example of two science fields, *biochemistry & molecular biology* and *mathematics*. The graph visualizes that the time-life distributions are not exponential since the peak in not in the publication year, i.e. the frequency is not monotonously decreasing. The slower ageing of mathematics (citing half-life >10a) is obvious. By contrast, the aggregated citing half-life of biochemistry & molecular biology amounts to 7.0a.

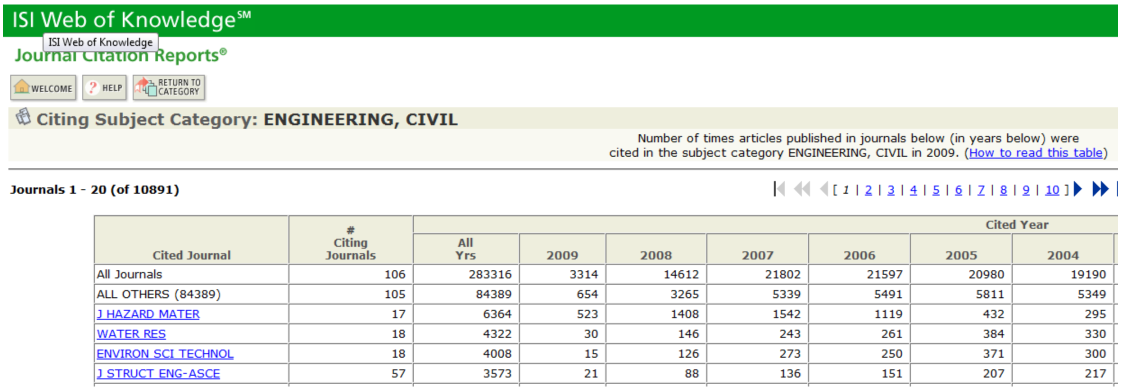
Citing half-life of biochemistry & molecular biology (left) and mathematics (right) (*Source*: Thomson Reuters – Web of Knowledge, 2011)



Price Index – A measure of the "hardness of science"

According to Derek de Solla Price (1970), the reference items of scientific publications also reflect characteristics concerning the "hardness" of scientific literature. He used the share of references not older than five years in all references of a journal to distinguish between hard science, soft science, technology, and non-science. He called this measure *Price Index*. The Price Index is defined as the share of references to 0 to 4 years old literature in all references. Price actually found that physics and biochemistry journals have high immediacy with Price Index typically between 60% and 70%, while journals in social sciences have a corresponding index ranging between 40% and 50%. Although the Price Index is not provided in the annual JCR editions, it is easy to calculate for both subject categories and journals.

A citing subject category as presented in the 2009 JCR (*Source*: Thomson Reuters – Web of Knowledge, 2011)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Citing Subject Category: ENGINEERING, CIVIL

Number of times articles published in journals below (in years below) were cited in the subject category ENGINEERING, CIVIL in 2009. (How to read this table)

Journals 1 - 20 (of 10891)

[1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10]

Cited Journal	# Citing Journals	Cited Year						
		All Yrs	2009	2008	2007	2006	2005	2004
All Journals	106	283316	3314	14612	21802	21597	20980	19190
ALL OTHERS (84389)	105	84389	654	3265	5339	5491	5811	5349
J HAZARD MATER	17	6364	523	1408	1542	1119	432	295
WATER RES	18	4322	30	146	243	261	384	330
ENVIRON SCI TECHNOL	18	4008	15	126	273	250	371	300
J STRUCT ENG-ASCE	57	3573	21	88	136	151	207	217

The Price Index is calculated for seven disciplines in the sciences and social sciences. The effect described by de Solla Price is obvious. Life and natural sciences have the highest share of references in the most recent five years. Engineering sciences have distinctly lower share, followed by the social sciences. Mathematics and history – both very slowly ageing fields – are among the disciplines with the lowest Price Index.

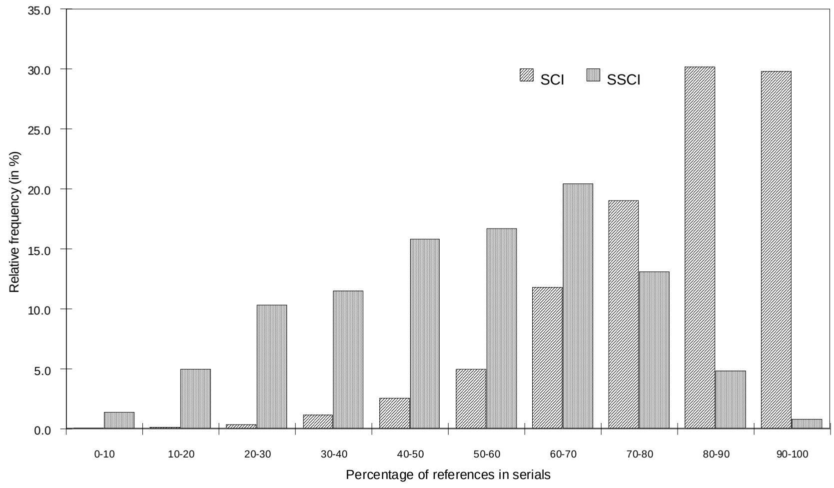
Price Index calculated for a subject category on the basis of the 2009 JCR (*Source*: Thomson Reuters – Web of Knowledge, 2011)

Subject category	cited years		Price Index
	all	last 5	
Cell biology	576915	220490	38.2%
Physics, particles & fields	398225	145150	36.4%
Engineering, civil	283316	82305	29.1%
Sociology	181660	43901	24.2%
Anthropology	137351	31769	23.1%
Mathematics	389650	78445	20.1%
History & philosophy of science	57873	11486	19.8%

A Further indicator for the distinction between "hard" and "soft" science has been found by Glänzel and Schoepflin (1999). The percentage of references to serials characterises typical differences in the communication behaviour in the sciences, social sciences and humanities. Unfortunately, indicators based on the share of periodical cannot immediately be obtained from the JCR. However, the heading "ALL OTHER" provides some information about this issue. This category covers all items only occurring one. Since many of them can be assumed to be non-periodicals the share of "All Other" gives a clue about the structure of references. This information can be used a supplement to the Price Index.

Ageing indicators help to better understand and interpret impact-factor type journal measures since fast ageing journals and journals in fast ageing fields are expected to have higher citation impact than those in slowly ageing fields like applied sciences, mathematics and social sciences.

Distribution of the share of references to serials over journals in the sciences and social sciences (*Source*: Glänzel and Schoepflin, 1999)



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