Applying Diachronic Citation Analysis to Ongoing Research Program Evaluations

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Abstract

Diachronic versus synchronous citation analysis methods are discussed in relation to research evaluation. Using selected results from an online mid-term evaluation of nine research centers funded by the Danish Strategic Environmental Research Program (1993-98), the essay illustrates and discusses the application of five diachronic scientometric indicators. Publication activity; center and program impact factors; impact factors for journals applied by the centers; international knowledge export; and the paper-journal impact factor correlation indicators are shown to be well understood by the scientists involved. In an informetric sense, the indicators afford robust tools for providing fair and reliable information on publication behavior and performance. In particular, the paper-journal impact factor correlation, applying the Pearson coefficient, may contribute to further understanding of the probabilities involved in achieving high impact when scientists succeed in publishing in high impact journals. The ISI databases, Science Citation Index and Social Sciences Citation Index, were used in their online versions provided by Dialog Knight Ridder Information Service.

1. Introduction

This essay demonstrates the application of diachronic online citation analysis to the evaluation of research programs. The chosen case is a mid-term evaluation of the Danish Strategic Environmental Research Program, which funded nine research centers during the period 1992-1996 with approximately US$3 million. The mid-term evaluation covers the publication period 1993-95 and the citation window 1993-98. A diachronic method was selected in order to make the performance evaluation as comparative and transparent as possible to both the client and the scientists involved.

Diachronic citation analysis is commonly used when calculating the cited half-life of a journal or a specific article (Egghe and Rousseau, 1990). Such analyses are historical in the sense that one calculates the total amount of citations given annually to an article over time. The citations are aggregated and when half of the total number of citations is reached – essentially the median point of grouped data in the form of a year – the half-life of that particular article journal is known. In future years, the half-life will change as new citations are added to the stock. In the annual Journal Citation Reports (JCR), produced by the Institute for Scientific Information (ISI), another kind of cited half-life for journals is presented. Here the cited half-life calculation is done in a synchronous manner, i.e., "the half-life is the number of years, going back from the current year, that account for 50% of the total citations received by the journal in that current year" (JCR, 1999, p.16). In the diachronic analysis it is possible to compare the cited half-life of a journal article with that of the journal itself. This comparison is not possible in a synchronous citation analysis, and a comparison between a diachronic article citation analysis and a synchronous journal citation analysis is likewise meaningless.

In the case study presented below, two diachronic online life citation analyses were carried out for each journal item produced by each of the nine research centers for the period 1992-95. Each item, out of a total of 201 publications provided by the centers through the client, the Strategic Environmental Research Program, was searched for the number of received citations. The search was carried out on the ISI databases, Science Citation Index (SCI) and Social Sciences Citation Index (SSCI), in their Dialog online versions, up to and including 1998. The sum of citations for each item represents its *diachronic publication impact*. Similarly, the relevant journal volume for

the publication year of the article was searched for the total of citations received during the same period in order to establish a *diachronic journal impact factor*. By journal item is meant any of the following document types: article, note, review article. The online citation analysis method has been developed by the Center for Informetric Studies (CIS) (Christensen and Ingwersen, 1996) and will be detailed below. The two impact factors can be compared and we obtain information about the *real* number of citations received by the item against the *expected* average of citations for the publishing journal for the same period. When aggregated for a center we name these impact factors *Center Impact Factor* (CIF) and *Center Journal Impact Factor* (CJIF), respectively. By saving the total amount of citing items online in a combined set per center we may investigate the *international knowledge export* distributed over the citing countries in order to determine the extent of a center's international impact. The online technique has been developed and published by Wormell (1998). Further, one may observe the level of ambition of the researchers, i.e., are they targeting high impact journals, and how successful are they in so doing? Applying the Pearson correlation coefficient to the CJIF of high impact journals and the corresponding distribution of received citations provides this measure. It then becomes possible to monitor not only the actual performance of each center by comparing the CIF and CJIF, but also to observe whether the well-known Matthew-effect, which holds for Danish science research (Bonitz *et al*., 1996), applies in the environmental domain. Partly in the same manner, Rousseau (1998b) has recently carried out a university evaluation using the CD-ROM versions of the ISI databases and a weighted journal citation impact factor based on the JCR as a comparative measure.

Obviously, the citations received by the single articles as well as by the journals involved will include both personal and journal self-citations, possible name dropping, and other types of citations frequently discussed as factors biasing performance measures (Cronin, 1984, 1998; MacRoberts and MacRoberts, 1989; Kostoff, 1998). However, by comparing across individual articles and journals any perceived bias is considered equally distributed. The most important reason for including the self-citations is that comparisons to the CJIF would otherwise be asymmetric since the latter impact factor necessarily contains personal self-citations. We believe, along with van Raan (1998, 1999) and Garfield (1997, 1998a), that advanced scientometric methods provide valuable insights into the performance and behavior of scientists, which complement peer review, provided proper ethical issues and careful data examination are taken into account.

In our case, the contribution is structured in the following way. First the differences between synchronous and diachronic citation analysis methodologies and our procedure are briefly presented and the reasons why the common ISI journal impact factor (JIF) has not been applied by CIS in performance evaluation. This is followed by a presentation of selected results from the environmental research evaluation, mainly to demonstrate the possibilities associated with diachronic methods. This section includes an additional comparative measure by Pearson´s *r* of the journal and actual impact correlation as well as an example of the distribution of citing countries. Finally, we discuss the outcome and methodology used in the survey.

2. Diachronic and synchronous citation analysis – the procedure

The common JCR journal impact factor (JIF) has frequently been applied as a measure of scientists' research performance, and also in evaluating research institutions. The method involves *assigning* the JIF score to each item published by the institution. However, this procedure is unethical (Calza and Garbisa, 1995). It is unfortunate to all involved since the JIF is a short-term impact measure, as shown in Figure 1. It tells us about the average number of citations received in one year T per journal article, note or review article published in a given journal during the two

previous years T-1 and T-2. This synchronous impact factor has as standard a two-year (maximum) citation window, but the window might cover longer periods as noted by Garfield (1972, 1979). For instance, Rousseau suggested for mathematics a four-year window (1998a). The citing publication year(s), traditionally being one year (T), might also, in theory, be extended, but that is less attractive from a commercial point of view, since the cited publication years then are pushed back in time and become less up-to-date.

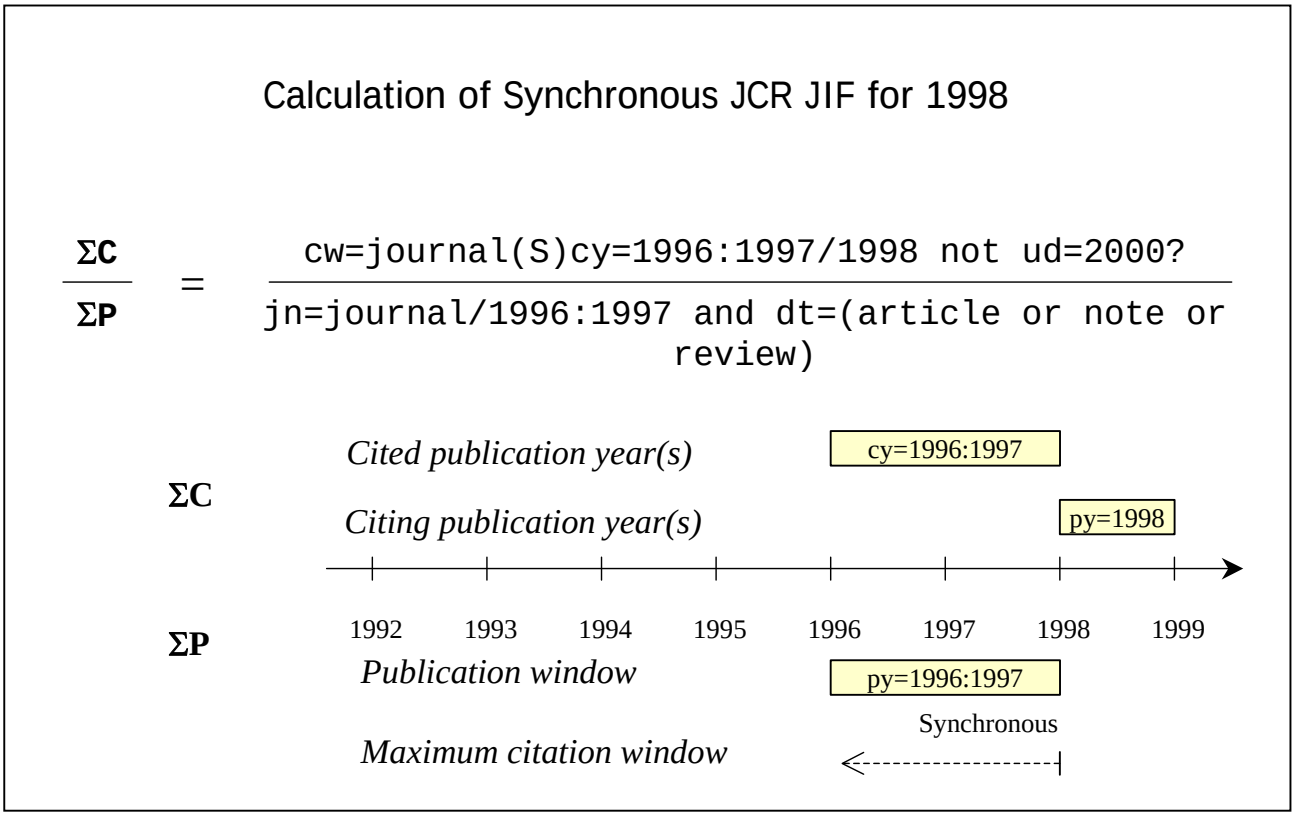

Figure 1. The Journal Impact Factor (JIF) calculated online as in the Journal Citation Reports (ISI). C = citations received by P publications.

But, most important, the JIF (regardless of the window length) only tells us about the *average expected impact* of the items published in a journal – never the real number of citations. As a measure of journal performance it tells us what a scientist might expect to receive in terms of citations (during a single year, e.g., 1998) to his work published in the journal either in 1996 or 1997. Already here we observe additional problems of using the JIF by assigning it as a personal score. There exists a problem regarding the year actually to be used as the basis for an assignment, the 1998 JIF score or that of 1997, since both years may provide citations to an item published in 1996 in the standard JIF calculation. The 1998 score is generally the higher one due to its two-year citation window (see Figure 1).

Further, by replacing the real score by an expected one we assume that *all* articles in that journal actually obtain citations and that the scientist is an *average scientist*. This problem is of course also true for the diachronic JIF, although it is regarded as being more robust due to a typically longer citation window (see Figure 2).

In itself, uncitedness is an interesting indicator (Garfield, 1998b) and can be observed for scientific fields in the annual National Science Indicators database (NSI), produced by ISI. Seglen (1997, p.499) demonstrates the actual citation rates in 1986 and 1987 for the articles published in

three Biochemical journals issued in 1983 and 1994 respectively and shows how few articles actually contribute to the impact factor.

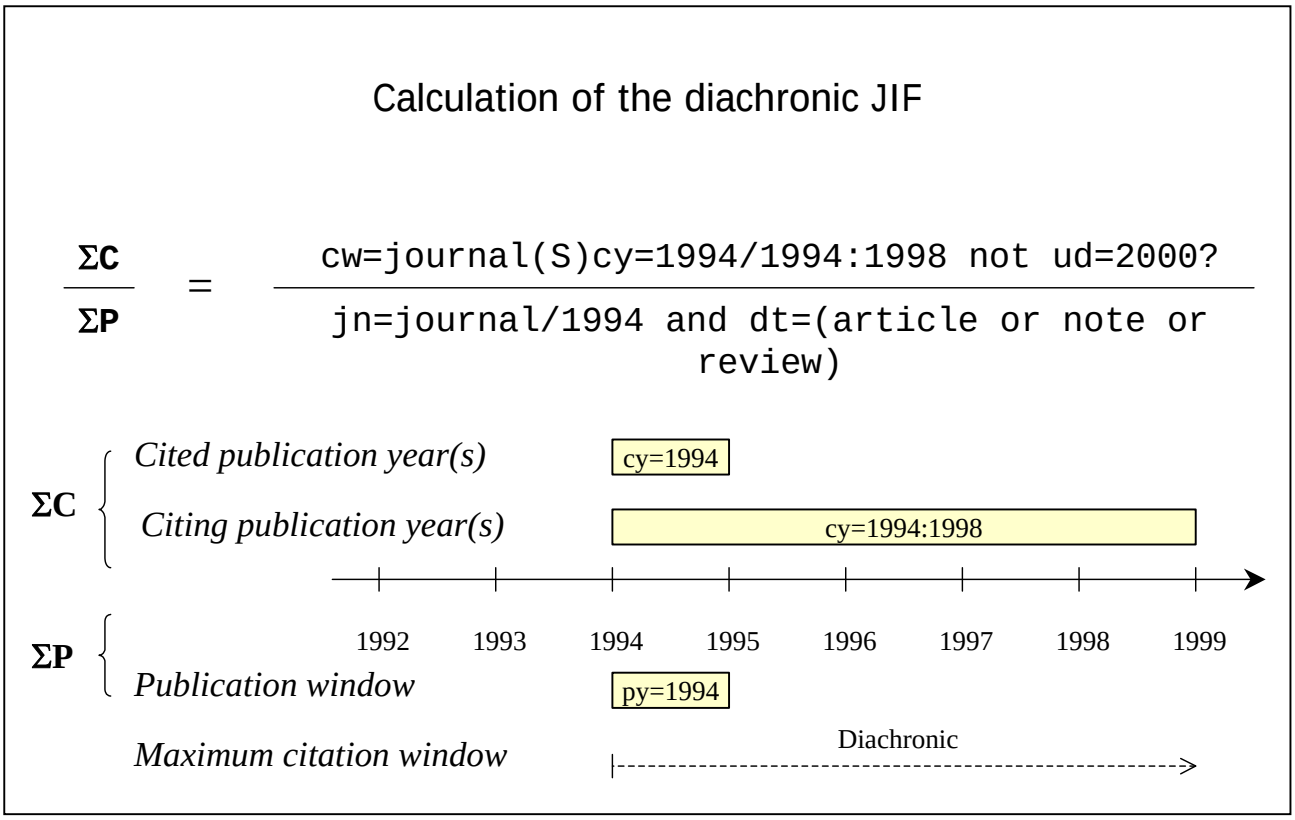

Figure 2. The online calculation of a diachronic Journal Impact Factor (JIF). C = citations received by P publications.

An additional misleading factor is the application of *only one JIF* value per journal even if the investigation covers several years and different volumes of each journal, as done by Gøtzsche for Danish medical research (1994). In our illustration (Figure 1) the standard JIF value calculated for 1998 could have been chosen as the one, although the article was published in 1994. The erroneous assumption behind this behavior is that an annual JIF does not change substantially over a given period. A small-scale study of 17 randomly selected medical and microbiology journals showed quite substantial JCR JIF variations over a five-year period. The variation ranged from 13-22 %, with 13 % among higher impact journals (Larsen, 1999). This unfortunate misuse of the JIF has been discussed and criticized in recent years, for instance by Seglen (1997) and Hecht *et al.* (1998).

Figure 1 displays the conceptions and search strings applied to the calculation of the JCR JIF. To retrieve the nominator figure online for the JCR JIF calculation one first has to check all the name forms of the journal in question as cited work (CW=). The update field (UD=) is used to limit the citations to come from publications issued in 1998 that are indexed through 1999 by ISI.[1] The search string retrieves the number of *items* that have cited the journal. To obtain the actual number of *citations* the Dialog feature "set postings on" should be applied and a logical procedure leads to the correct number of citations (Christensen and Ingwersen, 1996, p.50). The logic is that the number of postings contains figures from all the retrieved search statements. Hence, the number of citing items must be subtracted from the number of postings, since they only appear once. The

[1] ISI limits this period to the first months of the year (1999) in order to be able to produce JCR during Spring.

remaining number of postings is then divided by 2, giving the final number of citations, since for each citation the cited work (CW=journal) *and* the cited publication year (CY=1996) always appear together in pairs. The denominator string retrieves the number of citable items in the publication window. Here, the journal field (JN=) is commonly controlled by ISI.

Figure 2 illustrates the similar online search strings for a diachronic JIF calculation. The publication window is one year (the cited publications are published in 1994) and the citations derive from the citing publication years 1994-98, i.e., the maximum citation window is 5 years. The diachronic online method also makes use of the "postings" feature and logical procedure in order to find the number of citations for the nominator.

For a specific article published in the journal the search string is commonly made in order to check the index of cited references (CR=), and not to be searched directly. A given publication ,

> Kjær, C. and Jepson, P.C. (1994). The toxic effects of direct pesticide exposure…….*Environmental Toxicology and Chemistry*, 14, 993-999

would be transformed by CIS into: "KJAR C, 1994, v14, 993-999, Environ Toxicol Chem"
and expanded in the CR= field like: "KJAR C, 1994" - which may provide the following variations in the CR=index to be checked manually:

> ……
> CR=KJAR C, 1995, ENV TOX CHEM in press
> CR=KJAR C, 1995, v14, 993, ENVIRON TOXICOL CHEM
> CR=KJAR C, 1995, v14, 993-999, ENVIRON TOXICOL CHEM
> …….

After checking the variations, the total number of citations is cumulated for each center publication after limiting to include the citing publication year 1998 and removal of duplicates between the SCI and SSCI databases. Personal name forms, such as "Kjar" vs. "Kjaer" were also checked. The overall CIF is then found by cumulating all the citations given to all the publications published by a center. However, this overall CIF also contains citations to publications *not indexed* by the citation databases - although their citations received from ISI-indexed journals can be detected. In order to compare fairly to the CJIF such citations and publications from the center not indexed by ISI are set aside. Hence, one obtains two kinds of CIF. One CIF is the overall one, including all center publications and their citations. Another is the comparative CIF that alone includes publications found in the citation databases and their citations. Only the latter CIF can be compared to the corresponding CJIF signifying the journal package of each center.

A variety of citation windows were used in pairs, according to the publication year of each of the 201 items produced by the centers, i.e., 6 years ≥ window ≥ 4 years. This corresponds to the cited publication years (1993-95) and citing publication years (1993-98). Within each center some articles were actually published in the same annual journal volumes. The total number of diachronic JIF calculations are hence somewhat smaller than 201.

3. Illustrative diachronic evaluation results

To summarize the previous methodological discussion the following indicators were applied to the evaluation of the Danish Strategic Environmental Research Program.

- *Publication activity*: number of publications published by the centres over the analysed three-year period, 1993-95.
- *Center Impact Factor* (CIF): the number of citations per item found in the SCI/SSCI to centre publications that are *indexed by ISI*.
- *Overall CIF*: the total of citations per item found in the SCI/SSCI to *all* center publications.
- *Center Journal Impact Factor (CJIF)*: the diachronic IF calculated for each journal volume applied by a center and indexed by ISI.
- *International knowledge export*: frequency ranked listing of countries producing the publications *citing* the center publications.
- *Paper-journal impact correlation*: The correlation between high impact journal use and actual citation reception using Pearson´s *r*. The correlation observes the degree to which the strategic programme obtains citations corresponding to the JIFs of the journals applied by the centers.

3.1 Publication activity

Publication activity is illustrated in Table 1 below. We observe the expected pattern that the centres in this mid-term evaluation demonstrate a slow initial activity in the funding period which rapidly develops.

Table 1.Publication activity 1993-95. Source: SCI/SSCI, ISI, 1999.

Publication year	Number of articles, notes & review articles	%
1993	24	16
1994	48	32
1995	79	52
Total	151	100

Of the 201 publications issued by the nine centers 151 items were ISI-indexed as journal articles, notes and review articles. From 1993 the activity doubles in 1994 and trebles in 1995. The figures and publications were all re-checked by the individual centers to track possible errors.

3.2 The center citation impact factors

In total, 1538 citations were detected online to all 201 publications, i.e., including all the document types, such as conference papers, reports, articles in specialised journals, and book chapters. The *overall CIF* is thus 7.65 citations per publication. This impact is in line with the expected baseline, CJIF, reaching 7.8. Table 2 illustrates the distributions of the 1386 citations to the 151 *ISI indexed* centre publications retrieved online for the entire analysis period.

Table 2. All nine centers. Publications and citations; overall CIF, comparative CIF and CJIF. Source: SCI/SSCI & NSI, 1999 (ISI)

	Centre:	**SCI Publ.**	**Cit.-SCI**	**Center IF**	**Center JIF**	All Publ.	All Cit.
1.	*Air pollution*	15	153	10,2	10,93	20	172
2.	Terrestrial ecology	31	242	7,81	4,56	40	247
3.	*Groundwater*	7	43	6,14	7,73	13	47

4.	Agro ecosystems	9	37	4,11	3,44	14	44
5.	Agricultural soil	12	114	9,5	6,37	19	140
6.	*Freshwater*	13	209	16,08	6,02	14	230
7.	Marine ecology	16	204	12,75	9,56	20	216
8.	*Eco-toxicology*	37	250	6,76	8,67	49	306
9.	Biochem.-epidem.	11	134	12,18	12,08	12	136
	Mean - total	***151***	***1386***	***9,18***	***7,83***	*201*	*1538*
	Overall CIF						*7.65*

The strategic research program as such shows a quite substantial CIF, 9.2 citations per publication, which is 18 % higher than the corresponding CJIF (7.8). As stated, the average overall center impact – Overall CIF – approximates the CJIF, although the 50 publications not indexed by ISI receive far less citations on average (3 cit./publ.) than the indexed ones. The methodological strength lies in the detection of these extra citations, which become transparent to the researchers. Additionally, we may observe the proportion of SCI/SSCI-indexed publications for each center. This tells us about the publication behavior of the centers in the start-up phase. For instance, the Terrestrial ecology center produces 9 non-ISI indexed items, mainly articles in Danish journals, that yield only 5 citations during the period under analysis. On the other hand the Agricultural soil center produces 7 non-ISI items, that is, articles in books and specialized journals, that receive 26 citations or 3.5 cit./publ.

Six centres demonstrate a Center Impact Factor that is higher than CJIF, the comparative indicator values: Terrestrial ecology; Agro ecosystems; Agricultural soil research; Freshwater; Marine ecology; and Biochemical & work hygiene epidemics. Three centres, the Air pollution, Groundwater, and Eco-toxicology centers do not exceed the CJIF value.

The mid-term evaluation of the strategic program as a whole thus shows a promising level of international visibility and impact. For the three centers it seems, however, vital to become more visible in the next phase of publication activity 1994-98, which is due to be monitored in 2002.

A closer observation of the production from the three lower-impact centers demonstrates that, for instance, the Groundwater center has produced half of their (few) publications in specialized journals, although in English. This is not the case for the Air pollution and Eco-toxicology centers. They simply have been unable to harvest as high an impact as the corresponding impact factor of the ISI journals in which they published their research results. In particular, the case of the latter center is interesting, since 11 items were non-ISI indexed but nevertheless obtained 5.5 cit./publ. on average, a value close to the standard CIF (6.7) for that center.

In relation to the high-impact centers we observe (see Table 2) that, for instance, the Freshwater centre has published 13 out of 14 items in journals indexed by the ISI and obtained a real impact more than 2.5 times above the corresponding baseline CJIF.

3.3 International knowledge export

International knowledge export is illustrated on Table 3. The online technique makes use of the Dialog Rank command on the combined set of *citing* publications for each centre and has been developed by Ingwersen and Christensen (1997) and Wormell (1998) at CIS. The result is a frequency ranked list of the countries to which the *citing authors* belong. The table represents the Top-10 countries, i.e., the spreading of international knowledge from the Freshwater center.

Table 3. International knowledge export, 1993-98, the Freshwater Center.
Source: SCI/SSCI, ISI, 1999, Dialog version. Total no. of countries: 29

Rank no.	No. of publications	Percent	Ranked countries
1	50	27.0	DENMARK
2	45	24.3	USA
3	27	14.6	ENGLAND
4	25	13.5	NETHERLANDS
5	16	8.6	CANADA
6	12	6.5	SWEDEN
7	10	5.4	GERMANY
8	8	4.3	SPAIN
9	7	3.8	FRANCE
10	6	3.2	AUSTRALIA

Table 3 demonstrates that 29 countries cite the Freshwater center publications during the period under analysis. The most frequent citing countries are USA, England, and the Netherlands. The direct self-citation proportion is as maximum 27 % in this high-impact center. In principle, this indicator can be constructed for all the centers online. For instance, the lower impact centre for Groundwater research receives more than 40 percent of its citations from USA, and the productive Eco-toxicology centre obtains 23 % of the citing items from England, exports 20 % back to Denmark, and 18 % to USA. When ranking the combined set for a center one obtains the number of publications, *not citations* (see Table 3). By knowing the number of citations found in the citing publications it becomes possible to calculate the proportion of centre publications that are co-cited in the publications. For the Eco-toxicology center, for instance, 63 citations were co-cited.

3.4 Paper and journal impact correlation

The last indicator, the paper-journal impact factor correlation, concerns the correlation between high impact journal use and actual citation reception using the Pearson *r* coefficient. The correlation observes the degree to which the strategic program as a whole obtains citations corresponding to the impact values of the journals applied by the centers. The *r* score for the entire program and for all the 151 ISI indexed articles and corresponding journals is .5865 (p=.005). The critical value is .267 implying that the fit is *good*. The r^2 = .34 which implies that the unexplained variance of the individual article impact and the impact of the corresponding journal is 66 %. In 2/3 of the cases the individual articles have obtained less or, probably, more citations than expected from the CJIF. Since the CIF value on average is higher that the CJIF (see Table 2) one may assume that the latter phenomenon is the case. This can be tested for the 25 high-impact journals applied by the program and their corresponding article impact. The correlation between the 25 highest ranked CJIF and the article IF gives *r* = .68387 (p=.005) and a critical value of .0537. The r^2 value is .47 implying that approximately 50 % of the impact factors correlate. In other words, in half the cases the scientists succeed in obtaining a high(er) impact in high-impact journals. Diagram 1 plots the correlation. The 25 journal impact factors range from 9.8 to 54.8 citations per publication 1993-98.

This result is in line with the results of the Matthew Effect investigations made by Bonitz *et al.* (1996), which showed that Danish science research attracts more citations than one might expect from the baseline values, i.e., the domain (journal) impact. Evidently, half of those environmental scientists participating in the strategic program, who have succeeded in publishing in central high-impact journals, also obtain high citation impacts for their work, often even higher than expected in

this high-performance journal landscape. We might also say that in 50 % of the cases, when going for a high IF value by publishing in a high impact journal, the scientist may succeed in this domain. In contrast to the presented correlation figures Seglen (1994, 1997, p.500) and Gordon (1984) have shown poor correspondence between the synchronous JCR JIF and individual article citedness.

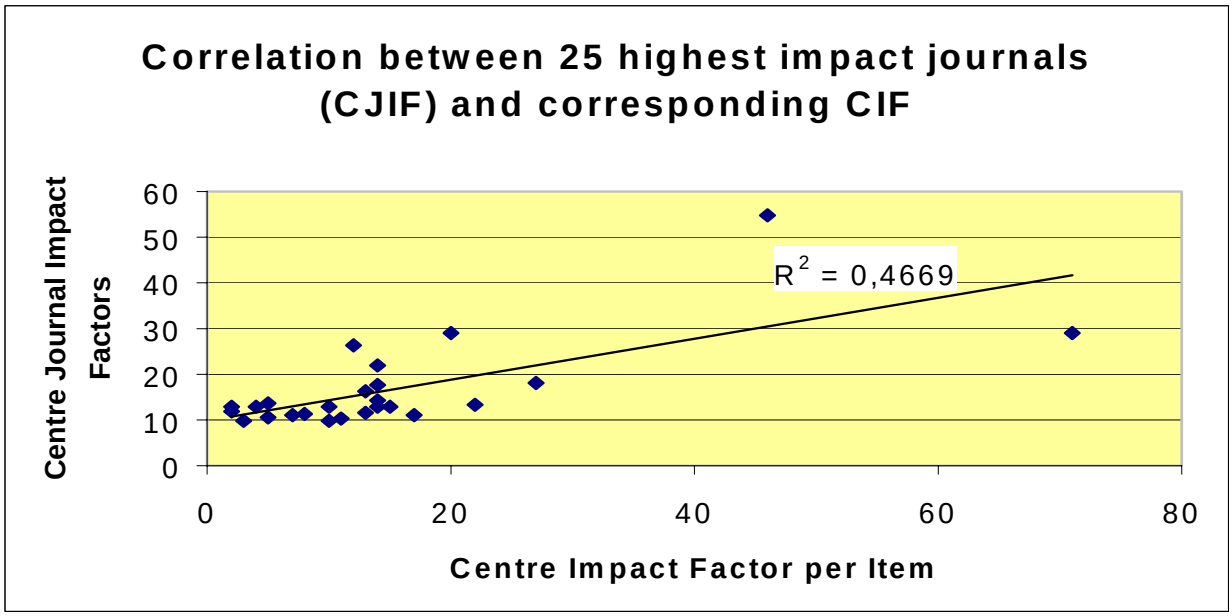

Diagram 1. Correlation covering 1993-98 for both single CIF and CJIF for all the nine centres. Source: SCI, ISI, 1999; Dialog version.

Obviously, the correlation is producible for each individual centre in turn and, hence, may illuminate publication behavior, ambition, and success or failure in more detail.

4. Discussion of the diachronic evaluation method

In practice, the pairwise use of the CIF and CJIF indicators was received very positively by the centers in a post-evaluation review. Both the funding agency and the centers saw the method as fair and comprehensive, in part because the non-ISI-indexed material was incorporated. It was surprising to the scientists that so many publications could receive substantial numbers of citations within a window of 4-6 years. It, thus, seems valuable to produce reliable indicators, which are immediately *understandable and informative* to both the client and the scientists to be monitored. It is important that the centers themselves are involved in the evaluation process.

From an evaluator's viewpoint the online methodology is economically feasible when the number of publications under investigation is small, as in the present case. The benefit lies in the added value provided by online features like the Rank and postings commands. The knowledge export indicator might easily be expanded to cover the subject categories assigned the citing journals in the SSCI/SCI online versions, and it is not difficult to rank the journals actually citing the center publications.

Finally, by means of diachronic analysis the clients easily understand that the Center Journal Impact Factor acts as the baseline for evaluating the actual center impact due to their pairwise mode of calculation and presentation. However, it becomes similarly feasible to use the same CJIF as a *value of success* in getting research published internationally. Obviously, this success value is

domain (or center) dependent. However, the application of regression analysis to monitor the *degree* of success in actually obtaining a high international citation impact by publishing in high-impact journals is domain-independent. As an indicator, it provides valuable insights into the probability of high performance in selected areas of research and journal landscapes.

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