A General Approach to Citation Analysis and an h-Index Based on the Standard Impact Factor Framework

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Abstract

We explain, using a complete publication-citation matrix, the relation between the data needed in the calculation of an *h*-index and those needed in the calculation of an impact factor. It is shown that there is no need to confine oneself to the standard cases. As an illustration *h*-indices are calculated based on the publication and citation windows of the classical impact factor.

Introduction

Citation analysis

Citation analysis is that subfield of informetrics where patterns and frequencies of citations, given as well as received are analyzed. Such an analysis is performed on the level of authors, journals, scientific disciplines and any other useful unit or level. Citation analysis further studies relations between cited and citing units (documents, authors, countries etc.). Experience has shown that a publication-citation matrix (in short: p-c matrix) is a handy tool for explaining many notions used in these analyses. In this article we use publication-citation matrices and relate them to the general conglomerate framework. In order to make the notions we want to discuss concrete we will use the example of a journal's p-c matrix. Yet, it is clear that the whole framework can be applied to many more source-item relations.

The complete publication-citation matrix

A journal's complete p-c matrix contains publication and citation information of each article separately. For simplicity's sake we consider a journal that was founded only three years ago and that published only a few articles a year. Its complete publication-citation history can be represented by a matrix of the type shown in Table 1. As usual, citations are derived from a pool of citing articles (Ingwersen et al., 2001).

Table 1. A complete p-c matrix for a hypothetical journal (or article set)

Publication year	1	1	2	2	2	3	3	3	4	4	4	4
Articles	A	B	C	D	E	F	G	H	I	J	K	L
Citations received in year 1	1	0										
Citations received in year 2	4	2	2	1	1							
Citations received in year 3	6	2	1	4	6	3	0	0				
Citations received in year 4	8	1	0	5	9	3	1	2	4	1	2	3

The number 6 in column 2E and the row denoted as "Citations received in year 3" in Table 1 means that article E, published in year 2, received 6 citations in year 3.

Impact factors

A p-c matrix containing the data necessary for the calculation of impact factors (Ingwersen et al., 2001; Frandsen & Rousseau, 2005) can easily be derived from the complete p-c matrix. Indeed, for the calculation of an impact factor no information about individual articles is necessary. Only the total number of publications and citations received per year is required. In this way, Table 1 becomes Table 2.

Table 2. The p-c matrix for determining a journal's impact factor as derived from Table 1

Publication year	1	2	3	4
Number of publications	2	3	3	4
Citations received in year 1	1			
Citations received in year 2	6	4		
Citations received in year 3	8	11	3	
Citations received in year 4	9	14	6	10

The first row gives the publication year and the second one the number of articles published in each consecutive year by this particular article set. We assume, for simplicity, that all these articles are 'citable' (no editorial material, meeting abstracts, book reviews, etc.). The other rows are citation rows. We see that, e.g. in the year 3 this set of articles received 8 citations to articles it published in year 1. It received 3 citations in year 3 to articles published that same year.

Based on this p-c matrix many different impact factors are defined in the literature. An important distinction is the one between synchronous and diachronous impact factors (Ingwersen et al., 2000, 2001). The standard Web of Science journal impact factor, denoted as IF_2, is a synchronous impact factor involving a single citation year and two publication years. Recall that the term 'synchronous' refers to the fact that citations used for the calculation were all received in the same year. As an example we note that the standard impact factor for the example from Table 2, in the year 4 is:

$$IF_2(4) = \frac{14+6}{3+3} \approx 3.33$$

It is this type of impact factor that is published annually in Thomson Reuters' *Journal Citation Reports* (JCR). Frandsen and Rousseau (2005) have shown how using different combinations of rows and columns leads to a plethora of synchronous and diachronous impact factors.

The h-index

The *h*-index (Hirsch, 2005) too is based on publications and citations and hence can be illustrated using a p-c matrix. Hirsch's original definition yields a scientist's instantaneous total career *h*-index. It is defined through the following procedure. Consider the list of all publications [co-]authored by scientist S, ranked according to the number of citations each of these has received (as determined using database D). Publications with the same number of citations are given different rankings (the exact order does not matter, anti-chronologically might be a good choice). Then scientist S' instantaneous total career Hirsch index (based on database D) is *h* if the first *h* publications received each at least *h* citations, while the publication ranked *h+1* received strictly less than *h+1* citations. Stated otherwise: scientist S' instantaneous total career Hirsch index is *h* if *h* is the highest rank (largest natural number) such that the first *h* publications received each at least *h* citations. We have added the word 'instantaneous' to stress the fact that if this *h*-index is determined one week later, it might be higher (but, by its definition, never lower).

Based on this idea Schubert, Glänzel and Braun (2005) defined a journal's *h*-index as follows. They fix a publication year (*Y*) and consider the list of all documents published in a particular journal J. This list is then ranked according to the number of citations each of these documents has received (again as determined using database D). Then journal J's year *Y h*-index is defined as the highest rank (largest natural number) such that the first *h* documents received each at least *h* citations. Note that this *h*-index as well as a scientist's total career index changes over time. So, they both are instantaneous *h*-indices.

Again, a subset of the data in the complete p-c matrix suffices. In particular, the data needed to derive the *h*-index in the year 4 of the hypothetical journal of Table 1 are shown in Table 3, derived from Table 1.

Table 3. The p-c matrix for determining a journal's total history *h*-index, as derived from Table 1.

Articles	A	B	C	D	E	F	G	H	I	J	K	L
Citations received in the period: year 1 - year 4	19	5	3	10	16	6	1	2	4	1	2	3

In order to derive this journal's *h*-index the citation row must be ranked from largest to smallest as shown in Table 4. It is clear that this journal's total history *h*-index is equal to 5.

Table 4. Ranked table for calculating a journal's total history *h*-index

Rank	Number of citations
1	19
2	16
3	10
4	6
5	5
6	4
7	3
8	3
9	2
10	2
11	1
12	1

The general journal *h*-index

It is shown in (Frandsen & Rousseau, 2005) that the calculation of an impact factor can be performed in any framework including a number of publication years and a number of citation years. Although not mentioned explicitly one could even have considered 'all' publication years and 'all' citation years. Then this historical impact factor would be defined as the total number of citations ever received (in the database) by articles published in this journal divided by the total number of (citable) articles ever published.

It is sometimes stated that one of the advantages of the classical *h*-index is the fact that there is no arbitrary publication or citation window. More precisely, a scientist's *h*-index is calculated using a publication and citation window that begins with her/his first publication and ends the day the *h*-index is determined. Stated in this way a journal's *h*-index can be determined in exactly the same way. Clearly, such a definition favours journals that have been established a long time ago. For most uses such a journal *h*-index does not seem useful. Similarly a total career *h*-index of a 60-year old scientist is only of restricted use. The point we want to make is that whether one wants to determine an *h*-index, an impact factor or another indicator derived from a p-c matrix (such as the R-sequence, (Liang, 2005)), in each case one must decide on the most suitable publication and citation window.

Clearly, there is no compelling reason to consider a journal's total publication-citation history in order to define an *h*-index. Every combination of publication and citation years can be used to calculate an *h*-index. The conglomerate framework (Rousseau, 2005; Rousseau et al., 2008) clarifies this.

The *h*-index of a conglomerate (Rousseau et al., 2008)

A conglomerate (Rousseau, 2005), is a framework for informetric and other research. Its basic parts are two collections and two mappings. The first collection is a finite set, denoted as S, and called the source collection. Its elements are called sources. The second collection, denoted as P, is called the pool. Further a mapping f is given from S to 2^P, the set of all subsets of P. For each $s \in S$, $f(s)$ is a subset of P, called the item-set of s. The union of all p in P belonging to at least one item-set is called the item collection, denoted as $I \subset P$. The map f itself is called the source-item map.

Each set $f(s)$ is mapped to a number, called the magnitude of this set. This mapping is denoted as m and maps $f(s) \in 2^P$ to $m(f(s)) \in \mathbb{R}^+$ (referred to as the m-value of source s). The mapping itself is called the magnitude function. In simple cases m is the counting measure which maps $f(s)$ to the number of elements in $f(s)$. The conglomerate is then the quadruple $C = (S,P,f,m)$.

The source-item relation of a conglomerate leads to three lists. The first one just consists of all sources and the magnitude of their corresponding item sets, e.g. articles and corresponding numbers of citations. The second list is the same as the first one, but sources are ranked in decreasing order of the magnitudes of their corresponding item-sets. We will refer to this list as a Zipf list and the rank of a source in this list is called its Zipf rank. The first list can also, if desired and meaningful, be rewritten in size-frequency form (e.g., 7 articles with 1 citation, 4 articles with 2 citations, etc.), leading to a third list associated with the source-item relation of a conglomerate. We may refer to this third list as a Lotka list. Such a list begins with the number of sources that have the lowest magnitude. The average of the elements in the first list, i.e. the ratio of the sum of all magnitudes of item-sets, and the number of elements in the source collection is referred to as the conglomerate ratio. In concrete cases this conglomerate ratio is e.g. a journal's impact factor.

If sources are articles or groups of articles, items are articles citing the corresponding source, and m is the counting measure, then the data obtained in this way can be represented by a p-c matrix. Based on Hirsch's original idea the *h*-index of a conglomerate is defined as follows (Rousseau et al., 2008).

Definition: the h-index of a conglomerate

The *h*-index of conglomerate C is defined as the highest rank such that the magnitude corresponding to Zipf rank *h* is at least equal to *h*.

Hirsch' original *h*-index for scientist R (her instantaneous total career *h*-index) is obtained for $C = (S,P,f,m)$ where S is the current publication list, P is, e.g. the current complete Web of Science, f maps each publication to the set of all articles in P that cite it, and m is the counting measure.

Clearly, by changing the set S and the pool P many types of *h*-indices can be defined. As an example we define a journal's *h*-index in the standard impact factor framework. A journal's *h*-index, for the year Y, in the classical impact factor framework is the *h*-index of the conglomerate $C_c = (S_c,P_c,f_c,m_c)$, where S_c is the set of all articles published in this journal during the years *Y-2* and *Y-1*; P_c is the set of all articles published in the year *Y* (and included in database D); f_c maps each article to the set of articles in P_c that cite it. Finally m_c is the classical counting measure.

An example

In order to illustrate that any period and any window suitable to calculate an impact factor can also be used to calculate an *h*-index, we calculated the *h*-index within the framework of the classical impact factor.

Data collection

We next explain the procedure used to collect the necessary data in the WoS. A query consists of two elements for which we form the conjunction (AND): name of the journal (J) and PY=2005-2006. This yields all documents published in the period 2005-2006 in the journal J. Next we click the “Create citation report” button and obtain a complete p-c matrix, ranked according to the total number of citations received from the moment of publication till the day the query is performed. The *h*-core is clearly indicated and the total *h*-index also. We are, however, not interested in these. We want the *h*-index based only on citations during the year 2007. The *Citation Report* frame provides the opportunity to save and download records. In theory we have to download all of them, but in practice it is easy to see a cut-off point where articles will certainly not contribute to the *h*-core for the year 2007.We just make sure that we do not miss articles as it is possible that articles fall outside the total *h*-core and at the same time belong to the *h*-core of the year 2007.

These downloaded data are then imported in an Excel file and sorted (descending) according to the 2007 column. Adding a column showing the ranks of the ranked items make it easy to determine the 2007 *h*-index based on the standard impact factor framework.

Results

We determined this type of *h*-index, the corresponding h_{rat} and h_{real}, and the R-index (for the definition of these *h*-type indices we refer the reader to (Guns & Rousseau, 2009; Jin et al., 2007)) for three groups of journals: journals in environmental and resource economics, as studied in (Rousseau, 2008), all journals in the JCR-category of Computer Science – Cybernetics, and all journals in the JCR-category Information and Library Science. Results are shown in the appendix. In these tables we further provide the IF (year 2007) and the number of articles used in the calculation of the IF. Details can be found in Tables 6, 7 and 8, in the Appendix.

Table 5. Pearson correlation coefficients (ρ)

Pearson correlation coefficients between:	All	Environmental economics	Cybernetics	Information and library science
h and R	0.98	0.97	0.99	0.98
h and IF	0.72	0.83	0.69	0.81
h_{rat} and IF	0.74	0.85	0.71	0.81
h_{rat} and # articles	0.54	0.86	0.27	0.46
R and # articles	0.55	0.87	0.28	0.48
R and IF	0.75	0.82	0.71	0.82
IF and # articles	0.14	0.63	0.03	0.10

The relation between the *h*-index (concretely the rational variant) and the impact factor, considered over the classical publication-citation frames is rather linear (the Pearson correlation coefficient equals 0.74) but is certainly not perfectly linear (see Fig.1). Relations between the indicators studied here are clearly field-dependent (see Table 5) and are generally highest for journals in environmental economics and lowest for cybernetics journals. We further observe that for the three fields in our study this correlation is somewhat lower than for the field of forestry journals (Vanclay, 2008). Vanclay found a correlation of 0.88, but note that in (Vanclay, 2008) the IF is the one for 2006 while the *h*-index is based on the period 2000-2007.

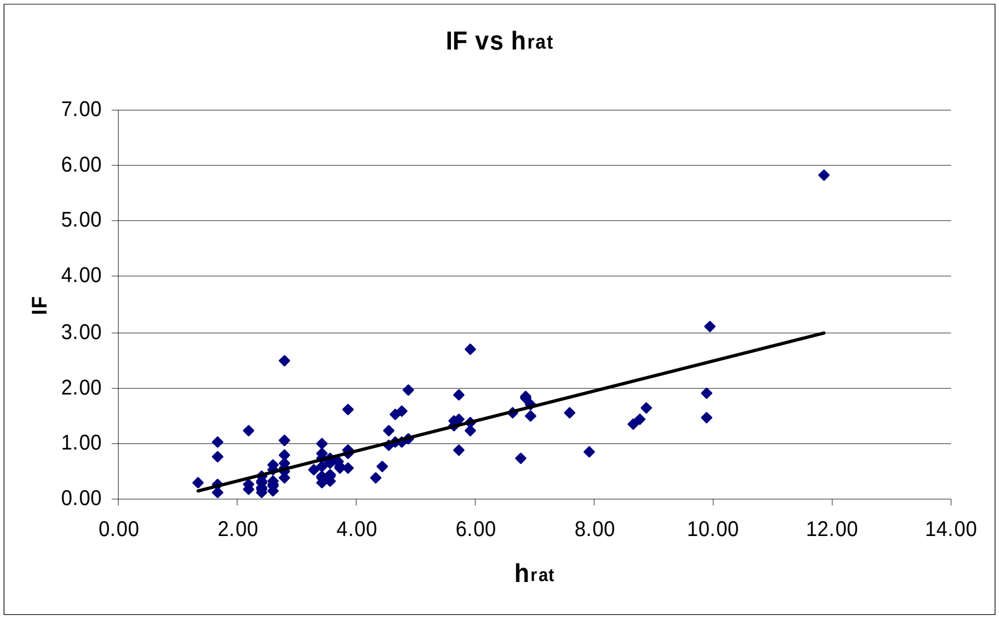

Figure 1. Scatter plot illustrating the relation between h_{rat} and IF

Table 5 further shows the following findings:
-) the *h*-index and the R-index are highly correlated ($\rho > 0.97$)
-) the correlations between *h*, resp. h_{rat} and the R index, and IF are very similar
-) correlations between the *h*-type indices and the number of articles used to calculate the impact factor are moderate ($\rho \approx 0.55$)

-) for these journals the correlation between IF and the number of articles used in its calculation is surprisingly low.
We also observe (see Tables 6, 7, 8) that for each journal $h_{rat} \geq h_{real}$ as predicted in (Guns & Rousseau, 2009). Moreover, equality occurs only once.

Research question: do citation models lead to an explicit relation between an *h*-index and an impact factor

Reflection on the research reported above and on its results leads us to the following research question. Let *f(r)* denote a positive, continuous and, not necessarily strictly, decreasing function defined on the interval [*a*, *a*+*T*]. This function represents a continuous model for the number of citations, within a given publication-citation framework, received by the r^{th} source, when sources are ranked according to the number of citations received. Then the relations

$$\begin{cases} f(h) = h \\ \dfrac{\int_a^{a+T} f(r)dr}{T} = IF \end{cases}$$

seem to define an implicit relation between the Hirsch index *h* and the impact factor IF for this particular publication-citation framework. Note that the symbol *T* denotes the total number of publications involved and that *a* is in practice usually 0 or 1. We further observe that the *h*-index used here is a real-valued one and that the impact factor (for journals) is nothing but an average number of citations. Concretely we wonder if the following procedure is meaningful. Assume, for instance, that *f(r)* is given by Zipf's (or Pareto's) law, i.e. the number of items produced by the r^{th} source is given by: $f(r) = \frac{B}{r^{\beta}}$, $B > 0$, $1 > \beta > 0$, with $r \in [0,T]$. This yields a description involving three independent parameters: B, β and the total number of publications, *T* (the case of a finite domain of definition for the corresponding size-frequency function, see (Egghe, 2005)). We also know that in this model $h = B^{1/(1+\beta)}$ (Egghe & Rousseau, 2006). The research problem is to find an explicit description of IF as a function of *h* and *T*, where, moreover, IF, *h* and *T* are independent parameters. We conjecture that this is, in general, not possible.

Conclusion

We provided a proof of concept that any period and any window suitable to calculate an impact factor can also be used to calculate an *h*-index. There is no reason to restrict oneself to periods that end at the day data are gathered (this is only due to practical considerations resulting from the structure of the WoS).

Clearly, a journal's two year synchronous *h*-index is as suitable as the journal's impact factor. They are, moreover correlated, but there are also large differences between fields. When revising this article we found out that a similar observation has been made in (Bornmann et al., 2009). For a group of 20 organic chemistry journals these authors obtained a Spearman rank-correlation coefficient between a two-year synchronous h-index and the journal IF (for 2007) of 0.8686.

We explained, using a so-called complete p-c matrix, the relation between the data needed in the calculation of an *h*-index and those needed in the calculation of an impact factor. We further note that a plethora of such indices can be defined (and are useful). Of course, for each of them a time-dependent study is possible, along the lines initiated in (Liang, 2006; Rousseau, 2006).

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Appendix

A. Environmental and resource economics

Table 6. Results for journals in environmental and resource economics, ranked according to h_{rat} (and in case of ties R, and then IF).

Journals	h	h_{rat}	h_{real}	R	IF	# articles
ENERGY POLICY	9	9.89	9	10.54	1.901	534
ECOLOGICAL ECONOMICS	7	7.60	7	9.85	1.549	388
ENERGY ECONOMICS	6	6.62	6	7.35	1.557	88
ENVIRONMENTAL & RESOURCE ECONOMICS	5	5.91	5.5	6.32	1.237	131
JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT	5	5.73	5	5.83	1.438	105
AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS	4	4.78	4	4.58	1.034	174
ENERGY JOURNAL	4	4.78	4	4.36	1.575	106
ENVIRONMENT AND DEVELOPMENT ECONOMICS	3	3.43	3	3.00	0.595	74
JOURNAL OF AGRICULTURAL AND RESOURCE ECONOMICS	3	3.43	3	3.00	0.380	71
LAND ECONOMICS	2	2.80	2.5	3.32	1.042	72
RESOURCE AND ENERGY ECONOMICS	2	2.80	2.5	2.83	1.050	40
AUSTRALIAN JOURNAL OF AGRICULTURAL AND RESOURCE ECONOMICS	2	2.80	2.5	2.45	0.635	52
NATURAL RESOURCES JOURNAL	1	1.67	1.5	2.00	0.111	54

B. Cybernetics

Table 7. Results for journals in cybernetics (JCR category), ranked according to h_{rat} (and in case of ties R, and then IF).

Journals	h	h_{rat}	h_{real}	R	IF	# articles
IEEE TRANSACTIONS ON SYSTEMS MAN AND CYBERNETICS PART B-CYBERNETICS	8	8.65	8	9.11	1.353	249
IEEE TRANSACTIONS ON SYSTEMS MAN AND CYBERNETICS PART C-	7	7.93	7.5	7.94	0.864	118

APPLICATIONS AND REVIEWS						
BIOLOGICAL CYBERNETICS	6	6.92	6.5	7.35	1.694	157
PRESENCE-TELEOPERATORS AND VIRTUAL ENVIRONMENTS	6	6.77	6	7.35	0.723	101
INTERNATIONAL JOURNAL OF HUMAN-COMPUTER STUDIES	5	5.91	5.5	6.24	1.364	140
IEEE TRANSACTIONS ON SYSTEMS MAN AND CYBERNETICS PART A-SYSTEMS AND HUMANS	5	5.73	5	5.83	0.868	182
BEHAVIOUR & INFORMATION TECHNOLOGY	4	4.67	4	4.80	1.028	72
INTERACTING WITH COMPUTERS	4	4.56	4	4.24	0.969	96
INTERNATIONAL JOURNAL OF HUMAN-COMPUTER INTERACTION	4	4.33	4	4.24	0.381	63
KYBERNETIKA	3	3.86	3.5	4.00	0.552	96
MACHINE VISION AND APPLICATIONS	3	3.71	3	3.32	0.682	66
CYBERNETICS AND SYSTEMS	3	3.57	3	3.32	0.655	87
USER MODELING AND USER-ADAPTED INTERACTION	3	3.43	3	3.16	1.000	27
HUMAN-COMPUTER INTERACTION	2	2.80	2.75	3.32	2.476	21
CONTROL AND CYBERNETICS	2	2.80	2.5	3.16	0.495	103
JOURNAL OF COMPUTER AND SYSTEMS SCIENCES INTERNATIONAL	2	2.60	2	2.24	0.145	200
KYBERNETES	2	2.40	2	2.24	0.175	229

C. Information and Library Science

Table 8: Results for journals in Information and Library Science (JCR category), ranked according to h_{rat} (and in case of ties R, and then IF).

Journals	h	h_{rat}	h_{real}	R	IF	# articles
MIS QUART	11	11.87	11.00	14.07	5.826	69
J AM MED INFORM ASSN	9	9.95	9.50	10.95	3.094	159
SCIENTOMETRICS	9	9.90	9.00	11.45	1.472	248
INFORM MANAGE-AMSTER	8	8.88	8.00	9.17	1.631	141
J AM SOC INF SCI TEC	8	8.77	8.00	9.33	1.436	287
INFORM PROCESS MANAG	6	6.92	6.50	7.68	1.500	188
J HEALTH COMMUN	6	6.85	6.00	7.21	1.836	122
INT J GEOGR INF SCI	6	6.85	6.00	6.71	1.822	107
INFORM SYST RES	5	5.91	5.67	7.07	2.682	44
J MANAGE INFORM SYST	5	5.73	5.00	5.48	1.867	83
J MED LIBR ASSOC	5	5.64	5.00	6.78	1.392	120
J DOC	5	5.64	5.00	5.83	1.309	68
J INF SCI	4	4.89	4.50	6.33	1.080	87
ANNU REV INFORM SCI	4	4.89	4.50	4.90	1.963	27
INFORM SYST J	4	4.67	4.00	4.69	1.531	32

J GLOB INF MANAG	4	4.56	4.00	4.36	1.241	29
HEALTH INFO LIBR J	4	4.44	4.00	4.47	0.592	98
GOV INFORM Q	3	3.86	3.67	4.80	0.81	58
J INF TECHNOL	3	3.86	3.50	3.61	1.605	43
PORTAL-LIBR ACAD	3	3.86	3.50	3.46	0.885	52
LIBR INFORM SCI RES	3	3.86	3.50	3.46	0.870	54
TELECOMMUN POLICY	3	3.71	3.00	3.46	0.593	81
J ACAD LIBR	3	3.71	3.00	3.46	0.551	136
SCIENTIST	3	3.57	3.00	4.69	0.322	338
ONLINE INFORM REV	3	3.57	3.00	3.61	0.671	79
ASLIB PROC	3	3.57	3.00	3.46	0.413	75
LEARN PUBL	3	3.57	3.00	3.16	0.738	61
INT J INFORM MANAGE	3	3.57	3.00	3.16	0.451	71
INFORM SOC	3	3.43	3.00	3.74	0.719	64
COLL RES LIBR	3	3.43	3.00	3.16	0.820	61
RES EVALUAT	3	3.43	3.00	3.16	0.413	46
LIBR J	3	3.43	3.00	3.16	0.295	234
INTERLEND DOC SUPPLY	3	3.29	3.00	3.00	0.533	60
LIBR QUART	2	2.80	2.75	3.32	0.556	45
LAW LIBR J	2	2.80	2.50	2.83	0.789	57
ONLINE	2	2.80	2.50	2.65	0.368	68
SOC SCI INFORM	2	2.60	2.00	2.45	0.523	44
LIBR COLLECT ACQUIS	2	2.60	2.00	2.45	0.250	48
ELECTRON LIBR	2	2.60	2.00	2.45	0.228	114
LIBR RESOUR TECH SER	2	2.60	2.00	2.24	0.628	43
LIBR TRENDS	2	2.60	2.00	2.24	0.333	78
LIBRI	2	2.40	2.00	2.45	0.286	42
J LIBR INF SCI	2	2.40	2.00	2.24	0.405	37
INFORM TECHNOL LIBR	2	2.40	2.00	2.24	0.326	43
ECONTENT	2	2.40	2.00	2.24	0.196	92
SOC SCI COMPUT REV	2	2.40	2.00	2.00	0.405	74
PROGRAM-ELECTRON LIB	2	2.40	2.00	2.00	0.111	54
J COMPUT-MEDIAT COMM	2	2.20	2.00	2.00	1.232	112
J SCHOLARLY PUBL	2	2.20	2.00	2.00	0.270	37
REF USER SERV Q	2	2.20	2.00	2.00	0.175	57
SERIALS REV	1	1.67	1.67	1.73	0.761	46
INFORM RES	1	1.67	1.50	1.41	1.027	75
RESTAURATOR	1	1.67	1.50	1.41	0.275	40
KNOWL ORGAN	1	1.33	1.00	1.00	0.280	25

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