Empirical Examination of Lotka's Law for Information Science and Library Science

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The paper presents a bibliometric study on the fit of Lotka's law on *Information Science & Library Science* journals indexed in *Social Science Citation Index* of *Journal Citation Report* from the period 1956 to 2014. The parameters of the Lotka's law model, *C* and *α*, were found using the linear least squares method and the Kolmogorov-Smirnov test was applied to estimate the kindness of adjustment of the results to the Lotka's distribution. It was found that the pattern of publication of the LIS category articles fits to Lotka's law.

Keywords: Lotka's law; Bibliometrics; Information Science & Library Science; Journals.

INTRODUCTION

Several researches on sciences point out that there are valid indicators to measure the degree of scientific production of a particular discipline, institution, department, author, research group and country (Garfield, Malin, & Small, 1978; Moed, 2005; Vinkler, 2010). As van Raan (2004) states, one of the objectives in bibliometric analysis is to reach to a common set of standardized indicators which allow evaluating scientific production. Indicators obtained from the bibliometric researches are useful for planning, development and organization of resources and services within the institutions responsible for administering them (Gupta, 1989; Schmoch & Schubert, 2009).

Lotka's law (Lotka, 1926) occupies a prominent place among the most frequently bibliometric laws used to determine certain accomplishments in various scientific disciplines. Lotka's law is a discrete probability distribution function which describes author productivity within a field and is presented as follows:

$$f(x) = \frac{C}{x^{\alpha}}$$

Where $f(x)$ represents the number of authors who have *x* publications, *x* is a positive integer, denoting the number of publications. α and C are parameters to be determined from the data, being C the number of authors having only one publication. The law can be explained as follows: the number of authors making *x* contributions is a fraction of the number of authors making one publication. This fraction is inversely proportional to the number of publications *x* ($1/x^{\alpha}$).

The mathematical justifications of this law, as well as different methodological ways to obtain the parameters, have already been studied and largely explained by several researchers (Egghe, 2004, 2005; Egghe & Rousseau, 2011; Nicholls, 1986, 1989; Pao, 1985; Pulgarín, 2012). Originally Lotka (1926) presented the procedure for calculating *C* only in the case of *α*=2 which resulted suitable for physical sciences. This law was called Lotka's inverse-square law. The value obtained in this article for constant *C* was approximately 6/π2. Later, Pao (1985) proposed the generalization that we apply to find both values (C and α), known as distribution of generalized inverse power or Lotka's inverse-power law, which is currently widely used in bibliometric research on different fields (Jiménez-Contreras & Moya-Anegón, 1997; Pao, 1986; Torbati & Chakoli, 2013).

LITERATURE REVIEW

The bibliometric studies have been carried out on the scientific publishing of a country in several disciplines by applying Lotka's law. For instance, Gupta (1987, 1989) applied it to the *Biochemical and entomological* literature of Nigeria and found that Lotka's law is fit for both the distribution of the main authors and the distributions of all authors, among others. Patra and Chand (2006) verified that this law was right for the *Library and Information Science* research in India from 1967 to 2004, taking the information from the database *Library and Information Science Abstracts* (LISA).

Other authors have done research in a generic way about Lotka's law in scientific production related in some way to the field of *Information Science & Library Science*. For example, Sen, Taib and Hassan (1996) studied the database LISA from the period 1992 to 1993. They started using α=2 and then considering the observed values; they found new α parameters; that is, α=3,23 for 1992 and α=3,1 for 1993. They concluded that the observed real values were very close to those calculated from the new values obtained for α.

Singh, Mittal, and Ahmad (2007) analysed the articles on digital libraries from LISA for the period of 1998-2004. They found that the observed values did not conform to Lotka's law. It might had happened because the authors did not find the value α from the observed data; they took the particular case of α=2 as Pao (1985) and many other researchers also did. On the other hand, Martin, Pestana, and Pulgarín (2008) analysed the articles of LISA published between 1996 to 2008 and concluded that the data showed an excellent fit to the Lotka's law.

Nath and Jackson (1991) examined 899 articles of *Management Information Systems* (MIS) from 1975 to 1987 published in ten journals from the field. They observed that the law did not work when only the first signatory authors are considered, but when each signatory author is assigned the same value (i.e., when in multi-authored articles every one of the authors received full credit), the law is fulfilled. They also found that the law did not accomplish if it is applied separately to each one of the journals. Therefore, the way in which we treat multi-authorship articles impacts on the fitness to Lotka's law. Patra, Bhattacharya, and Verma (2006) found that in the literature on *Bibliometrics* in LISA from 1968 to 2004 Lotka's law applied.

Jiménez-Contreras and Moya-Anegón (1997) analysed the authorship of 1671 articles published in 11 Spanish journals of *Librarianship and Documentation* from 1975 to 1995. They found a high number of occasional authors (72%) and pointed out certain limitations in producing a "natural" Lotka.

Another study for the period of 1985-2013 based on Web of Science, Scopus, LISA and Library, Information Science & Technology Abstracts (LISTA) (Pinto, Escalona, Pulgarín, & Uribe-Tirado, 2015) stated that Lotka's law accomplished and that the value found for the α parameter was high, which happens when the concentration of authors is low. This is interpreted as that field is in a phase of dynamic development and not consolidated. Table 1 shows the information about five fields analysed in the researches previously presented.

Some studies have proved that when the articles have a high number of authors, the authors inflation leads to a breakdown of Lotka's law (Kretschmer & Rousseau, 2001), this phenomenon affects especially those fields where signing of more than 100 authors is frequent, for example in the field High Energy Physics.

To summarize the literature review, it can be said that there are many studies (Table 1) that found Lotka's law applicable to consolidated sciences, and to

LIS particularly. All of those had a common factor that they were applied to the whole discipline, considering all the journals indexed on a specific database (e.g. LISA) and not focusing in a reduced number of them. Most of the researchers concluded that Lotka's law does not apply to presented methodological lacks or errors, such as fixing *α* to 2, instead of computing its value.

Table 1

Comparison of the parameters obtained in several studies

Article	Data Sources	Years	Field	Record	Author	α	C
Nath and Jackson (1991)	Journals	1975-1987	Management Information Systems	899	594	2,66	0,7775
Sen et al. (1996)	LISA	1992-1993	Library and Information Science	14692	15948	3,23 and 3,1	7229,0
Jiménez-Contreras and Moya-Anegón (1997)	Journals	1975-1995	Library and Information science	1671	1262	2,2952	0,6965
Patra and Chand (2006)	LISA	1967-2004	Library and Information Science	3396	2732	2,12	0,64
Patra et al. (2006)	LISA	1968-2004	Biblio-metris	3781	4000	2,09	0,64
Singh et al. (2007)	LISA	1998-2004	Digital libraries	1066	1127	2	1,1270
Martin et al. (2008)	LISA	1996-2008	Information Science	2825	2695	2,756	0,7947
Pinto et al. (2015)	WoS Scopus LISA LISTA	1985-2013	Information Literacy	340	568	3,27	0,8648

To properly test the applicability of Lotka's law to measure author productivity in *Library and Information Science* field, further studies must be carried out, paying special attention to both methodological aspects (estimating *C* and *α*, full credit in multi-authorship articles, etc.) as well as to the sample (number of journals indexed, period analysed, database). To this purpose, extending the type of scientific database to be used is crucial. That is why this study focuses on the *Social*

Science Citation Index of WOS, an international database used for evaluation scientific activity, among others, that has been world-wide used for this purpose; and selecting sources on the Journal Citation Report (JCR).

RESEARCH OBJECTIVES

Table 1 shows that the main source of information for researchers on Lotka's law related to *Information Science & Library Science* is the LISA database and that the largest range of years analysed is from 1967 to 2004. However, there are no studies about the entire field using as a source the databases from the *Web of Science* (WOS) of Thomson-Reuters, even though the *Journal Citation Reports* (JCR) includes a specific section for this field. Therefore, we considered necessary to make this study. Due to the fact that WOS has one of the most demanding indexing processes, therefore, less journals are indexed there than LISA database. It aims to address whether Lokta's law would also be applicable to the category *Information Science & Library Science* (JCR of WOS) in the same way it applied to LISA database. The articles published from 1956 to 2014 in the journals indexed in JCR under the category of *Information Science & Library Science* were analysed.

METHODOLOGY

Initially, the title of every LIS journal indexed in JCR 2014 was consulted. This category had 85 journals. Then, in September 2015, they were consulted in the database of the *Social Science Citation Index* (SSCI) all the documents published in these journals and indexed on WOS from 1956 to 2014. Reviews, notes, letters, editorials, news and meeting abstracts were excluded while articles were the only items considered for this study. The information was obtained from 65162 articles and was downloaded to make a database. Articles with anonymous authorship were discarded, so finally there were 64637 papers for analysis. For the authors account it was used the normal count, which gives full credit to all contributors as indicated by Rousseau (1992). In order to apply Lotka's law in the equation (1), parameters C and α from the observed data have to be found. To obtain α, it is used the linear minimum square method (Pao, 1986) which is expressed by the equation:

$$\alpha = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - (\sum X)^2}$$

Where, N= number of pairs of data considered, X= decimal logarithm of *x*,
Y= decimal logarithm of *y.* The estimation of the parameter *C* is done through the inverse of the Riemann zeta function as follows:

$$C = \frac{1}{\sum_{x=1}^{p-1}\frac{1}{x^2} + \frac{1}{(n-1)p^{\alpha-1}} + \frac{1}{2P^{\alpha}} + \frac{n}{24(P-1)^{\alpha+1}}}$$

Where *P* is the number of observed data pairs. Pao (1985) checked that the residual mistake is no significant if P is equal to 20.

In order to verify the goodness of fit for the obtained results to Lotka's distribution, the Kolmogorov-Smirnov (K-S) test was applied as Coile (1977) suggested. K-S test is a non-parametric test used to verify the adjustment or fitness of one dataset distribution (empirical) to the theoretical one. K-S test is based on the work of Kolmogorov (1933) and Smirnov (1948) and it was developed by Massey (1951). It measures the maximum distance (D_{max}) between both dataset distributions, empirical and theoretical ones, leading to a bad fitness if this distance is too high.

Several researches have applied this goodness-of-fit test, particularly in determining normality of variables. Razali and Wah (2011) have compared this test (K-S test) with others for the same purpose concluding that for studies with a sample size greater than 100 or 150, K-S test is the most suitable one.

FINDINGS & DISCUSSION

For the period from 1956 to 2014, in total 66758 different authors were found from 65162 analysed papers. Table 3 in Appendix A shows these authors' distribution according to their production. With the data of Table 3, α was calculated:

$$\alpha = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - (\sum X)^2} = \frac{76 \times 76,9559 - 114,406 \times 74,0632}{76 \times 186,7558 - (114,406)^2} = -2,3758$$

To estimate *C*, the inversion of the Riemann zeta function has been made in which it is substituted with the α absolute value.

$$C = \frac{1}{\sum_{x=1}^{P-1}\frac{1}{x^{\alpha}} + \frac{1}{(\alpha-1)P^{\alpha-1}} + \frac{1}{2P^{\alpha}} + \frac{\alpha}{24(P-1)^{\alpha+1}}} =$$

$$c = \frac{1}{\sum_{x=1}^{19}\frac{1}{x^{2,3759}} + \frac{1}{(1,3759)20^{1,3759}} + \frac{1}{2(19)^{2,3759}} + \frac{2,3759}{24(19)^{3,3759+1}}} = 0,7171$$

C is the percentage of authors with only one work published at the authors' distribution. Replacing the previously obtained values for the parameters *α* and *C* in equation of Lotka's law, the following Lotka's law model is obtained:

$$f(x) = \frac{C}{x^{\alpha}} = Cx^{-\alpha} = 0,7117\,x^{-2,3758}$$

A signification level of 0, 01 in the K-S goodness-of-fit test was applied. The obtained critical value is

$$\frac{1,63}{\sqrt{66758}} \approx 0,0063$$

Table 2 shows the difference between the observed (empirical) and the expected (theoretical) values.

Table 2

Kolmogorov-Smirnov adjustment test of the authors' distribution of production

X	y	y_x/Sy_x	$S(y_x/Sy_x)$	$C.\,x^{-\alpha}$	$\Sigma(C.\,x^{-\alpha})$	D_{max}
1	47481	0,711241	0,711241	0,717100	0,717100	0,005859
2	9617	0,144058	0,855298	0,138154	0,855254	-0,000045
3	3619	0,054211	0,909509	0,052721	0,907975	-0,001534
4	1866	0,027952	0,937461	0,026616	0,934591	-0,002869
5	1106	0,016567	0,954028	0,015664	0,950255	-0,003773
6	714	0,010695	0,964723	0,010157	0,960412	-0,004311
7	494	0,007400	0,972123	0,007042	0,967454	-0,004669
8	348	0,005213	0,977336	0,005128	0,972582	-0,004754
9	275	0,004119	0,981455	0,003876	0,976458	-0,004997
10	209	0,003131	0,984586	0,003018	0,979476	-0,005110
11	159	0,002382	0,986968	0,002406	0,981882	-0,005086
12	124	0,001857	0,988825	0,001957	0,983839	-0,004986
13	107	0,001603	0,990428	0,001618	0,985457	-0,004971
14	94	0,001408	0,991836	0,001357	0,986814	-0,005022
15	73	0,001094	0,992930	0,001152	0,987965	-0,004964
16	54	0,000809	0,993739	0,000988	0,988953	-0,004785
17	44	0,000659	0,994398	0,000855	0,989809	-0,004589
18	39	0,000584	0,994982	0,000747	0,990555	-0,004426
19	39	0,000584	0,995566	0,000657	0,991212	-0,004354
20	27	0,000404	0,995971	0,000581	0,991794	-0,004177
21	21	0,000315	0,996285	0,000518	0,992311	-0,003974
22	23	0,000345	0,996630	0,000464	0,992775	-0,003855

X	y	y_x/Sy_x	$S(y_x/Sy_x)$	$C. x^{-\alpha}$	$\Sigma(C. x^{-\alpha})$	D_{max}
23	17	0,000255	0,996884	0,000417	0,993192	-0,003692
24	14	0,000210	0,997094	0,000377	0,993569	-0,003525
25	11	0,000165	0,997259	0,000342	0,993911	-0,003348
26	14	0,000210	0,997468	0,000312	0,994223	-0,003246
27	7	0,000105	0,997573	0,000285	0,994508	-0,003066
28	9	0,000135	0,997708	0,000261	0,994769	-0,002939
29	8	0,000120	0,997828	0,000240	0,995010	-0,002818
30	18	0,000270	0,998098	0,000222	0,995231	-0,002866
31	7	0,000105	0,998202	0,000205	0,995437	-0,002766
32	11	0,000165	0,998367	0,000190	0,995627	-0,002740
33	10	0,000150	0,998517	0,000177	0,995804	-0,002713
34	6	0,000090	0,998607	0,000165	0,995969	-0,002638
35	6	0,000090	0,998697	0,000154	0,996123	-0,002574
36	9	0,000135	0,998832	0,000144	0,996266	-0,002565
37	1	0,000015	0,998847	0,000135	0,996401	-0,002445
38	4	0,000060	0,998906	0,000127	0,996528	-0,002379
39	6	0,000090	0,998996	0,000119	0,996647	-0,002350
40	6	0,000090	0,999086	0,000112	0,996759	-0,002328
41	4	0,000060	0,999146	0,000106	0,996864	-0,002282
42	4	0,000060	0,999206	0,000100	0,996964	-0,002242
43	4	0,000060	0,999266	0,000094	0,997058	-0,002208
44	1	0,000015	0,999281	0,000089	0,997148	-0,002133
45	4	0,000060	0,999341	0,000085	0,997232	-0,002108
46	4	0,000060	0,999401	0,000080	0,997313	-0,002088
47	2	0,000030	0,999431	0,000076	0,997389	-0,002042
49	2	0,000030	0,999461	0,000069	0,997458	-0,002002
50	1	0,000015	0,999476	0,000066	0,997524	-0,001952
52	2	0,000030	0,999506	0,000060	0,997584	-0,001921
53	3	0,000045	0,999551	0,000057	0,997642	-0,001909
54	1	0,000015	0,999566	0,000055	0,997697	-0,001869
56	1	0,000015	0,999581	0,000050	0,997747	-0,001834
59	2	0,000030	0,999611	0,000044	0,997791	-0,001819
60	1	0,000015	0,999626	0,000043	0,997834	-0,001791
61	1	0,000015	0,999640	0,000041	0,997875	-0,001765
65	1	0,000015	0,999655	0,000035	0,997911	-0,001745
67	1	0,000015	0,999670	0,000033	0,997943	-0,001727

X	y	y_x/Sy_x	$S(y_x/Sy_x)$	$C.\ x^{-\alpha}$	$\Sigma(C.\ x^{-\alpha})$	D_{max}
68	1	0,000015	0,999685	0,000032	0,997975	-0,001710
69	1	0,000015	0,999700	0,000031	0,998006	-0,001695
73	3	0,000045	0,999745	0,000027	0,998033	-0,001713
78	1	0,000015	0,999760	0,000023	0,998056	-0,001705
79	1	0,000015	0,999775	0,000022	0,998078	-0,001697
82	1	0,000015	0,999790	0,000020	0,998098	-0,001692
84	1	0,000015	0,999805	0,000019	0,998117	-0,001688
86	2	0,000030	0,999835	0,000018	0,998136	-0,001700
92	1	0,000015	0,999850	0,000015	0,998151	-0,001699
99	1	0,000015	0,999865	0,000013	0,998164	-0,001701
100	1	0,000015	0,999880	0,000013	0,998177	-0,001703
103	1	0,000015	0,999895	0,000012	0,998189	-0,001707
115	1	0,000015	0,999910	0,000009	0,998198	-0,001712
119	1	0,000015	0,999925	0,000008	0,998206	-0,001719
126	1	0,000015	0,999940	0,000007	0,998213	-0,001727
127	2	0,000030	0,999970	0,000007	0,998221	-0,001749
128	1	0,000015	0,999985	0,000007	0,998228	-0,001757
156	1	0,000015	1,000000	0,000004	0,998232	-0,001768

Table 2 shows that the maximum deviation is 0.005859, hence, it is lower than the critical value 0.0063 of the K-S test for a significance of 0.01. We can deduce that the hypothesis of homogeneity is fulfilled and that the distribution of authors' productivity in LIS category fits the Lotka's law with a 0.01 level of significance.

CONCLUSION

The paper has made an analysis of the authorship of a collection of 64637 papers belonging to the journals indexed in the category *Information Science & Library Science* from JCR, published from 1956 to 2014. It has been found that 71.12% of the 66758 authors have published only one article in the field, i.e., they are transient authors. On the other hand, just nine authors have published over one hundred papers.

We have presented a wide study about the fitness of Lotka's law for the category *Information Science & Library Science* at the SCCI, on both the number of articles analysed and the period of years covered. It has been verified empirically that generalized Lotka's law for authors' productivity is fulfilled in this field, confirming the results of previous studies on this field which carried out mainly on LISA database. We obtained values of 0.7117 and 2.3758 for C and α respectively, which are close to those found by Jiménez-Contreras and Moya-Anegón (1997) and are shown in Table 1. In the before mentioned study, the field *Library and Information Science* was also analysed through selected journals indexed on LISA database. Our procedure was very similar to the previous studies because we only covered selected LISA journals indexed on WOS, particularly those presented on the JCR.

Comparing our results to other studies carried out in the field (Table 1), we can claim that we obtained the similar results (Patra and Chand, 2006), but slightly far away. We consider that taking into account the whole LISA database, instead of selected journals may impact the results. Therefore, further studies on the field must be conducted, and also on others social sciences to compare them to detect regularities and differences among them. It would be also interesting to analyse how the period covered impacts on the results for the same sample.

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APPENDIX A

Table 3

Observed data and data needed to calculate the parameters on Information Science & Library Science

x	y	log x	log y	log x. log y	(log x)^2
1	47481	0,0000	4,6765	0,0000	0,0000
2	9617	0,3010	3,9830	1,1990	0,0906
3	3619	0,4771	3,5586	1,6979	0,2276
4	1866	0,6021	3,2709	1,9693	0,3625
5	1106	0,6990	3,0438	2,1275	0,4886
6	714	0,7782	2,8537	2,2206	0,6055
7	494	0,8451	2,6937	2,2765	0,7142
8	348	0,9031	2,5416	2,2953	0,8156
9	275	0,9542	2,4393	2,3277	0,9106
10	209	1,0000	2,3201	2,3201	1,0000
11	159	1,0414	2,2014	2,2925	1,0845
12	124	1,0792	2,0934	2,2592	1,1646
13	107	1,1139	2,0294	2,2606	1,2409
14	94	1,1461	1,9731	2,2615	1,3136
15	73	1,1761	1,8633	2,1914	1,3832
16	54	1,2041	1,7324	2,0860	1,4499
17	44	1,2304	1,6435	2,0222	1,5140
18	39	1,2553	1,5911	1,9972	1,5757
19	39	1,2788	1,5911	2,0346	1,6352
20	27	1,3010	1,4314	1,8622	1,6927
21	21	1,3222	1,3222	1,7483	1,7483
22	23	1,3424	1,3617	1,8280	1,8021
23	17	1,3617	1,2304	1,6755	1,8543
24	14	1,3802	1,1461	1,5819	1,9050
25	11	1,3979	1,0414	1,4558	1,9542
26	14	1,4150	1,1461	1,6217	2,0021
27	7	1,4314	0,8451	1,2096	2,0488
28	9	1,4472	0,9542	1,3809	2,0943
29	8	1,4624	0,9031	1,3207	2,1386
30	18	1,4771	1,2553	1,8542	2,1819
31	7	1,4914	0,8451	1,2603	2,2242
32	11	1,5051	1,0414	1,5675	2,2655

x	y	log x	log y	log x. log y	(log x)^2
33	10	1,5185	1,0000	1,5185	2,3059
34	6	1,5315	0,7782	1,1917	2,3454
35	6	1,5441	0,7782	1,2015	2,3841
36	9	1,5563	0,9542	1,4851	2,4221
37	1	1,5682	0,0000	0,0000	2,4593
38	4	1,5798	0,6021	0,9511	2,4957
39	6	1,5911	0,7782	1,2381	2,5315
40	6	1,6021	0,7782	1,2466	2,5666
41	4	1,6128	0,6021	0,9710	2,6011
42	4	1,6232	0,6021	0,9773	2,6349
43	4	1,6335	0,6021	0,9834	2,6682
44	1	1,6435	0,0000	0,0000	2,7009
45	4	1,6532	0,6021	0,9953	2,7331
46	4	1,6628	0,6021	1,0011	2,7648
47	2	1,6721	0,3010	0,5034	2,7959
49	2	1,6902	0,3010	0,5088	2,8568
50	1	1,6990	0,0000	0,0000	2,8865
52	2	1,7160	0,3010	0,5166	2,9447
53	3	1,7243	0,4771	0,8227	2,9731
54	1	1,7324	0,0000	0,0000	3,0012
56	1	1,7482	0,0000	0,0000	3,0562
59	2	1,7709	0,3010	0,5331	3,1359
60	1	1,7782	0,0000	0,0000	3,1618
61	1	1,7853	0,0000	0,0000	3,1874
65	1	1,8129	0,0000	0,0000	3,2867
67	1	1,8261	0,0000	0,0000	3,3345
68	1	1,8325	0,0000	0,0000	3,3581
69	1	1,8388	0,0000	0,0000	3,3814
73	3	1,8633	0,4771	0,8890	3,4720
78	1	1,8921	0,0000	0,0000	3,5800
79	1	1,8976	0,0000	0,0000	3,6010
82	1	1,9138	0,0000	0,0000	3,6627
84	1	1,9243	0,0000	0,0000	3,7029
86	2	1,9345	0,3010	0,5823	3,7423
92	1	1,9638	0,0000	0,0000	3,8565
99	1	1,9956	0,0000	0,0000	3,9826
100	1	2,0000	0,0000	0,0000	4,0000

x	y	log x	log y	log x. log y	(log x)^2
103	1	2,0128	0,0000	0,0000	4,0515
115	1	2,0607	0,0000	0,0000	4,2465
119	1	2,0755	0,0000	0,0000	4,3079
126	1	2,1004	0,0000	0,0000	4,4116
127	2	2,1038	0,3010	0,6333	4,4260
128	1	2,1072	0,0000	0,0000	4,4403
156	1	2,1931	0,0000	0,0000	4,8098
Total	66758	114,4060	74,0632	76,9559	186,7558