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LOTKA LAW APPLIED TO THE SCIENTIFIC PRODUCTION OF INFORMATION SCIENCE AREA

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ABSTRACT

We introduce an application of Lotka Law at whole of authors with publication in field of “Information Science”, between 1996 and 2007. The application executed applied the methodology of Lee Pao (1985). It was selected every authors who appears in authors camps, doesn’t make any cut in the distribution and the estimate of critical values was been calculate using the proposal formula by Nicholls (1989). The results show us the data: one pending equal a ‘-2,75’, the obtained it is lower in the work of Voos (1974), as in the Sen, Taib e Hassan (1996), in this camp; a percentage of authors, executors of one work only, it is equal a 79% and a excellent adjust of the Lotka Law, to be application at the Kolmogorov-Smirnov.

Keywords: Lotka Law; Scientific Production; Information Science; Bibliometrics.

INTRODUCTION

In 1926, Alfred J. Lotka, examined the distribution of frequencies of chemical and physics scientific productivity (publications listed in *Chemical Abstracts,* since 1907 to 1916, and in Auerbach´s *Geschichtstafeln der Physik,* since the beginning of its publication until 1900), it is observed a quantitative relation among the authors and their scientific production. The Lotka´s observation shows an asymmetric distribution (as happened previously to the one of Bradford or Zipf), with a concentration of articles among a few authors (authors great producers), while the remaining articles would be distributed among a great amount of authors. The correlation between authors and their productivity, in the case studied by Lotka, showed a negative outstanding, about ‘-2’.

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Since then, many are the work accomplished, with the aim to apply or reformulate the Lotka Law, obtaining contradictory results and not always with good results (OPPENHEIMER, 1986).

There is a wide literature which deals about the Lotka Law´s application. Among them we can highlight the following work:

Murphy (1973) applied the Lotka Law, at the humanities field, concluding that the law came true, not applying any statistics test to check the significance degree.

In 1974, Voos studied the authors´ productivity at the information science field, between 1966 and 1970, and compared the results with the Lotka´s observation (n=2), and discovered that the distribution of authors adjusted itself so well to a new constant equals to x -3,5. The percentage of authors with only one work, obtained by Voos, was 88%, instead of the 60% obtained by Lotka. Although Voos makes the study of the five years separately, year by year, we checked that if we consider the group of the five years is also adjusted. Schorr published three articles in which he presented other Lotka´s Law applications: the librarianship, the libraries organization and the history of legal medicine. In his first article (SCHORR, 1974) he found a law which was quadruple (x -4), instead of the inverse quadratic of Lotka (x-2). In other experiences about libraries organization (SCHORR, 1975), after applying the test x2 he concluded that this discipline adjusted itself to the Lotka´s law. In this third article (SCHOOR, 1975b), he studied the productivity in the history of legal medicine and applying the test x2, he discovers that the authors with multiple works were very below from the expected according to the Lotka´s law (<60%), concluding that this law was not the most appropriate to this subject.

Coile, in an article published in 1977, denies the conclusion of the second article of Schorr about libraries organization, stating that it was not correct as it was applied to some data, a not appropriate statistics test (referring to the test x2). Coile,after presenting the Lotka´s law, extracted from the original work, examined and checked the data from the article of Murphy, in humanities, and the ones of Schorr, in libraries organization, using the test of Kolmogorov-Smirnov (K-S), concluding that in no one of the cases it was accomplished the Lotka´s law.

Two years later, Radhakrishnan and Kerdizan (1979) checked that the law of Lotka did not apply appropriately to the data about publications in informatics, observing that it was nearest to a law x-3. These authors assumed that when a work had many authors, to each one of them belonged the complete work (normal count). This association had an unanswerable effect to estimate the number of authors who wrote only one work, and were from the opinion that it was only registered the article to the main author or to the first author, as Lotka did "straight count), adjusting to an inverse quadratic (x-2). To prove this hypothesis, it was examined an aleatory sample from this field, registering only one author for each work, and without applying any statistics test, concluded that the data adjusted themselves to the law of Lotka. Followed, they accomplished the same experience with the data from the first article of Schorr, about the libraries sciences, registering only the first author and without applying any test it was obtained results that adjusted themselves to a law x-3, instead of x-4, obtained by Schorr.

Vlachý (1978), in the section referring to the bibliography of the first number of Scientometrics, presents a bibliography about Lotka and related work, among them about Bradford and Zipf, as well as distribution of frequencies and of bibliometrics. In previous work (VLACHÝ, 1974, 1976) he had found discrepancies among the empiric data and the inverse square law, that is, the exponent value of Lotka´s law was variable.

In 1985, Miranda Lee Pao publishes an article where she presents the application process of Lotka´s law, step by step, calculating the values of the constant and the exponent, being based at the method of Lotka, as well as at the use of a test to check the degree of significance. One year later (PAO, 1986), this same author applies this procedure to 48 group of authors, representing 20 distinct scientific fields. The results are conclusive, in 80% of the cases they adjusted themselves to the law of Lotka.

Two modifications to Pao procedure are proposed by Nicholls, (1986) and applied to 15 samples of humanities, social sciences and sciences. The modifications refer to the calculation of the pendant (exponent), which proposes to calculate around the maximum probability (repeated numeric methods) and in a way to consider all the co-authors of the work. For the calculation of the critic value which will be served as comparison with the maximum difference (Dmax), proposes the following formula:

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$$v.c. = 1{,}63 / \left(\sum y_x + \left(\sum y_x / 10 \right)^{1/2} \right)^{1/2}$$

Nicholls (1989), at a second work, gives opinion that exists a considerable literature about the empiric valid of Lotka´s law, nevertheless these studies are on their majority incomparable and inconclusive, having substantial differences at the applied method. According to Nicholls, the main elements implied at the success of the empiric data to a bibliometric model are: the model specification, the measure of the variables, the data organization, the parameters estimate and the calculation of the significance degree. Gupta (1987), at a study about entomology of Nigeria, analyzes and studies productivity models of authors and checks the applicability of Lotka´s law to four different groups of data. It is showed that Lotka´s law, on its original shape, as inverse quadratic is not applicable to any of the four groups of data. in another previous work, Gupta, (1989a) applied the Lotka´s law to the literature about psychology in Africa

It is observed that the law was not applicable to the data in its generalized form (n=2,8), applying in this case both the statistics tests (K-Sy x2). At a third work, at the biochemical field from Nigeria, this same author (GUPTA, 1989b), created four different FICHEIROS, one with all the authors, another with only the first ones, with the non collaborators and one fourth only with the co-authors, it was checked that the Lotka´s law could be applied at the four cases, but with distinct values at the exponent. To check the adjustment it was used the test Kolmogorov-Smirnov, to a significant level of 0,01.

Sen, Taib and Hassan (1996), working at the domain of information science tries to estimate de Lotka´s law, checking that it is applicable to this field.

Jiménez Contreras Anegón (1997), analyses the authors´ productivity at the field of Librarianship and Documentation in Spain, concluding that the Lotka´s law described fairly well the data distribution.

Pulgarín and Gil-Leiva (2004) are out to develop a study with references about INDIZAÇÃO since 1956 to 2000, concluding that the data adjust themselves to a Lotka´s distribution.

Urbizagástegui (2006), recently, analyzed the distribution of the inverse potency, and describes step by step the application of the model proposed by Pao in 1985. The literature studied adjusts itself to the Lotka´s model.

2 METHODOLOGY

Since 1996, year in which Sen, Taib and Hassan published their work, it was not observed any previous work where it was applied the Lotka´s law, at the field of information science. That was the reason that led us to up to date the application of Lotka´s law, following the methodology of Pao (1985) to this field.

The data were obtained from the data base Library and Information Science Abstracts (LISA) making a retrospective research since 1996 to the beginnings of 2008, using the term "Information Science" as descriptor.

The count was made, attributing the same credits to each one of the authors who appeared in each work (Normal count) (NICHOLLS, 1986; LINDSEY, 1982).

To the calculation of the pendant it was not accomplished any cut, that is, it was proceeded to the determination of this parameter using all the data. Since that perspective, less predicted and more descriptive, to eliminate the data is an objective loss of information and it has something of scientific engine.

The law of Lotka establishes that the number of author, yx, each one of them 'x', is inversely proportional to x, that is the productivity of each individual author.

The relations is expressed as: $x^n \cdot y_x = c$; x = 1, 2,.., x_{max}, $c > 0$, $n > 1$, where yx represents the probability of an author to publish 'x' times at this area, , x_{max} represents the maximum value of productivity, and 'n'and 'c' are two parameters that are necessary to estimate for each specific group of data.

The pendant was calculated, following the protocol proposed by Lee Pao, that is, through the method of the minimum squares.

$$n = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - \left(\sum X\right)^2},$$

Where

N= number of pairs of data considered

X= decimal logarithm of x

Y= decimal logarithm of y

The estimate of the parameter ‘c’, percentage of author with only one work, is more problematic. The simplest solution is to accept the Lotka conclusion which says: “*The proportion of authors with only one work is 60%,* which was to % that obtained on his two samples $6/\pi^{2.}$ Many investigators choose this inverse quadratic law to accomplish verifications because it is easier to calculate.

Extrapolating the Lotka´s calculation, for the special case of n=2, the general formula of n is the following way:

$$y_1 = C\left(1/1^2 \right)$$
$$y_2 = C\left(1/2^2 \right)$$

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$$y_x = C\left(1/x^n \right)$$

Adding both the terms of the equations we obtain:

$\sum y_x = C\left(1/1^2 + 1/2^2 + 1/3^2 + \ldots\ldots\ldots + 1/x^2 \right)$, and dividing both the terms by the total number of authors, $\sum y_x$ we have $\frac{\sum y_x}{\sum y_x} = \left(\frac{C}{\sum y_x} \right)\left(\sum \frac{1}{x^2} \right)$.

as $\frac{\sum y_x}{\sum y_x} = 1$, doing $\left(\frac{C}{\sum y_x} \right) = c$, we have to $1 = c\left(\sum \frac{1}{x^2} \right)$, and then $c = \frac{1}{\left(\sum 1/x^2 \right)} = \frac{1}{\frac{\pi^2}{6}} = \frac{6}{\pi^2} = 0{,}6079$, as for n = 2, the serial $\sum 1/x^2$ converges till $\pi^2/6$.

For the case of other fractionated values, not negative, of n, the sum of the infinite serial, on its general shape, $\sum 1/x^n$, may only be approximate to a function which calculates the sum of the first P terms. The calculation of P=20 first terms, ignoring the calculation of the remaining terms until ∞, is found developed at the work of Pao (1985).

The result of the sum of this infinite serial $1 + 1/2^n + 1/3^n + \ldots + 1/x^n$, when n > 1, to the P first terms is:

$$\sum_{x=1}^{\infty} 1/x^n \cong \left[\sum_{x=1}^{P-1} \frac{1}{x^n} + \frac{1}{(n-1)(P^{n-1})} + \frac{1}{2P^n} + \frac{n}{24(P-1)^{n+1}} \right]$$

Soon to estimate c, fraction of authors with only one work in a distribution of authors, it is used the inverse function z of Riemann:

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

Finally, we should choose an adequate statistics test to verify the significance of the adjust degree, with a determined level of importance, to check if the distribution observed is in agreement or is adjusted to the function of theoretical distribution.

Coile (1977) criticized the use of the test χ^2 on the part of some authors, arguing that the value of this test roots at the need to match the data in several categories, suggesting the test of Kolmogorov-Smirnov as the most powerful statistically. For this reason, this will be the test used at this study.

3 RESULTS

The result of the research accomplished to the data base LISA, using the term "*Information Science"* as descriptor, generated a total of 2825 registers. Out of each register obtained it was selected the blank author, obtaining 2695 authors. The results of the research are shown at the table 1, where it is indicated the number of published work (column1), the number of authors with x published work (column 2) and the pertinent calculations to calculate the pendant of the authors´ distribution (columns 3 to 6).

Table 1: Data Observed and Data to Calculate the Pendant

x	y	X = log x	Y = log y	XY	XX
1	2137	0	3,32980	0	0
2	341	0,30103	2,53275	0,76243	0,09061
3	104	0,47712	2,01703	0,96236	0,22764
4	48	0,60205	1,68124	1,01220	0,36247
5	27	0,69897	1,43136	1,00048	0,48855

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6	12	0,77815	1,07918	0,83976	0,60551
7	9	0,84509	0,95424	0,80642	0,71419
8	4	0,90308	0,60205	0,54371	0,81557
9	2	0,95424	0,30103	0,28725	0,91057
10	2	1	0,30103	0,30103	1
11	2	1,04139	0,30103	0,31349	1,08449
12	2	1,07918	0,30103	0,32486	1,16463
13	1	1,11394	0	0	1,24086
14	1	1,14612	0	0	1,31360
15	1	1,17609	0	0	1,38319
16	1	1,20411	0	0	1,44990
25	1	1,39794	0	0	1,95423
TOTAL	**2695**	**14,7185**	**14,8318**	**7,1540**	**14,8061**

Source: LISA – 1996-2008.

With the data of table 1 it goes to the pendant calculation (n).

$$n = \frac{N\sum XY - \sum X \sum Y}{N\sum X^2 - \left(\sum X\right)^2} = \frac{17 \times 7{,}154 - 14{,}71850 \times 14{,}8318}{17 \times 14{,}8061 - 14{,}7185^2} = -2{,}756$$

To estimate c, it goes to the calculation of the function z of Riemann

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

Previously it is obtained the sum of the infinite serial to the P-1 first terms:

$$\sum_{x=1}^{\infty} 1/x^{2,7569} \cong \left[\sum_{x=1}^{19} \frac{1}{x^{2,7569}} + \frac{1}{(1{,}57)(20)^{1,7569}} + \frac{1}{2(20)^{2,7569}} + \frac{2{,}7569}{24(19)^{3,7569}} \right] = 1{,}258$$

$$C = \frac{1}{1{,}2583} = 0{,}794723 .$$

This is the percentage of authors with only one work published at the authors´ distribution, the first data of the column 5 from table 2 starts from the one which calculates the remaining theoretical values.

The table 2 is built with the purpose to submit the data observed to a statistics test, to verify the significance degree. At this case we will apply the test K-S.

Table 2: Data to Apply the Test of Kolmogorov-Smirnov.

x	y	y/∑y	∑(y/∑y)	fe	∑fe	Dmax
1	2137	0,79294	0,79294	0,79472	0,79472	0,00177
2	341	0,12653	0,91948	0,11757	0,91229	0,00718
3	104	0,03858	0,95807	0,03844	0,95074	0,00733
4	48	0,01781	0,97588	0,01739	0,96813	0,00774
5	27	0,01001	0,98589	0,00940	0,97753	**0,00836**
6	12	0,00445	0,99035	0,00568	0,98322	0,00712
7	9	0,00333	0,99369	0,00371	0,98694	0,00674
8	4	0,00148	0,99517	0,00257	0,98951	0,00566
9	2	0,00074	0,99591	0,00186	0,99137	0,00454
10	2	0,00074	0,99666	0,00139	0,99276	0,00389
11	2	0,00074	0,99740	0,00107	0,99383	0,00356
12	2	0,00074	0,99814	0,00084	0,99467	0,00346
13	1	0,00037	0,99851	0,00067	0,99535	0,00316
14	1	0,00037	0,99888	0,00055	0,99590	0,00298
15	1	0,00037	0,99925	0,00045	0,99635	0,00290
16	1	0,00037	0,99962	0,00038	0,99673	0,00289
25	1	0,00037	1	0,00032	0,99706	0,00293
TOTAL	**2695**					

Fonte: LISA – 1996-2008.

The Dmax obtained at accomplishing the differences in absolute value between the two columns of accumulated data (observed and theoretical) is equals 0,008363.

The critical value, to a signification level of $\alpha = 0{,}01$, according to Nicholls is:

$$v.c. = \frac{1{,}63}{\sqrt{\sum y_x + \sqrt{\frac{\sum y_x}{10}}}} = \frac{1{,}63}{\sqrt{2695 + \sqrt{\frac{2695}{10}}}} = 0{,}0313$$

FINAL CONSIDERATIONS

The substantial differences, observed at the different studies accomplished to validate the Lotka law at different subjects root at the applied methodology, fundamentally (NICHOLLS, 1989). This provoked that the results had been contradictory and not always adjusted to a lotkiana distribution (OPPENHEIMER, 1986).

As it may be confirmed, with a considerable number of cases, including some of the examples of Lotka himself, the law is not executed, having obtained values of the pendant different to -2.

In the case of Murphy (1973) the data were not submitted to a statistics test, with the one it is impossible to state that the Lotka law is executed nor not. The Voos study (1974) presents two problems: the first is that the data are studied year after year, then, the period is fairly short, much shorter to the ten years as suggests Potter (1981); the second problem is the test that is used (χ^2), inappropriate test, according to Coile (1977), as it requests to group the categories which present frequencies inferior to 5, with the consequent loss of information. Schorr (1974, 1975a,1975b), also uses the χ^2, as statistics test, what may displace the results from their studies, as checked Coile when applying an adequate test, as it is the one of Kolmogorov-Smirnov.

We are not in agreement with Radhakrishnan and Kerdízan (1979), when considering all the authors of one work (*normal count)*, instead of doing it as Lotka did (*straight count)*, that is, to attribute the work to the main author, being the number of authors beneficiary. This method would not have consequences at the age of Lotka, as the percentage of authors who published in collaboration would be much smaller in relation to the ones who make it at the current time (one of the characteristics of Big Science (PRICE, 1963), but at the current time we can not ignore this deed, at least, we have to consider all the co-authors. Radhakrishnan and Kerdizan, also do not apply any test to check the adjustment of their data.

According to Vlachý (1974-1976), Pao (1985, 1986) and Nicholls (1986, 1989), we have to admit that the exponent value of Lotka law (pendant) is variable and, therefore, the constant (number of authors with only one work) will also be

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different for each distribution of authors (different to 60% of the total of authors of the distribution which Lotka proposed). Equally, it will be necessary to apply an appropriate statistics test, which does not distort the data, mainly of the great producers, as the test of Kolmogorov-Smirnov.

We believe that all the co-authors should be used, such and which as Nicholls indicated and, to the calculation of the critical value, use the proposal of Pao or the modified of Nicholls.

Since 1974, year in which Voos published his article, until 1996 we can not observe the publication of no other article applying the Lotka law to the field of "Information Science." This second article was elaborated by Sen, Taib and Hassan, using the annual index of names from 1992 (with a result of 8284 names) and the annual index of authors from 1993 (with a result of 7664 authors), from LISA. Using as constant (C) the number of authors observed with only one work, discovers the pendant, which turns out to be to the data of 1992 equals to 3,23 and to the ones of 1993 equals to 3,1. It is concluded saying that both distributions adjusted themselves to the Lotka´s law, as the theoretical data calculated with the found pendants approach a lot to the real data.

Regarding the article of Sen, Taiba and Hassan, we do not agree with for the following reasons:

1. The fact to select the data of only one year seems to us a period of time too short, according to Potter (1981)
2. The method used to the calculation of the pendant seems inadequate to us. Using the data observed in 1992, we obtained a pendant equals to 3,4 to 1992, instead of 3,23 and of 3,2 to 1993, instead of 3,1. The method we used was the one of the minimum squares and, also, in a graphic shape.
3. The authors with only one work published, coming from the observed data can not replace to the theoretical data and from then, considering this value as C, calculate the different values to authors with two works, three works, etc. We have to calculate the theoretical value of C, previously.
4. We also observed that there was not the application of any statistics test which justifies or adjusts the distributions.

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5. At last, if it is considered the pendant of Lotka equals -2, to check how the data are adjusted, it should be considered, also, the value of C, as refers Lotka, that is, 0,6097 = $6/\pi^2$. So the value of C would be 8284 × 0,6097 = 5050 authors instead of 7229, to case of 1992 and of 7601 × 0,6097 = 4634, to the case of 1993. If we sum the authors calculated with n = 2, to 1992 it is obtained 10580 authors, instead of 8284, and to the case of 1993 a total of 8484, instead of 7601.

Our results show a new view, regarding the methodology applied until now in “Information Science”.

We are convinced that with the methodology used at this study it is possible to obtain results more trusted, providing a higher rigidity to the investigation.

We use at the recount all the co-authors, due to the characteristics that the current investigation presents, relatively to the work in group, characteristic we referred to previously when we mentioned Price (1963).

We are not apologists of accomplishing a cut to the distribution, even that the data show themselves less attractive. For that reason we consider all the data.

We believe it is fundamental to apply an adequate methodology to the calculation of the Lotka´s law parameters, the pendant of distribution and C, theoretical proportion of authors with only one work. In our case we consider the methodology proposed by Pao, to the calculation of both the parameters, showing as results a pendant equals to 2,7569 and a C equals to 0,794723. As we can observe, these results are smaller than in the case of Voos and of Sen, Taib and Hassan, what means that the number of punctual work (authors who in a certain moment write an article and do not do it again, what would indicate a discontinuity in the investigation) is about to diminish. Consequently, of course the pendant also diminishes.

To a higher rigidity and as part of the following methodology, it is important the application of a statistic test, with the aim to prove the hypothesis of departure and to be able do confirm the adjustment or not to a distribution of Lotka kind. In our case we opted for the non parametric test of Kolmogorov-Smirnov, the test seemed to us equals to one Coile suggested, more appropriate than the χ^2 to apply it to an asymmetric distribution as it is the one of authors.

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At last, the critical value obtained follows the formulation proposed by Nicholls, to a level of significance of a = 0,01, was of 0,0313, while the one of Dmax found was of 0,008363. As v.c. > Dmax accepts a null hypothesis. Therefore, also at this third study, equally to what happened in the two previous ones, it is necessary to confirm the adjustment of author´s distribution, at the field of "Information Science", referring to the Lotka ´s law.

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