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Lotka's Law and productivity patterns of authors in biomedical science in Nigeria on HIV/AIDS: A bibliometric approach

Ifeanyi Adigwe

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Ifeanyi Adigwe
University of South Africa, Pretoria, South Africa

Received 3 February 2014
Revised 20 March 2015
Accepted 8 May 2015

Abstract

Purpose – This study aims to analyze the productivity patterns of authors in Nigeria using publications indexed in Medline from 2008 to 2012 based on Lotka's Law. Lotka's Law of scientific productivity provides a platform for studying inequality in authors' productivity patterns in a given field and over a specified period.

Design/methodology/approach – This study covers all the journal articles on HIV/AIDS pandemic in Nigeria over a period of five years (2008-2012) in Medline, of which 512 articles were reported to have been published during this period. In this paper, 306 articles that had HIV/AIDS in the title, published in 20 journals, and articles that had HIV/AIDS as author keywords were analyzed. Because no local database that indexed biomedical literature from Nigeria was available, Medline was used, which is not only a robust and flexible database that includes articles from Nigeria but is also the largest medical database that indexes over six-and-a-half million articles from 3,400 biomedical journals.

Findings – While HIV/AIDS can be considered a global pandemic, Nigeria has the second highest number of new infections reported each year, and an estimated 3.7 per cent of the population is living with the dreaded disease. This study presents a general picture of the distribution of papers as single-author papers, multiple-author papers and the measures of co-authorship. The findings of the study reveal that in the productivity distribution for authors on the subject of HIV/AIDS, only co-authors and non-collaborative authors' categories fit in the Lotka's Law, whereas all-authors and first-author categories differ from the distribution of Lotka's inverse square law.

Research limitations/implications – The empirical evidence used in this paper was based on only articles of HIV/AIDS pandemic in Nigeria that had HIV/AIDS the title. Therefore, the findings of this study might not be the generalized to other biomedical research studies.

Originality/value – The originality of this paper lies in the fact that the productivity pattern of each of the different author categories on the subject of HIV/AIDS is a first of its kind in the Nigerian context.

Keywords Nigeria, HIV/AIDS, Bibliometrics, Medline, Productivity patterns

Paper type Research paper

Introduction

Since its introduction by Lotka in 1926, the versatility of Lotka's Law has been pivotal in bibliometric studies, and it has been expanded on through the years (Leydesdorff *et al.*, 2013; Yang *et al.*, 2014). Perceptions of research productivity patterns of authors differ

The author wants to appreciate Ms. Beth Thomsett-Scott, Editor of *The Electronic Library*, who ensured that this paper saw the light of the day and did not end up in the dustbin. Her numerous contributions added flavor and direction to this paper. The author is forever grateful to the *TEL*'s editor for this kind gesture.

The Electronic Library
Vol. 34 No. 5, 2016
pp. 789-807

0264-0473
DOI 10.1108/EL-02-2014-0024

greatly (Seglen, 1992; Tijssen, 2007; Uthman and Uthman, 2007). The productivity pattern of authors is not only subjective but also a function of an enabling scientific environment. Several prominent authors (Burrell, 2008; Fang and Fang, 1995; Huber, 2002; Pao, 1985; Potter, 1981; Vlachy, 1976) have identified variables that influence the distribution of author productivity patterns in any given field. Variables include subject or discipline, distribution sampling technique, representative coverage over a ten-year period, community of authors involved, types of creative communities and methodology adopted. According to the above mentioned studies, these variables are not sacrosanct to a particular law or model in the distribution of an author's productivity in any given discipline. Other studies have provided extensive reasons behind the variation of productivity patterns of authors (Araújo *et al.*, 2014; Baby and Kumaravel, 2012; Egghe, 2010; Naranan, 1971; Ruiz-Castillo and Costas, 2014; Schorr, 1974; Sudhier, 2013; Suen and Yang, 2012; Torbati and Chakoli, 2013). Nwagwu (2006) noted that the literature on bibliometric studies has expanded beyond the level of publication analysis and that many communities have yet to utilize them as a strategy for gathering information that could be useful in understanding the patterns and trends in their local science. This is the situation in developing countries, including Nigeria. He further noted that even though there are comprehensive bibliometric studies in the crucial field of biomedicine, biomedical science is inexhaustible because it is one of the disciplines where emerging issues and terminologies continue to be developed.

Several bibliometric studies regarding author productivity patterns in biomedical literature have been conducted in previous studies (Araújo *et al.*, 2014; Nwagwu, 2004, 2005, 2006, 2007; Onyancha, 2008a, 2008b, 2009, 2014; Ruiz-Castillo and Costas, 2014; Uthman, 2010). Results provided a holistic view underpinning the productivity patterns in biomedical literature. Although citation studies have been used to map out cluster topic maps in biomedical literature, the situation remains scattered and obscured (Nwagwu, 2007; Onyancha, 2014; Uthman, 2010).

Out of all the fields of biomedical science, research productivity in Africa in the research field of HIV/AIDS is still highly skewed (Uthman, 2010). While HIV/AIDS can be considered a global pandemic, Nigeria has the second highest number of new infections reported each year, and an estimated 3.7 per cent of the population is living with HIV (Federal Republic of Nigeria, 2012; UNAIDS, 2012). Despite the fact that South Africa, Egypt and Nigeria make up a striking 60 per cent of the total number of articles on HIV/AIDS indexed by PubMed between 1996 and 2005 (Uthman, 2010), Uthman (2010) and Uthman and Uthman (2007) noted that the contribution of Africa to global research production was persistently low through this period. Well-known authors, including Rosmarakis *et al.* (2005) and Vergidis *et al.* (2005), have reiterated that the USA and Europe are champions in biomedical research because of the favorable scientific environment that characterized these countries. As a result of this, innovations and inventions are at a peak in these regions. Considering the fact that more developing countries become major hubs for publication and research in the global research community, scientific research in Africa is still lagging far behind other regions in the world and in dire need of large investments in order to catch up with other developing regions (Tijssen, 2007; Uthman and Uthman, 2007; World Bank, 2005).

The empirical investigations of Lotka's assertions have been fundamental in generating new approaches and methodologies in the field of bibliometrics. A recent study by Yang *et al.* (2014) offered another confirmation of this fact. To date, most

bibliometric analyses of scholarly communication have been focused on determining the applicability to Lotka's assertions. To illuminate this, a certain rule between author frequency and quantity of papers was postulated by Lotka. Yang *et al.* (2014) drew out the parallels in the rule postulated by Lotka:

> […] if the quantity of authors who issued one paper in a special domain is determined, then it's easy to calculate the number of authors who write 2, 3 or more papers.

The equation below summarizes Lotka's Law as:

$$X^{\alpha}Y = K \tag{1}$$

where Y is the number of authors producing X number of articles in any given subject area (Lotka, 1926).

In other words, Lotka established, through the rule above, that the number of authors making x contributions is about 1/x of those making one, and the proportion of all those making a single contribution is 60 per cent. This means that out of all the authors in a given field, 60 per cent of authors will have just one publication each, 15 per cent will have two publications each ($1/2^2$ times 60), 7 per cent of authors will have three publications ($1/3^2$ times 60) each and only about 6 per cent of authors in the literature of any field will produce up to 10 contributions each. Lotka's Law is often called "inverse square law", indicating that there is an inverse relation between the number of publications and the number of authors producing these publications (Araújo *et al.*, 2014; Nwagwu, 2004, 2005, 2006; Ruiz-Castillo and Costas, 2014).

Crucial questions have been asked regarding the applicability of Lotka's Law to other disciplines beyond studies of Lotka's litmus test in the fields of physics and chemistry. Prominent authors (Barrios *et al.*, 2008; Pao, 1985, 1986; Vlachy, 1978) in the field of bibliometrics used different approaches in determining the applicability of Lotka's Law in other fields. Closely following the approaches and procedures of Lotka, Pao (1985) used least squares; the following year she devised a new method on how to compute values of the exponent "α" and the constant "c" with the Kolmogorov-Smirnov (K-S) test (Pao, 1986). According to Pao (1986), there exists a rich stream of variation from the aforementioned factors that could influence the productivity patterns of authors in a given field. Her studies reinforced that the applicability to Lotka assertions is predetermined by the degree of productive authors in the said discipline. That is to say that conformity to Lotka's assertions is sacrosanct to the productivity patterns of a community of authors in a given discipline. Arguably, if Lotka's Law is applicable within a specific discipline, it should then also be applicable across disciplines and throughout all global communities. The significance of the present study is to proffer an answer to the question posed by applying this method to a new community of researchers. Further, this study will also explain if there are deviances in the new community of authors and implications for further study will be discussed.

Literature review

The applicability of Lotka's Law and productivity pattern of authors

Over the years, various studies have attempted to test the applicability of Lotka's Law and its conformity in other disciplines (Abrizah and Wee, 2011; Behrens and Luksch, 2012; Chiang and Yang, 2012; Elango and Rajendran, 2012; Pinto *et al.*, 2012; Santos and García, 2011; Talukdar *et al.*, 2011; Tsai, 2013; Wallace, 2012). Pulgarín (2012) noted that

the applicability of Lotka's Law was subject to the state of development of a discipline. He further observed that in an emerging and evolving field, such as biomedical science, the co-authorship pattern of authors was most likely to be prevalent than in other emerging fields in the social sciences, but it is not the sole factor to support Lotka's assertions. Even though the state of development of a discipline varies from country to country, Behrens and Luksch (2012) and Pulgarín (2012) argued that understanding Lotka's assertions is a complex phenomenon which is tied to many factors. Mere statistical calculations substituting for Lotka's assertions cannot provide sufficient basis to support or dispute Lotka. It is, therefore, not surprising to note that a divide still exists overtly in countries with capability and stamina in terms of human, material and mechanical resources to cope with the complexities of biomedical research compared to countries with less capability and stamina over a given period of time. All of these affect the level of research outputs in the specific discipline and country which will, in turn, influence the productivity patterns of authors in biomedical science.

Beyond the discussion of skewedness of research outputs from developed to developing countries, more fundamental outstanding concerns are the misinterpretations of Lotka's Law. Although some authors, such as Pulgarín (2012), Talukdar *et al.* (2011), have argued – confined to the limitations of discrete data and research tools – the misinterpretations of Lotka's Law have provided the basis for the empirical distribution of authors to be perceived as highly skewed. In either case, this indicates that Lotka's Law has led to new methodologies and approaches to providing statistical evidence of testing its applicability in various disciplines in the literature.

However, often, as in this case, an established law can remain debatable among scholars. Many well-known authors, including Baby and Kumaravel (2012), Burrell (2008), Egghe (2010), Fang and Fang (1995), Huber (2002), Naranan (1971), Potter (1981), Pao (1985), Schorr (1974), Sudhier (2013), Suen and Yang (2012), Torbati and Chakoli (2013) and Vlachy (1976), have subjected the pioneer study of Lotka to testing. Studies on the fitness of Lotka's Law began in a systematic manner starting with Vlachy (1978), who observed that non-conformity of Lotka's assertions could be influenced by the variables discussed earlier. In addition to Vlachy's factors, Pao (1985) asserted that the subject or discipline, distribution sampling technique and good representative coverage should be put into consideration when compiling data. She also tried to verify the procedure used by Lotka by devising a new method on how to compute values of the exponent "α" and the constant "c", as well as how to perform the K-S test of conformity. The following year Pao (1986) used a different approach, the least square method and found that a majority of the data sets conformed to Lotka's distribution as a generalized inverse power function ($\alpha = 2$). Barrios *et al.* (2008) adopted the method proposed by Pao to validate Lotka's assertions. Their study was a bibliometric analysis of psychology between 1990 and 2005. They studied 572 articles produced by 854 authors. All the authors of the publications (first authors and collaborators) were considered. To determine whether the data fit Lotka's Law, the α value was calculated using the least squares method ($\alpha = 3.26$), obtaining a c value of 0.87. They concluded that the data did not fit into Lotka's Law.

Regarding the productivity pattern of authors, several studies conducted by others in various fields of science corroborated Lotka's findings, including early studies on the history of technology (Murphy, 1973), finance (Chung and Cox, 1990), geophysics

(Gupta, 1992), dental science (Kawamura *et al.*, 1999) and sport psychology (Baker *et al.*, 2003). Recent studies have corroborated Lotka's Law in a variety of disciplines, including marketing (Talukdar *et al.*, 2011), computer science (Abrizah and Wee, 2011), sport psychology and sports economics (Santos and García, 2011), health sciences (Pinto *et al.*, 2012), mathematics (Behrens and Luksch, 2012), financial risk literature (Chiang and Yang, 2012), marine sciences literature (Elango and Rajendran, 2012), knowledge management (Wallace, 2012) and knowledge management and data mining (Tsai, 2013). Rowlands (2004) extended the application of Lotka's Law to the productivity of a multidisciplinary journal publisher.

Lotka's Law has been modified by Baby and Kumaravel (2012), Burrell (2008), Coile (1977), Egghe (2010), Fang and Fang (1995), Huber (2002), Naranan (1971), Pao (1985), Potter (1981), Schorr (1974), Sudhier (2013), Suen and Yang (2012) and Vlachy (1976). Recently, Torbati and Chakoli (2013) suggested that the modifications and non-conformity to Lotka's assertions were a result of the counting method adopted, period covered, sources of data, community of authors, nature of discipline, errors in data and statistical test adopted. From the various studies enumerated above, skewed distributions, depending on the appropriateness of the methodology adopted, will greatly affect the variations and interpretations of Lotka's assertions in determining author productivity patterns in a given field.

It has been argued that the disparity between Lotka's assertions varies from discipline to discipline and from time to time. Nicholls (1986) and Pulgarín (2012) noted that such discrepancies in validation of Lotka's Law are perhaps because of a steady increase of co-authored publications over time. Despite the marked difference among them, Lotka's Law predicts the proportion of authors at different levels of productivity. To illuminate this, Newby *et al.* (2002) provided empirical findings that suggested that Lotka's Law is not intended to predict a particular author's productivity. Instead, its prediction lies in a cumulative and collective behavior across a large number of authors. Indeed, the identification of such validity and conformity and empirical regularity is imperative because it creates an avenue to discover the field where there are more collaborative authorships and how it differs from one field to another (Talukdar, 2011).

Bibliometric studies on HIV/AIDS literature

According to Chuang *et al.* (2011), bibliometrics uses a quantitative analysis and statistics to describe patterns and trends of publication within a given field or body of literature. To date, bibliometrics has been used as indices, tools and techniques by prominent scholars in the field of biomedical science (Chen *et al.*, 2006; Guan and Gao, 2008; He *et al.*, 2005; Uthman, 2008) and other disciplines (Carrera-Fernández *et al.*, 2014; Satpathy *et al.*, 2014; Sethi and Panda, 2014) as measure of scientific productivity. Over time, these tools have been validated by researchers as a means for determining productive trends of authors in a field or discipline. For example, researchers may use bibliometric methods of evaluation to determine trends in publications or to identify the focus of research (Chuang *et al.*, 2011). Bibliometric studies have been on the rise in HIV/AIDS literature stemming from monitoring and evaluating research by UNAIDS and the World Health Organization (WHO) (Onyancha and Ocholla, 2004). There are a number of studies that have adopted bibliometric approaches to study HIV/AIDS literature in various countries, including Iran (Rahimi-Movaghar *et al.*, 2012), Kenya and Uganda (Onyancha and Ocholla, 2004), USA (Naidoo *et al.*, 2013), sub-Saharan Africa

(Uthman, 2010), Nigeria (Uthman, 2008), Kenya and South Africa (Onyancha and Ocholla, 2007), Central Africa (Macias-Chapula and Mijangos-Nolasco, 2002), India (Patra and Chand, 2007), Eastern and South Africa (Onyancha, 2008a, b), Latin America and the Caribbean (Macias-Chapula *et al.*, 1998) and Haiti (Macias-Chapula, 2000). These bibliometric studies on HIV/AIDS have described the distribution and variation in the scientific output over time (Rosas *et al.*, 2011). Nwagwu carried out several studies (Nwagwu, 2005, 2006, 2007) on biomedical authors in Nigeria based on Lotka's Law. The findings of Nwagwu's (2005, 2006) studies were not in line with Lotka's assertions. This could be a result of inappropriate methodology adopted resulting in a skewed distribution. Nwagwu's studies were unable to provide evidence on author productivity patterns in the various biomedical science disciplines, such as HIV/AIDS. This knowledge gap is important and provides a clear priority to researchers to determine Lotka's Law and productivity patterns of authors in the field of biomedical science in Nigeria on the subject of HIV/AIDS in the Medline database.

Research hypotheses

The general hypothesis for this study is that the authorship distribution pattern in the biomedical science literature in Nigeria fits Lotka's Law. For this paper, the authorship distribution pattern is classified into four categories, using the methodology outlined by Gupta (1987). The four categories are:

(1) Authorship distribution pattern (all authors) in the biomedical science literature in Nigeria does not fit Lotka's Law.

(2) Authorship distribution pattern (first authors) in the biomedical science literature in Nigeria does not fit Lotka's Law.

(3) Authorship distribution pattern (co-authors) in the biomedical science literature in Nigeria does not fit Lotka's Law.

(4) Authorship distribution pattern (non-collaborative authors/single author) in the biomedical science literature in Nigeria does not fit Lotka's Law.

Methodology

The Medline database, accessed through the Web of Knowledge interface, was used to extract relevant data on HIV/AIDS research in Nigeria. This study covers a period of five years (2008-2012) of articles on the HIV/AIDS pandemic in Nigeria. Medline searches resulted in 512 relevant articles. For retrieval of information, the advanced search option was used. "TS = HIV/AIDS" was used as topic/subject, "CU = Nigeria" as address/affiliation of authors and "2008-2012" as the time span for the published articles. In this paper, only articles with HIV/AIDS in the title and HIV/AIDS as an author keywords were selected, which resulted in 306 articles. The selected articles were published in 20 journals.

Medline was used because there was no local database available that indexes the biomedical literature from Nigeria (Nwagwu, 2010). Medline is a robust and flexible database that includes articles from Nigeria and is also the largest medical database because it indexes over six-and-a-half million articles from 3,400 biomedical journals (Chikonzo, 2009). The most recent bibliometric studies have focused more on the quantitative measures as the methodology adopted (Carrera-Fernández *et al.*, 2014; Satpathy *et al.*, 2014; Sethi and Panda, 2014). Ocholla *et al.* (2012) questioned the

subjectivity of qualitative measures of research output because of the flaws inherent in it. Quantitative measures are free from flaws but are more objective and more preferred when both methods are triangulated. In this study, the authors used the Publish or Perish (Harzing, 2007) software that relies on raw data from Google Scholar to establish author citation and impact analysis (it measures the impact of publications over a given period). Onyancha (2009) reiterated that the limitations associated with Google Scholar are its inclusion of non-scholarly citations, limited coverage of scholarly journals and update issues as compared to other databases, such as Medline. To overcome these challenges, the software developed by Harzing (2007) retrieves and analyses academic publications by using raw data from Google Scholar, among other sources, number of papers, number of citations, years of citation, cites per year, cites per paper, cites per author where multiple authors occur, papers per author and the *h*-index for measuring author/journal impact over time. The researchers examined the retrieved articles and sampled authors, author strength and journal impact.

Pao (1985) and Nicholls (1986) estimated the parameters of α and k, using the least square method. Nwagwu (2006) noted that the major limitation of the least square method is that the data needs to be truncated for acceptable results to be obtained. Nwagwu (2006) and Gupta (1987) used the free online software, LOTKA (Rousseau and Rousseau, 2000), which is capable of isolating all the values of α and k, as well as testing these parameters for goodness-of-fit at 1, 5 and 10 per cent levels of significance, respectively. Rousseau and Rousseau's program follows Nicholls' methodology (Nicholls, 1986), namely, specification of the model (Lotka's Power Law). Lotka's Power Law seeks the goodness-of-fit by comparing K-S maximum difference test statistic (D-Max), with the K-S table value at 0.01, 0.05 and 0.1 significance levels and a given degree of freedom.

To examine the uniqueness and the category of productive authors in biomedical research in Nigeria, the distribution of papers was categorized as *all authors* (this involves counting each of the authors and giving a credit equal to one each time his or her name appears on the by-line of an article in a bibliography), *first authors* (this involves counting only the first author, neglecting the co-authors), *co-authors* (this involves counting only authors who appeared as co-authors) and *non-collaborative authors* (this involves counting which authors who appear only as single author). For ease of data management, the entire period was subdivided into categories of five years each (2008, 2009, 2010, 2011 and 2012).

Data presentation and analysis

Data were analyzed and presented in relationship to Lotka's Law. The tables below show the results. Table I provides the distribution of the articles per year. There is an

Years	No. of papers	(%)
2008	58	19.0
2009	60	19.6
2010	66	21.6
2011	56	18.2
2012	66	21.6
Total	306	100

Table I. Distribution of articles per year of publication

incremental growth in publications up to 2010. Although there was a decrease in publication by 18.2 per cent in 2011, an increase in publications was observed in the following year. From the study, it could be deduced that Nigerian authors in the field of biomedicine seem to carry out research in the subject of HIV/AIDS. The productivity pattern of research in biomedicine will increase geometrically with continuous funding and decreases asymmetrically with insufficient funding.

There is a total of 988 authors (Table II) contributing to the publication of 306 articles on the subject of the HIV/AIDS pandemic in Nigeria during the studied time period. According to this data set, 988 authors (65.8 per cent) contributed one article, which disproves Lotka's Law that about 60 per cent of authors contribute only one paper. The maximum number of articles by five authors is 11 per cent, and this value also disproves Lotka's Law that only about 6 per cent of the authors in the bibliography of any field produce up to ten contributions each.

Table III shows the distribution of articles over authors. Across the different categories of authors that were considered (*all authors*, *first author*, *non-collaborative/single author* and *co-authors*), a higher percentage of authors contributed one article each during the period of 2008 to 2012. The number of *non-collaborative authors/single authors* was low, accounting for 29 out of the total of 988 authors; this indicates that authors in biomedical science tend to collaborate more. Of the 988 authors, 729 collaborated to publish an article in a journal. This supports the theory that biomedical science is one of the few disciplines that accommodates co-researchers in its research activities, which thus makes co-authorship central to the development of biomedical science in Nigeria.

Number of contributors

Figure 1 shows the distribution of authors against the total contribution. The graph displays an inverse *J*-shape for all the categories of authors; this is one of the properties of a bibliometric distribution. Table IV displays the parameters for each category of author using the Lotka software to analyze the distribution of articles over the categories of author.

The productivity distribution for authors in biomedical literature on the subject of HIV/AIDS shows that only the *co-authors* and *non-collaborative authors* categories fit

Table II.
Productivity patterns of authors in HIV/AIDS biomedical literature

No. of articles	No. of authors	% of authors	Total no. of contributions
1	650	65.8	650
2	90	9.1	180
3	73	7.4	219
4	40	4.1	160
5	35	3.5	175
6	30	3.0	180
7	23	2.3	161
8	17	1.7	136
9	15	1.5	135
10	10	1.0	100
11	5	0.5	55
Total	988	100	2151

No. of contributions (x)	All authors (y) $n = 988$		First authors $n = 229$		Non-collaborative authors $n = 30$		Co-author contributions $n = 729$	
Total	No. of authors	% of authors	No. of authors	% of authors	No. of authors	% of authors	No. of authors	% of authors
1	650	65.8	70	30.6	10	33.3	630	86.4
2	90	9.1	40	17.5	5	16.7	50	6.9
3	73	7.4	36	15.7	4	13.3	20	2.7
4	40	4.1	27	11.8	2	6.7	14	1.9
5	35	3.5	18	7.9	2	6.7	2	0.3
6	30	3.0	12	5.2	1	3.3	3	0.4
7	23	2.3	10	4.4	2	6.7	4	0.6
8	17	1.7	8	3.5	–	–	2	0.3
9	15	1.5	5	2.2	2	6.7	2	0.3
10	10	1.0	2	0.9	2	6.7	2	0.3
11	5	0.5	1	0.4	–	–	–	–
Total	988	100	229	100	30	100	729	100

Table III. Distribution of articles over authors

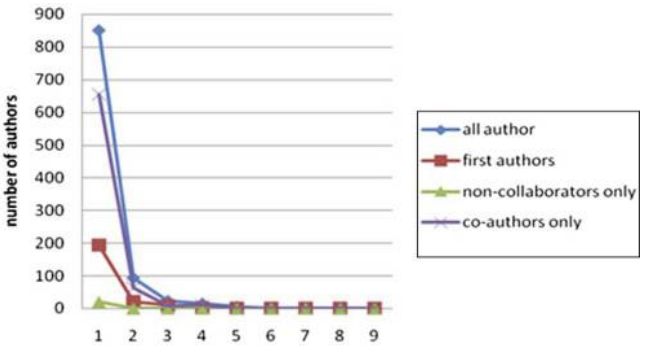

Figure 1. Size frequency distribution of authors making x contributions

	Kolmogorov-Smirnov statistics							
Author categories	D Max	Parameter	N	Df	1%	5%	10%	?
All authors	0.0522	$\alpha = 3.28$	988	8	0.0519	0.0433	0.0388	$k = 86.55\%$
First authors	0.0105	$\alpha = 3.22$	229	6	0.1077	0.0899	0.0806	$k = 85.9\%$
Non-collaborating authors	1	$\alpha = 1.26$	21	2	0.3557	0.2968	0.2662	$k = 0\%$
Co-authors	1	$\alpha = 1.26$	738	6	0.0600	0.0501	0.0449	$k = 0\%$

Table IV. Parameters of the various author categories

into Lotka's Law, whereas *all authors* and *first authors* categories differ from Lotka's Law when applying Lotka's inverse square law in its original form. This confirms that although the four data sets represent a collection of samples of publications for a fairly long period, Lotka's Law does not apply to the scientific community of this subject

specialty in Nigeria. The productivity distribution of each category was tested with generalized form of the law and results of each file are discussed below.

All authors

The entire set of authors in the category of *all authors* was considered as a single entity, and this constituted the 988 authors in the data set. An examination of the distribution of articles in this category (Table III) shows that about 66 per cent of the authors contributed just one article each, whereas about 9 per cent contributed two articles each; about 7 per cent contributed three articles. On the other hand, less than 5 per cent of the authors in the bibliography contributed at least ten papers each. This result follows Lotka's original result closely. For instance, Lotka estimated that out of all the authors in a given field, 60 per cent will have just one publication each; 15 per cent will have just two publications each, whereas 7 per cent of the authors will have three publications each. Only about 6 per cent of authors in any bibliography in any field would produce up to ten papers each. For all authors, the LOTKA software indicated that $k = 86.6$ per cent, which is higher than Lotka's value of $k = 60.8$ per cent; with a single contribution, the productivity coefficient $\alpha = 3.28$ of the authors is also higher than Lotka's estimated value of $\alpha = 2$. The maximum difference value of 0.0522 is greater than the significance level of 0.0519 at 1 per cent, 0.0433 at 5 per cent and 0.0388 at 10 per cent based on K-S statistics. This implies that the D-Max value is greater than the K-S value at 1, 5 and 10 per cent; therefore, the null hypothesis is accepted. Thus, the category of *all authors* in biomedical literature on HIV/AIDS discipline did differ from the inverse power (Table IV).

First authors

There were 229 first authors. About 31 per cent of authors in this category made a single contribution each, whereas about 17 per cent made two contributions each; about 16 per cent made three contributions each. More than 30 per cent contributed between four and nine publications, whereas less than 5 per cent contributed at least ten publications each. The α was 3.22 using the LOTKA software (Table IV). The distribution of the *first-author-only* category in the bibliography also followed the inverse power type of relationship. The values of the parameters α and k were determined in the same manner as the *all authors* category and were found to be 3.22 and 85.9 per cent, respectively. Similarly, for first authors $k = 85.9$ per cent, indicating that high numbers of first authors contributed once, and the productivity coefficient of authors was $\alpha = 3.22$. The maximum difference value of 0.0105 is less than the significance level of 0.1017 at 1 per cent, 0.0809 at 5 per cent and 0.0806 at 10 per cent based on K-S statistics. For the first author, the null hypothesis is not rejected because the D-Max was less than the K-S value at the 1, 5 and 10 per cent significance levels, so the category of *first authors* in HIV/AIDS discipline did differ from the inverse power.

Non-collaborative authors

In any discipline, there is a sub-community of authors whose publications appear as sole author without co-authoring with any other author. With the presumption that the productivity pattern of this community of authors should also follow Lotka's Law, the K-S test was applied to test the applicability of the law. This community of 29 authors showed a Lotka's Law distribution and were non-collaborative authors. The data were found fitting with the value of $\alpha = 1.26$ at the 0.01 level of significance when tested with

the K-S test. The maximum difference value of 1 is greater than the significance level of 0.3557 at 1 per cent, 0.2968 at 5 per cent and 0.2662 at 10 per cent based on K-S statistics. This implies that the D-Max value is greater than the K-S value at 1, 5 and 10 per cent; therefore, the null hypothesis is rejected. Thus, the category of *non-collaborative authors* in biomedical literature on HIV/AIDS discipline did not differ from the inverse power (Table IV).

Co-authors

A separate file was created for those authors who appeared only as co-authors, and each author was given full authorship for each appearance of his or her name in the by-line of the publications. A total of 729 authors were counted. About 86 per cent of authors in this category made a single contribution each, whereas about 7 per cent of authors made two contributions each; about 3 per cent made three contributions each. LOTKA (Table IV) indicated that the value of $k = 0$ per cent, whereas $\alpha = 1.26$, which is similar to the value obtained from non-collaborative authors. The maximum difference value is 1 which is greater than the significance level of 0.0600 at 1 per cent, 0.0501 at 5 per cent and 0.0449 at 10 per cent based on K-S statistics. This implies that the D-Max value is greater than the K-S value at 1, 5 and 10 per cent; therefore, the null hypothesis is rejected. Thus, the category of *co-authors* in biomedical literature on HIV/AIDS discipline did not differ from the inverse power (Table IV).

It was revealed from Table V that the journal *Nigerian Journal of Medicine: Journal of the National Association of Resident Doctors of Nigeria* has the highest frequency of published articles in the duration of the study compared to other journals indexed in Medline. The *Nigerian Quarterly Journal of Hospital Medicine* has the least publications (of the top ten journals) in the subject of HIV/AIDS in biomedical science in Nigeria (Table V).

The total number of authors who contributed to HIV/AIDS research during the period from 2008 to 2012 is 988. The authors are ranked according to the weight age or credit given for their position, as indicated by software analysis (Table VI). The top ranked author is Abubakar with 27 publications and an *h*-index of 7. Azodo had the fewest publications and an *h*-index of 3, within the top ten most productive authors in the subject of HIV/AIDS in biomedical science in Nigeria.

Table V. *h*5-index of the first ten journals in descending order using Google metrics

Name of journal	No. of publications	*h*5-index
Nigerian journal of medicine: Journal of the national association of resident doctors of Nigeria	26	10
African journal of reproductive health	17	14
African journal of medicine and medical science	15	14
Nigerian journal of clinical practice	13	11
West Africa journal of medicine	10	8
African health science	9	8
East African journal of public health	8	7
AIDS care	7	5
The journal of infection in developing countries	6	5
Nigerian quarterly journal of hospital medicine	6	4

Discussion of findings

This study showed that the number of articles on biomedical research has increased over the years. Several factors may have contributed to the increasing trend. One important factor for the increase is that global response to AIDS launched by the WHO lately has provided more resources to biomedical research in Nigeria. Because co-authorship is perceived to be more prevalent in the medical sciences as compared to social sciences (Pulgarín, 2012), the tendency for any genre of science, be it medical or social science, to be applicable to Lotka's Law, the country research strength in the said discipline coupled with the enabling scientific environment can impact positively or negatively to the applicability of Lotka's Law. The negative impact of a scientific environment would position the authors in a slow state of development, thereby, affecting the research output of authors in the said discipline and said country. This is a position that is supported by several interpretations in the literature and points to the fact that centralized scholarly outcomes are skewed in favor of developed countries. This still occurs despite developing countries now being seen as important hubs for publication and research in the global research community. The literature shows that the skewedness is a result of the slow state of development and lack of innovation that has bedeviled developing countries. Affirmative to this fact, Nwagwu (2006) opined that no matter how flexible foreign databases would be in capturing and documenting publications from Africa, there may be still location bias. There is a strong support for Africa to create its own database to capture and reflect its local science, accompanied by periodic production and dissemination, which would better serve their scientific output. It should be noted that the guiding ideologies in Lotka's Law only provide the foundation for determining the productive patterns of primary authors, who are termed senior authors in Lotka's study.

With a critical examination of Lotka's assertions, it is pertinent to say that the spread of authors in dynamic fields where there is a heavy growth is inversely proportionate to the general productivity patterns of authors leading to lower values of the Lotka parameters of "c" and "α" as was noted by Pulgarín (2012). If this is indeed the case, it can be asserted that the geometric growth in biomedical disciplines does not necessarily translate into an author's productivity pattern in the community of authors involved in biomedical science. That is to say, the level of growth in a discipline, such as biomedical science, perhaps might be seen as a cumulative effort of a few productive authors in the

Table VI. *h*-index of the top ten authors in descending order using publish or perish software

Author name	No. of publications	*h*-index
Abubakar, I.S	27	7
Essien, E.J	10	6
Asuzu, M.	16	5
Aliyu, M.H	12	5
Iliyasu, Z.	9	5
Salami, A.K	9	5
Monjok, E.	6	5
Adedigba, M.A	5	4
Babashani, M.	4	3
Azodo, C.C	4	3

field, who are termed the *inventors*. Because Lotka's study only focused on a specific category of authors – that is, *first authors* – several studies that have attempted to focus on other categories of authors resulted in divergent views from Lotka's assertions (Gupta, 1987; Nwagwu, 2006, 2007). Out of the four categories of authors used in this study, only two categories conformed to Lotka's assertions. The two categories of authors are *non-collaborative authors* (single authored articles) and *co-authors*. The other categories, *first authors* and *all authors*, were not applicable to Lotka's assertions. Because co-authorship acts as a catalyst for improving and enhancing the quality and quantity of publication in diverse disciplines, various studies confirm the findings of this study that co-authorship is fundamental to enhancing the quality of research across boundaries (regional, national and even disciplinary boundaries) leading to new innovations and discoveries (Fox and Faver, 1984; Nwagwu, 2007; Vimala and Reddy, 1996).

Because Lotka's Law predicts the proportion of authors at different levels of productivity, it can be asserted that collaborative authorship increases an author's productivity, which, in turn, leads to a robust growth in biomedical science. Considering the fact that Lotka's exponential value varies from discipline to discipline, various well-known authors, such as Pulgarín (2012) and Talukdar (2011), argued that the procedure adopted and the statistical technique used could be responsible for the variation. For instance, because Lotka's Law fails to satisfy the supposition underlying the χ^2, it seems to be a misuse to apply the K-S test to the data related to Lotka's Law. Talukdar (2011) suggested that for one sample test with various author categories, the K-S technique could be used, trusting it to be more powerful than the χ^2 test method. The researchers in this paper note that Lotka's Law has gone beyond the research productivity across authors and can also be applied in the evaluation of research productivity and performance of authors in biomedical science. However, Lotka's Law is not a panacea because it does not provide insight into the motivations of authors or the actual meaning and content of publications. If that be the case, there needs to be research to determine the indicators to measure research productivity and performance of authors in a wide range of fields. Currently, this question is silent in the literature. Even though the rate of publication and the career duration of authors could influence research output in a wide range of fields, it is important to note that the distributions of talent and tenacity should not be over-looked.

Conclusions and recommendations

The purpose of this study was to analyze the productivity patterns of authors in Nigeria using publications indexed in Medline from 2008 to 2012 based on Lotka's Law. Results examine Nigeria's strength and capability in HIV/AIDS research. The categories of *non-collaborative authors* and *co-authors* did fit into Lotka's inverse law with different parameters of $\alpha = 1.26$, $\alpha = 1.26$, respectively. Findings were compared with Nwagwu (2006). Nwagwu (2006) demonstrated that for biomedical literature between the period of 1967-2002, only three of the four author categories fit into Lotka's assertions with parameters of *all authors* $\alpha = 1.26$, *first authors* $\alpha = 1.64$ and *non-collaborating authors* $\alpha = 1.97$. The results of Lotka analysis used in this study suggest that HIV/AIDS literature is in conformity with the general expectations for author productivity revealed by past Lotka's Law studies (Araújo *et al.*, 2014; Gupta, 1987; Nwagwu, 2005, 2006; Onyancha, 2008a, 2014; Ruiz-Castillo and Costas, 2014).

The findings of the current study show that only the categories of *non-collaborative authors* and *co-authors* fit Lotka's inverse power law. Overall, there was an incremental growth in the productivity of authors within the HIV/AIDS discipline during the period of 2008 to 2012. *Non-collaborating authors* and *co-authors* ranked highest ($\alpha = 1.26$) during this period. Data were derived from 988 articles published in peer-reviewed journals between 2008-2012.

Because Lotka's Law provides a platform for measuring the productivity patterns of authors over a given period of time, it is known that each subject area in a discipline can be associated with an exponent, representing its specific rate of author productivity. This reason is not sufficient enough to explain why one individual should be more productive in producing dozens of published papers on a subject, another individual produces few papers and a third individual produces none. The discrepancy of author productivity could be partly explained by each individual's background. For instance, author productivity is not tied to collaborative authorship, but collaborative authorship could influence an author's productivity over a given period of time. Of course, it is noteworthy that an extension of the methodology used in this study may be useful for exploring author productivity in an expanded realm of publications, particularly in domains of other subjects in the medical sciences.

There were some limits to the methodological approach in the present research, including the use of a single search, the difference in sensitivity of the selected keywords used and that the selection of articles was made only for articles with HIV/AIDS appearing in the title and having HIV/AIDS as author keywords without stratifying results according to impact factor. The uniqueness of these findings may be because of the use of only one database. Thus, future research could include examining if the extent of the co-authorship productivity pattern increases if more articles are sampled in different databases. Despite these shortcomings, some results of the current study appear to be of interest and worthy of further discussion.

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Corresponding author

Ifeanyi Adigwe can be contacted at: ifeanyiadigwe62@gmail.com