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Research Article

Quantitative Estimation of Trends in Artificial Intelligence Research: A Study of Bradford Distributions using Leimkuhler Model

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ABSTRACT
The ubiquitous applications of Artificial Intelligence (AI) in various domains of human life have resulted in a phenomenal increase in AI research. The research output in AI has grown rapidly during the last decade. While some scientometric studies have noted this growth in publications, there are virtually no studies that could characterize the growth in publications in terms of the increase in domains and journals in which AI research is being carried out and published. This article makes an attempt to fill this research gap by using the Leimkuhler model of Bradford's law of productivity to produce quantitative estimates of AI research publishing. Publications indexed in Web of Science for the period 2011 to 2020 are used for analysis. The analysis explains the variation in the corpus of AI research using productivity distribution and its characteristics. The quantitative findings support the idea that AI research has not only increased in volume but also in terms of applications to a wider list of areas.

Keywwords: Artificial Intelligence, Bradford Law of Scattering, Leimkuhler Model, Journal Productivity Distribution

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INTRODUCTION

The research in Artificial Intelligence (AI) has grown tremendously in recent years. The growth is observed not only in the volume of publications but also in terms of expanding the scope of AI research in different disciplines and subject areas. AI is now so widely used that various countries are proposing national plans and strategies for AI. Such strategies include scientific research, talent development, skills and education, deployment in the public and private sectors, inclusion and ethics, standards and laws, and data and digital infrastructures, etc. As there are more and more use cases for AI, the value of the market has also expanded. For all of these reasons, an increasing number of researchers are excited about the potential applications of AI systems in a wide set of areas. AI is now believed to be a technology that can help solving some of the most difficult problems in the world and enhance the quality of life of the people. It is becoming so profound that some people refer it as the key technology of the *Fourth Industrial Revolution*.[1,2]

Owing to massive growth in research publication in AI, many previous studies have tried to explore the patterns of growth in AI research.[3-7] While many tried to measure the growth in volume of publications, various others discussed about the ubiquitous nature of AI. Almost all studies have shown that there is a significant growth in AI research volume. However, none of the previous studies tried to see this phenomenon in terms of Bradford's productivity distributions. It is not known whether the growth in AI research volume is mainly due to increased number of publications in journals publishing AI research or if the publication span (or width) of AI research has also significantly increased. Given the wider application of AI research, one may expect that AI research may now be published not only in journals specializing in the area but also in journals from various other domains. However, this needs to be confirmed through a quantitative characterization using the notion of Bradford's productivity distributions.

Motivated by the research gap discussed above, this article attempts to characterize the AI research growth by using the Leimkuhler model in association with the Bradford Law of Scattering. The research publications in journals indexed in Web of Science for the period 2011 to 2020 are used for the analysis. The analysis provides a way to interpret the AI research growth in mathematical terms. To the best of our knowledge this is the first such effort on characterizing AI research in the context of Bradford's productivity distribution. The study analyses the growth in AI research not only in terms of volume of publications but also in terms of growth in publication span (spread across different disciplines and

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subject areas). In other words, the article attempts to answer the following research questions:

RQ1: What factors characterize the rapid growth in AI research volume during 2011 to 2020?

RQ2: What are the characteristics that enables us to explain the variations in productivity distribution?

To address the first research question, we used the Leimkuhler model to apply the Bradford law of scattering to the AI literature. We compared the productivity distributions seen by adjusting the number of Bradford groups to further understand the patterns. The second question is answered by taking a note of the internal parameters/ properties related to the distribution of publications. The rest of the article is organized as follows: Section 2 presents a brief description of the Bradford's law of scattering along with Leimkuhler model. Section 3 lists some related studies in the area. Section 4 describes the data and methodology used for the research work. Results along with some discussions are presented in section 5. The paper concludes with a summary of the work and major findings in section 6.

Bradford law of scattering

The fundamental building blocks for understanding how academic information flows and interacts are bibliometric laws. Bradford's law of scattering,[8] Lotka's law of author productivity,[9] Zipf's law of word frequency,[10] Pareto's law,[11] Mandelbrot's law,[12] etc. are a few examples of well-known laws. These laws aid in the investigation of scientific literature communication, information flow, the improvement of scientific comprehension, and efficient information administration.

Journals and scientific publications have a quantitative relationship that is established by Bradford's law of scattering. Bradford initially introduced the idea of "Scattering of literature" in 1934.[8] The study looked at the journals in decreasing order of productivity and divided the articles into three roughly equal groups: *Core group* (nucleus or most productive zone), *Allied group* (moderately productive zone), and *Alien group* (peripheral or less productive zone). Bradford formally put it this way: "If scientific journals are arranged in order of decreasing productivity of articles on a given subject, they may be divided into a nucleus of periodicals more specifically devoted to the subject, and several groups containing the same number of articles as the nucleus, then the groups will be 1: n: n^2......i.e., groups are in the form of geometric progression." Here "n" is a "Bradford Multiplier."

Vickery (1948)[13] provided one of the first illustrative articles on the law and described the variations between Bradford's law of Scattering's verbal and graphical applications. The scattering of journal articles, according to Kendall (1960),[14] is comparable to the distribution of income. Given that Bradford doesn't offer a mathematical model for the law, other academicians, like Brookes, Vickery, and Leimkuhler, have developed their own models to explain the law of scattering. Leimkuhler (1967)[15] explains how Bradford's Distribution operates. The paradigm provided by Leimkuhler (1980)[16] was based on Bradford's verbal formulation. If R(r) refers to the cumulative number of articles produced by the journals of rank 1, 2, .., r. then,

$$R(r) = a \log (1 + br) \quad (1)$$

This is known as the Law of Leimkuhler, where "a" and "b" are the constants.

Later, Egghe[17,18] referred to these Bradford laws and demonstrated that they are mathematically identical to the Leimkuhler model. He also carried out an application of the Leimkuhler law's fundamental principle. In his explanation of the Leimkuhler law, also referred as *Egghe's Leimkuhler law*, he demonstrated that its constants, a and b, may be modelled as –

$$\mathbf{a} = \frac{\mathbf{y_0}}{\mathbf{\log k}} \quad (2)$$

$$\mathbf{b} = \frac{\mathbf{k - 1}}{\mathbf{r_0}} \quad (3)$$

Note that, this study followed standard notations described by Leimkuhler. Here

r_0: No. of sources in first Bradford group.

Y_0: No. of items in each Bradford group.

p: The no. of groups.

k: Bradford multiplier.

Y_m: No. of items in most productive source.

Choosing the value of "p" is the first step in using the *Egghe's Leimkuhler model*. In general, the value of the parameter p can be set at random. The value of "p" which varies depending on the size of the bibliography, must be chosen appropriately. This justification led us to choose p=3 and 5 for our investigation. After choosing the value of p, the next step is to determine the value of k, which is determined as follows:

$$\mathbf{k} = (\mathbf{e}^{\gamma} \mathbf{Y_m})^{1/p} \quad (4)$$

Where γ is Euler's number & is turned to be equal to 1.781, the previous equation can be rewritten as follows.

$$\mathbf{k} = (\mathbf{1.781 Y_m})^{1/p} \quad (5)$$

And y_0 is calculated as:

$$Y_0 = \frac{A}{p} \quad (6)$$

Here A denotes the total no. of articles.

Let T be the total no of journals then if we have "p" groups then T can be expressed as:

$$T = r_0 + r_0 k + r_0 k^2 + r_0 k^3 + \cdots + r_0 k^{p-1}$$

or,

$$r_0 = \frac{T(k-1)}{k^p - 1} \quad (7)$$

So,

$$r_0 = \frac{T}{1 + k + k^2 + \cdots + k^{p-1}}$$

Since A and T both are known from the dataset, we will easily calculate y_0 and r_0 by the equations (6) and (7).

Next, we apply the equation to determine the average number of articles per journal as –

$$\mu = \left(\frac{6p}{\pi^2}\right) * \log k \quad (8)$$

Similar to Leimkuhler Brookes (1977),[19] also conducted a thorough analysis of the law, describing law's theoretical concerns and pointing out the broad applicability of Bradford's law. Several alternative models have been developed in order to explain the law of scattering.[20-27] Although there are many interpretations and models for Bradford law, the Leimkuhler model as explained by Egghe is one of the most widely used. Thus, in this research, we used the aforementioned Leimkuhler equations (eq. 5, 6, 7) to apply the Bradford law.

Related Work

Bibliometrics offers a method for examining the body of research on a certain topic. It comprises analysis of a variety of bibliometric data, including publication and citation, journals, authors and institutions contributing to research, major funding agencies etc. Several previous studies attempted a bibliometric oriented analysis of growth and development of AI research.[3-7] Researchers also carried out bibliometric analyses of research based on AI in several academic disciplines, such as textile industry,[28] maritime industry,[29] healthcare,[30,31] mathematics education,[32] finance,[33] etc.

Several studies have been conducted to confirm the validity and applicability of Bradford's law in various fields. Rao (1990)[34] investigated the journal productivity trends in economics. Similar to this, several researchers verified this law on diverse domains, such as agriculture,[35] zoology,[36] horticulture,[37] bioenergy,[38] microbiology,[39] neural networks,[40] information sciences,[41] astronomy & astrophysics.[42] Similarly, the applicability of the law is also analyzed on literatures of several disciplines like physics,[43-44] crop sciences,[45] LIS,[46] neurology,[47] pediatrics surgery,[48] and so on. The use of the scattering phenomena in the economics literature of China and India was compared by Savanur (2019).[49] Apart from this Vuković(1997),[50] performed a thorough examination of the mathematical development of Bradford's law in a series of research papers on the scattering phenomenon. A quantitative analysis of the dynamic behavior of journal productivity distribution was carried out by Vuković (1992).[51]

It may be noted that all research using the Bradford law as a sole was mainly centered on the extrinsic aspects of bibliographic data, such as the subject matter, volume of the data, searching strategies, etc. The elements of the dynamics and the functions of time are either ignored or simply vaguely considered. Therefore, the characteristics on the basis of which the growth in volume and publication span is understood are important to explore. To the best of our knowledge, the growth in publication volume and disciplinary span of AI research has not been analyzed in terms of Bradford's law. Therefore, the present study is novel in its subject matter and in terms of the analyses carried out and inferences drawn.

DATA AND METHODOLOGY

The data for the study is obtained from the Web of Science (WoS) database. Publication years from 2011 to 2020 are selected for query and data download. The query used was "Artificial Intelligence", with the document type set as "article" and publication year set to "XXXX". Here, XXXX varied from 2011 to 2020. The document type "article" was selected as we were primarily interested in journal articles reporting research in AI. The data download was done in the month of October 2021.

A total of 20,742 publication records were downloaded. From this data, a ranked list of journals and their corresponding articles for each year is identified by using the "SO" and "TP" fields of metadata. To see how the publications varied by year, we plotted publications graphs. The next task was to observe the applicability of the Bradford Law on each recorded year-by-year list.

The Leimkuhler model, as described earlier, was applied to understand the patterns of Bradford law on AI literature. Section 2 presents the model's specifics as well as the equations utilised. To start verification of law, we must first provide the value of "p." The Bradford Multiplier (k) was then determined using equation 5 and its value was used to divide the literature into various groups. Further, we determined y_0 and r_0 using equations 6 and 7. After evaluating each of these values, we used equations 2 and 3 to calculate the constants (a and b) of the Leimkuhler law. Once all of these computations have been completed for a single year, the process is repeated for the data from other years. These calculations give the distributions of journal papers during the designated study period. After that, the dynamics underlying the observed distribution should be understood. To do this, we must track different distribution-related metrics. The detailed methodology followed in this study is summarized in Figure 1.

RESULTS

First of all, the number of journals and the total cumulative number of papers published by them in each year is shown in Table 1. Over the studied years, a general pattern of rise in the number of publications in the field of AI can be seen. In 2011, there were only 597 papers published in 388 journals taken together. By 2020, there were 7927 articles published in total 2377 journals. Thus, the number of articles and journals publishing AI research have both increased.

Table 1 gives a glimpse of the journals and research publications (i.e., articles) listed under the AI domain. We visualized these pieces of information and examined the development of the AI literature from 2011 to 2020 to gain additional insights. Its growth was linear in the first year (until 2015), but in the last five years, it has taken on an exponentially growing shape, which is a definite sign of the expansion of AI-based research over time. We have applied Bradford law on the year-wise

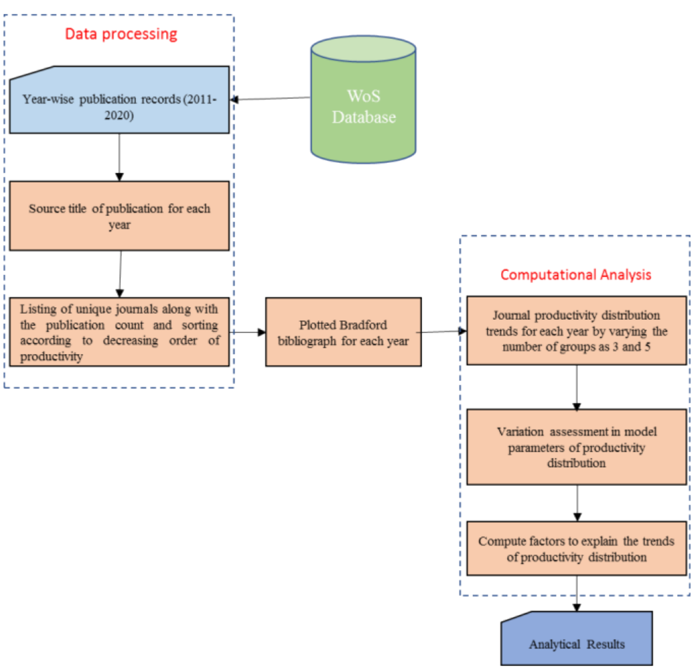

Figure 1: Methodological steps followed for the analysis.

Table 1: Representation of total no. of articles and journals recorded in each year.

Year	No. of articles (A)	No. of journal titles (T)
2011	597	388
2012	669	408
2013	749	459
2014	848	477
2015	873	557
2016	1013	591
2017	1358	722
2018	2310	1077
2019	4353	1678
2020	7972	2377

ranked data to conduct a more thorough examination of the publication span of AI literature.

We first plotted the data for each year in order to see the scattering pattern before using the Bradford law equations. Leimkuhler Curves were plotted for yearly data to observe the distributional pattern necessary for the applicability of the Bradford Law of scattering (see supplementary information).

The next step is to use the Leimkuhler model to apply the Bradford law after it has been confirmed using plots. In order to apply Leimkuhler equations, we must first decide how many Bradford groupings will be there. We settled on two values of "p" for this study as 3 and 5, respectively, for cases 1 and 2.

Case 1

Take into account the data for the year 2011, in the first scenario values are computed as,

$$\begin{aligned} k &= (1.781 Y_m)^{1/p} \\ &= (1.781 * 45)^{1/3} \\ &= 4.31 \end{aligned} \qquad \text{from eqn. 5}$$

$$\begin{aligned} Y_0 &= \frac{A}{p} \\ &= \frac{597}{3} \\ &= 199 \end{aligned} \qquad \text{from eqn. 6}$$

$$\begin{aligned} r_0 &= \frac{T(k-1)}{k^p - 1} \\ &= \frac{388(4.31-1)}{4.31^2 - 1} \\ &= 16.24 \end{aligned} \qquad \text{from eqn. 7}$$

$$u = \left(\frac{6p}{n^2}\right) * \log k = \frac{6*3}{3.14^2}\log 4.31 = 1.16$$ from eqn. 8

$$a = \frac{y_0}{\log k} = \frac{199}{\log 4.31} = 341.11$$ from eqn. 2

$$b = \frac{(k-1)}{r_0} = \frac{4.31-1}{16.24} = 0.1$$ from eqn. 3

From Table 2, we observed that for the year 2011, the number of journals in nucleus zone is 16.24 and the value of Bradford multiplier is 4.31. Therefore, the Bradford distribution is written as:

$$16.24: 16.24*(4.31): 16.24*(4.31)^2 = 1: k: k^2$$

i.e., 16.24: 69.99: 301.67

According to the given distribution, each zone receives an increase in the number of journals publishing articles of 4.31. The results of the zonal analysis show that the first zone has about 16 journals, the second zone has 70 journals, and the third zone has 302 journals. We can interpret the distribution for other years in a similar way. For detailed calculations, please refer to Table 2.

Case 2

The experiment was then repeated with five groups (p=5). Consider the data for the year 2011, then values are computed as,

Table 2: Journal productivity distribution with three groups.

Year	First Group	Second Group	Third Group
2011	16.24	69.99	301.67
2012	19.43	77.72	310.88
2013	28.07	96.84	334.1
2014	28.48	99.68	348.88
2015	41.72	127.25	388.11
2016	33.04	120.27	437.78
2017	29.51	128.96	563.56
2018	30.8	164.78	881.57
2019	23.53	185.89	1468.53
2020	23.78	224.96	2128.12

$$k = (1.781 Y_m)^{1/p} = (1.781 * 45)^{1/5} = 2.4$$ from eqn. 5

$$Y_0 = \frac{A}{p} = \frac{597}{5} = 119.4$$ from eqn. 6

$$r_0 = \frac{T(k-1)}{k^p - 1} = \frac{388(2.4-1)}{2.4^5 - 1} = 6.91$$ from eqn. 7

$$\mu = \left(\frac{6p}{\pi^2}\right) * \log k = \frac{6*5}{3.14^2}\log 2.4 = 0.96$$ from eqn. 8

$$a = \frac{y_0}{\log k} = \frac{119.4}{\log 2.4} = 314.04$$ from eqn. 2

$$b = \frac{(k-1)}{r_0} = \frac{2.4-1}{6.91} = 0.2$$ from eqn. 3

From Table 3, we observed that for the year 2011, the number of journals in nucleus zone is 16.24 and the value of Bradford multiplier is 2.4. Therefore, the Bradford distribution is written as:

$$6.91: 6.91*(2.4): 6.91*(2.4)^2: 6.91*(2.4)^3: 6.91*(2.4)^4 = 1: k: k^2: k^3: k^4$$

i.e., 6.91: 16.58: 39.80: 95.52: 229.25

According to the aforementioned distribution, there are 2.4 times as many journals providing papers to each zone. The results of the zonal analysis show that the first zone has approximately 7 journals, the second zone contains 16 journals, the third zone contains 40 journals, the fourth zone contains approximately 96 journals and about 229 journals are included in the fifth zone. We can also interpret the distribution for other years in a similar way. For further details please refer to Table 3.

Table 3: Journal productivity distribution with five groups.

Year	First Group	Second Group	Third Group	Fourth Group	Fifth Group
2011	6.91	16.58	39.79	95.5	229.2
2012	8.37	19.25	44.28	101.84	234.23
2013	12.67	26.61	55.88	117.35	246.44
2014	12.77	27.07	57.39	121.67	257.94
2015	19.46	37.95	74	144.3	281.39
2016	14.68	31.86	69.14	150.03	325.57
2017	12.5	30.25	73.21	177.17	428.75
2018	12.21	33.46	91.68	251.2	688.29
2019	8.34	28.86	99.86	345.52	1195.5
2020	8.02	30.88	118.89	457.73	1762.26

Table 4: Comparing the impact of Bradford groups on parameters.

Year	p=3					p=5				
	k	r_0	μ	a	b	k	r_0	μ	a	b
2011	4.31	16.24	1.16	313.64	0.2	2.4	6.91	1.16	314.04	0.2
2012	4.0	19.43	1.1	370.39	0.15	2.3	8.37	1.1	369.89	0.16
2013	3.45	28.07	0.98	464.23	0.09	2.1	12.67	0.98	464.9	0.09
2014	3.5	28.48	0.99	519.55	0.09	2.12	12.77	0.99	519.71	0.09
2015	3.05	41.72	0.88	600.87	0.05	1.95	19.46	0.88	602	0.05
2016	3.64	33.04	1.02	601.8	0.08	2.17	14.68	1.02	602.15	0.08
2017	4.37	29.51	1.17	706.77	0.11	2.42	12.5	1.17	707.63	0.11
2018	5.35	30.8	1.33	1057.18	0.14	2.74	12.21	1.33	1055.4	0.14
2019	7.9	23.53	1.64	1616.48	0.29	3.46	8.34	1.64	1614.99	0.29
2020	9.46	23.78	1.78	2722.98	0.36	3.85	8.02	1.78	2723.33	0.36

Next, we traced the values of several parameters of Leimkuhler model and tried to identify significant variances that emerged when "p" was changed from 3 to 5. We deduced that all of these parameters are explained by "p" based on the equations provided by the model. Therefore, we wanted to examine how p affected these factors. In order to achieve this, we organised the values of the parameters such as Bradford multiplier (k), number of core journals (r_0), average productivity (μ), and Leimkuhler equations constants (a and b) in the Table 4 in a year-by-year fashion.

Table 4 shows that variations in "p" have an impact on both the values of "k" and the sizes of each group. One thing to note is that changes in "p" have an impact on all of the parameters, including r_0, k_{ij}, a and b (as observed from equations). Since changes in p directly affect r_0 and k, we obtained different values of the parameters in both scenarios. However, the values of "a"," "b", "μ " and "kij" had an indirect impact on "p" thus we didn't notice much variation in their values. Since the size of the data directly affects the multiplier's value, as a result, we discovered that the multiplier value decreased with decreasing data.

Table 4 also demonstrated that in past five years the average no. of articles per journal (i.e., μ) increased in frequency which concluded that in addition to an increase in the number of journals, there has also been an increase in the number of articles published in each journal over the previous five years. This lends credence to the claim that the nature of the article distribution curve has changed during the past five years. Additionally, we noticed that the Bradford Multiplier's value also increased from 2011 to 2020, indicating that the publication span (or width) of the AI literature has grown over the past few years.

Table 4 showed that the Bradford multiplier's value is dependent on the Bradford groups, or that the multiplier k is group dependent. Egghe[17] introduced the idea of "group free multiplier" to eliminate such dependence. The Leimkuhler equation, which is defined as follows, was also used to describe this idea.

$$k = (1.781\ Ym)^{1/p}$$

So, we can rewrite it as

Table 5: Demonstration of Bradford multiplier and group free Bradford multiplier.

Year	p=3		p=5	
	k	k^p	k	k^p
2011	4.31	80.06	2.4	79.63
2012	4	64	2.3	64.36
2013	3.45	41.06	2.1	40.84
2014	3.5	42.88	2.12	42.82
2015	3.05	28.37	1.95	28.2
2016	3.64	48.23	2.17	48.12
2017	4.37	83.45	2.42	83
2018	5.35	153.13	2.74	154.44
2019	7.9	493.04	3.46	495.88
2020	9.46	846.59	3.85	845.87

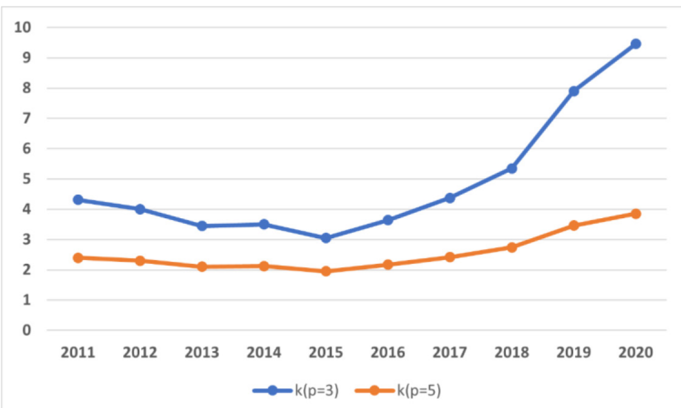

Figure 2: Impact of different no. of Groups on Bradford Multipliers.

$$k^p = 1.781 * Y_m$$

Here k^p can be treated as "group free Bradford multiplier".

Table 5 shows that although "k" has a distinct value in each case, the values are nearly identical when we evaluate k^p. This leads us to the conclusion that even if different groupings result in different individual values for k, the overall proportion is conserved. Additionally, these findings show that in this situation, the group free Bradford multiplier notion is valid. We also plotted the variation in "k" against the change in "p."

Figure 2 represented that despite the individual values of k being impacted by the change in p, the trend that k for the given bibliography follows, is preserved. This indicates that the distributional trend of k is essentially the same.

Table 1, Figure 1, and Table 4 already show that the nature of the distribution changed as a result of changing time windows, which leads to the logical conclusion that, if such variations are seen over time, how will the dynamics of the productivity distribution be explained? In order to respond to this argument, we used the strategy that is described by Vuković(1992).[51] The work addressed the distribution behavior by elaborating on a number of characteristics.

Some of these characteristics and their interpretations are described below-

Proportion between the number of the lowest productive journals and maximal value of variable y_m i.e., the maximum number of publications assigned to a journal. Here "a" is total number of journals containing only one paper.

Periphery\core ratio (p\c) - The relationship between two opposing effects, such as paper concentration against dispersion, is quantified using this attribute. This ratio identifies the breadth of subject categories covered by publications in the domain.

The table below organises the computations for these defined characteristics.

Table 6 showed that when the number of publications increase over time, the concentration of the most prolific journal also rises (as described by column 2). Additionally, it is evident that when the overall number of journals rises, the proportion of journals having only one article gradually declines (as described by column 5). It is also observed that the journals having one article (see column 3) increased more or less steadily during the study period.

The decreasing a/ym (column 6) values and noticeably rising values of y_m showed a clear tendency toward increasing article concentration for each publication over time. These characteristics showed a rapid growth in the amount of AI literature during the ten-year timeframe. However, the ratio of number of journals in the peripheral groups to core groups (periphery/core) has increased fast, demonstrating how the application base for AI has expanded over time.

The expanding body of literature on Artificial Intelligence (AI) (number of papers and journals) and the range of its applications are both shown by the declining values of a/ym and the significantly greater values of p/c and ym (width of coverage). The claim that the scope of disciplines covered by AI literature broadened over time is supported by this quantitative investigation. Further to elaborate the insights of these quantitative results, we tried to map these groupings with the actual journal titles i.e., the journal names, for the years 2011 and 2020. Results indicate that there is a transition among the journals of varied groupings for the year 2011 and 2020 i.e., there are several journals that lies in the periphery of 2011 that will now lies in the core and allied groups of 2020. They expand their capabilities of publishing the literature related to AI over the time and become important in the field of AI. However, few journals of core groups of 2011 would disappear in the list of journals in 2020 (Table 7).

Table 6: Characteristics of journal productivity distribution.

(1) Year	(2) y_m	(3) No. of journals having 1 article ("a")	(4) a/A	(5) a/T	(6) a/y_m	(7) No. of core journals ("c")	(8) No. of periphery journals ("p")	(9) Periphery\Core ratio (p\c)
2011	45	299	0.5	0.77	6.64	17	301	17.71
2012	36	298	0.45	0.73	8.28	20	310	15.5
2013	23	336	0.45	0.73	14.61	28	334	11.93
2014	24	332	0.39	0.70	13.83	29	348	12
2015	16	411	0.47	0.74	25.69	42	388	9.24
2016	27	422	0.42	0.71	15.63	33	438	13.27
2017	47	503	0.37	0.70	10.7	29	564	19.45
2018	86	720	0.31	0.67	8.37	30	882	29.4
2019	277	1058	0.24	0.63	3.82	23	1469	63.87
2020	476	1329	0.17	0.56	2.79	24	2128	88.67

Table 7: Journal Transition between the Core, Allied and Periphery group for the year 2011 and 2020.

Journals	Transition
Sensors	$P_{2011} \rightarrow C_{2020}$
Multimedia Tools and Applications	$P_{2011} \rightarrow C_{2020}$
Neural Computing & Applications	$P_{2011} \rightarrow C_{2020}$
Renewable Energy	$P_{2011} \rightarrow A_{2020}$
Knowledge Based Systems	$P_{2011} \rightarrow A_{2020}$
Journal of Mechanics	$P_{2011} \rightarrow$ *No more in list*
Journal of Real Estate	$P_{2011} \rightarrow$ *No more in list*
Journal of Social Issues	$P_{2011} \rightarrow$ *No more in list*
IEEE Latin America Transactions	$C_{2011} \rightarrow A_{2020}$
International journal of innovative computing information and control	$C_{2011} \rightarrow$ *No more in list*
Journal of natural gas science and engineering	$C_{2011} \rightarrow A_{2020}$

Note: Here, C_{XXXX} denotes Journal in the Core group for year XXXX; A_{XXXX} denotes Journal in the Allied group for year XXXX and; P_{XXXX} = Journal in the Periphery group for year XXXX.

Additionally, journals from a variety of different fields, such as Science and Public Policy, Plant Pathology, Polymer, Nanoethics, Molecular Imaging and Biology, Safety Sciences, Nutrients, Mechanism and Machine Theory, Management Decision, and others are included in the periphery group for the year 2020. These journals are related to disciplines that are not typically associated with artificial intelligence, but these disciplines are now started using AI tools and techniques to solve the problems related to the specific field. Thus, growth in AI research is characterized not only in terms of growth in volume of published articles but also in terms of expanding publication span of AI research in various disciplines and subject areas.

CONCLUSION

This study attempted to examine the literature in the field of AI research and has found that the corpus has grown in terms of the volume of papers produced annually. Bradford's law is applied to data using the Leimkuhler model and the scattering of literature is observed with two distinct numbers of groupings, namely 3 and 5. The observed ratio for p=3 grouping is 1: k: k^2, and for p=5 grouping is 1: k: k^2: k^3: k^4 (Table 3). When comparing the parameters of the two cases, we found that while the individual values of k may differ in cases of various groupings, the trend followed by the various values of k will remain conserved, i.e., we observed the same trend line in both cases. Therefore, we came to the conclusion that the final fraction of k's values is still conserved (Figure 2). The study shows that during the recent 5 years, there is rapid growth in AI literature. The number of articles published in each journal as well as the average number of articles per journal (i.e., μ) are both increasing, which could be one of the contributory factors in exponential growth of AI literature. On further analysis, the concentration and dispersion of research journals in the three productivity groups also showed an upwards trend indicating an increase in research activity. Further quantitative analysis of data distribution (see Table 6) shows that the concentration in AI literature has grown over time.

Thus, the results confirm that increase in AI research can be attributed not only to increase in volume of articles but also to wider application of AI in a wide range of disciplines and subject areas. In other words, the growth in AI research can be characterized in terms of increase in its publication span, suggesting application of AI techniques to a wide variety of domains and areas. The observed patterns thus help in answering the two research questions proposed. AI techniques are seen to have expanded in their applicability across various other problem domains which may not have been traditionally an application area of AI research. Further, research can be carried out on application of AI in different areas using quantitative/ qualitative as well as domain specific studies.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Supplementary Data

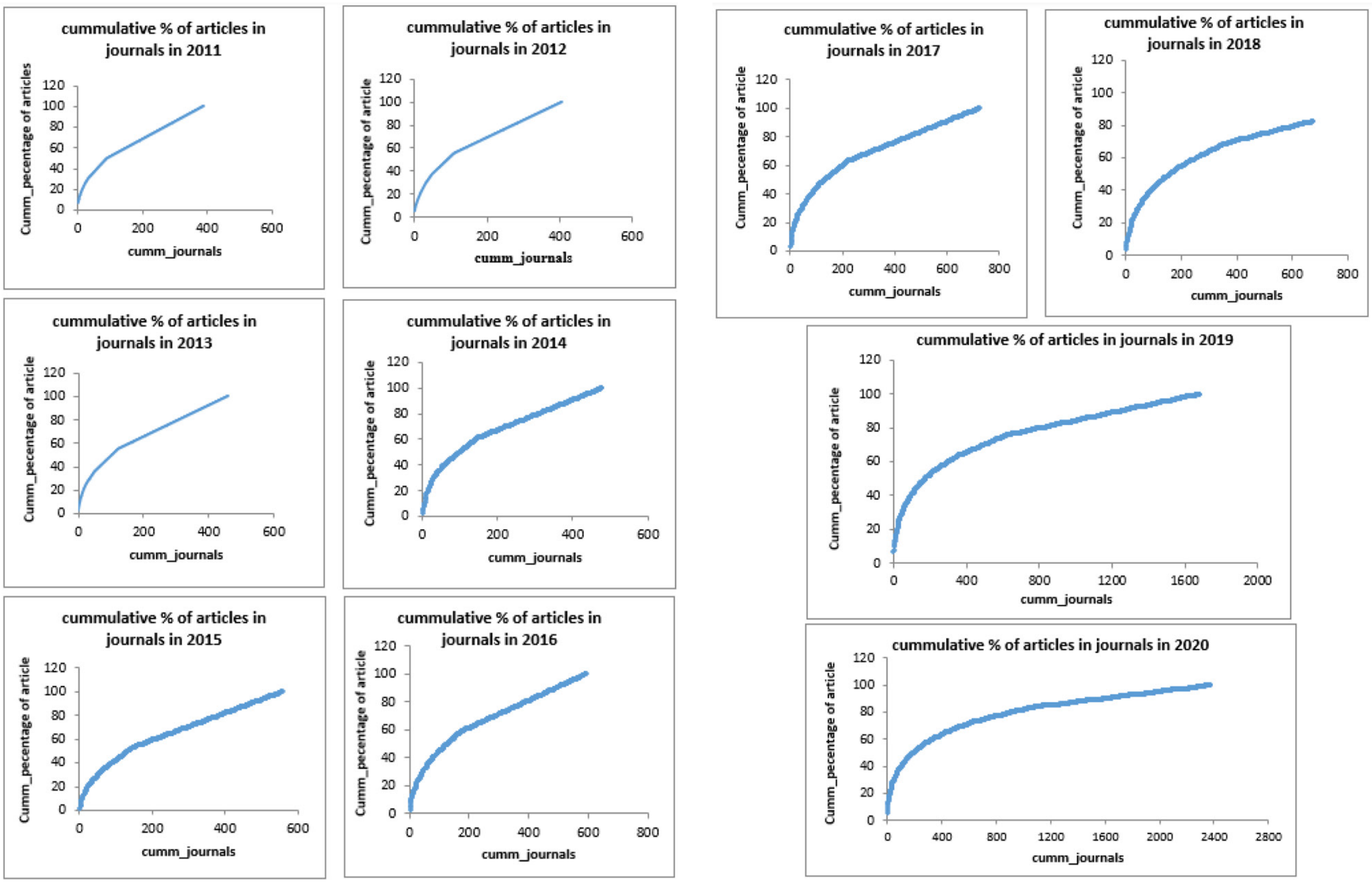

Figure S1: Graphical demonstration of Year wise Leimkuhler Curves of Bradford distribution.