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PRODUCTIVITY OF MANAGEMENT INFORMATION SYSTEMS RESEARCHERS: DOES LOTKA'S LAW APPLY?

RAVINDER NATH and WADE M. JACKSON
Department of Management Information Systems and Decision Sciences,
Fogelman College of Business and Economics, Memphis State University,
Memphis, TN 38152, USA

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Abstract—By examining 899 Management Information Systems (MIS) research articles published in ten journals between 1975 and 1987, it is shown that while Lotka's inverse-square law relating the number of authors of papers to the number of papers written by each author does not apply, a generalized version of Lotka's law referred to as the inverse-power law fits remarkably well.

While investigating and attempting to determine "if possible, the part which men of different calibre contribute to the progress of science," Alfred J. Lotka in 1926 summarized his findings (Lotka, 1926):

> In the cases examined, it is found that the number of persons making 2 contributions is about one-fourth of those making one; the number making three contributions is about one-ninth, etc.; the number making n contributions is about $1/n^2$ of making one; and the proportion, of all contributions, that make a single contribution, is about 60 percent. (p. 323)

In other words, if 100 authors contributed one paper each, the number of authors contributing two papers each would be 25 ($100/2^2$), the number of authors contributing three papers each would be about 11 ($100/2^3 = 11.1$), the number of authors contributing four papers each would be about 6 ($100/2^4 = 6.25$), and so on. This assertion is referred to as Lotka's inverse-square law and can be mathematically expressed as

$$a_n = (6/\pi^2)1/n^2, \qquad n = 1,2,3,\ldots, \tag{1}$$

where a_n is the proportion of authors making n contributions each. Furthermore, in a footnote, Lotka (1926) noted that "joint contributions have in all cases been credited to the senior author only."

In a generalized form Lotka's law (commonly referred to as Lotka's inverse-power law) was presented by Bookstein (1977):

$$a_n = c/n^b, \qquad n = 1,2,3,\ldots, \tag{2}$$

where b and c are constants to be estimated from a given set of data. Lotka asserted that eqn. 2 applies to a variety of fields. But by considering two data sets from two different areas—physics and chemistry—he formulated the rule as given in eqn. 1.

In the literature, there exist many studies covering a myriad of disciplines that have investigated the applicability of Lotka's inverse-square law to the research productivity of authors (Murphy, 1973; Radhakrishnan & Kernizan, 1979; Schorr, 1974, 1975a, 1975b; Subramanyam, 1979; Voos, 1974; Worthen, 1978). Coile (1975, 1977) has correctly pointed out that the results reported by Murphy (1973), Schorr (1974), and Voos (1974) are flawed. Contrary to the claims made by the authors of these three papers, Coile shows that Lotka's inverse-square law does not apply to the data given in these publications.

While in some cases Lotka's inverse-square law holds, in others it does not. Radhakrishnan and Kernizan (1979) showed that for computer science literature, the inverse-square law does not fare well when applied to individual journal data. In a subsequent

study, however, Subramanyam (1979) showed that the computer science literature does conform to this law if data taken from a large collection of journals and papers with multiple authors are credited to the first author only (as was done by Lotka).

Pao (1985) proposed a five-step testing procedure for "fitting" Lotka's inverse-power rule given by eqn. 2. These steps are follows:

1. Create a frequency table consisting of pairs (n, a_n) where n represents the number of papers and a_n is the number of senior authors writing n papers each.
2. Adopt Lotka's inverse-power law as given in eqn. 2.
3. The parameter b is estimated by the least-squares method in the simple regression model:

$$\log a_n = \log c - b \log n, \qquad n = 1,2,3,\ldots$$

   In estimating b, the part of the data for prolific authors is excluded. Pao (1985) recommends that the cutoff point be determined by visually inspecting the data so that the linearity of the above equation is optimized. Nicholls (1986) advocates a formal criterion. He suggests truncating the data at the first $a_n = 1$.
4. The parameter c is determined by

$$c^{-1} = \sum n^{-b}, \qquad n = 1,2,3\ldots.$$

   Pao provides an excellent approximation for this infinite series as follows:

$$c^{-1} = \sum_{n=1}^{19} n^{-b} + (1/(b-1))(20^{b-1}) + (1/2)(20^b) + (b/24)(19^{b+1}).$$

5. Apply the Kolmogorov-Smirnov (K-S) goodness-of-fit test to ascertain whether the data fits the model.

In this paper we test the appropriateness of Lotka's inverse-power law as applied to the field of Management Information Systems (MIS). The discipline of MIS is barely 20 years old. Dickson (1981) describes the evolution of the field of MIS. There exist a limited number of studies that have analyzed the MIS literature and the publication patterns of MIS researchers. This can perhaps be attributed to the newness and the interdisciplinary nature of the field of MIS. In a 1986 paper, Culnan and Swanson (1986) analyzed 271 MIS papers published during 1980–1984 and found three foundational fields underlying the research work in MIS. These fields are computer science, management science, and organizational science. In two other studies (Culnan, 1986, 1987), she reports on the results of a co-citation analysis of MIS publications. In one (Culnan, 1986), she discusses the development of the field of MIS by identifying the current and past MIS research themes. A weak link is reported between the organization theory and the published MIS work. The second study (Culnan, 1987) identifies subfields of MIS and using factor analysis bonds MIS researchers with each subfield. Hamilton and Ives (1982) studied knowledge utilization among MIS researchers by examining references in 532 MIS papers published in 15 journals during 1970–1979. They report summary statistics concerning the number of references per article, number and frequency of cross discipline references, and time gap between citing and cited articles. In another investigation, Hamilton and Ives (1983) categorize MIS publication outlets using several measures, which include opinions of MIS experts, and results of citation analysis (how often the publication is cited). Vogel and Wetherbe (1984) consider the leading MIS journals and identify those universities whose researchers frequently publish their research articles in these journals. In a recent study Farhoomand (1987) has chartered the progress of the MIS field as evidenced by the research strategies (field experiments, lab experiments, survey, case, etc.) employed in 536 MIS papers published in six journals during 1977–1985. A major finding of this research is that MIS re-

search has moved towards empirical studies from nonempirical ones during the time period studied.

None of the aforementioned studies has considered the publication patterns of MIS researchers and whether the number of articles published follow certain trends. The research presented here does this. The primary purpose of this investigation is to examine the applicability of Lotka's law to the research productivity of MIS researchers. A measure of research productivity is taken to be the number of MIS articles published. As side issues, we examine and compare three different methods of counting an MIS researcher's journal publications. Also, we report the percent of solo- and multiple-authored MIS papers published in various MIS journals.

DATA COLLECTION

There exist a myriad of publication outlets for research in MIS. It would be nearly impossible to examine and collect data from all these sources. Therefore, to keep the study at a manageable level, ten journals rated by Hamilton and Ives (1983) as the most desirable publication outlets for MIS researchers were considered. Table 1 lists the ten journals. Because of the relative newness of the field of MIS, we focused on the MIS papers published during the period 1975–1987. Since two journals—Management Information Systems Quarterly (MISQ) and Information & Management exclusively publish MIS articles, all papers published in these two journals were included. From the rest of the journals, those articles whose titles and the accompanying list of the key words indicated that they were MIS papers, were selected. The two authors, independently, scanned these journals and identified the MIS papers. Each author used his own judgment in deciding whether or not a paper fits the MIS category. In a few cases the two raters disagreed; then, a third faculty member's opinion was sought and his judgment ruled. This process resulted in identifying 899 MIS articles from the ten journals. A breakdown of the number of articles by journal also appears in Table 1. A majority of the MIS articles (56%) appear in two journals: Information & Management, and MISQ.

In order to ascertain the degree and extent of jointly published MIS work appearing in the ten journals, percents of solo, two-author, three-author, and four- or more-author articles are given in Table 2 for each journal. Sloan Management Review and Harvard Business Review have published the highest percentage of solo MIS articles (70% and 64%, respectively); the lowest percentage is for Management Science (29%). Academy of Management Review, and Management Science are tied for the highest percent (60%) of two-author MIS papers; Sloan Management Review has the lowest (27%). Decision Sciences has the largest percent of MIS papers with three or more authors (28%).

Table 1. A list of journals publishing MIS articles

Journal	# of MIS articles (1975–87)	% of total
Information & Management	271	30.1
MIS Quarterly	235	26.1
Journal of MIS[1]	99	11.0
Communications of the ACM	80	8.9
Sloan Management Review	60	6.7
Havard Business Review	50	5.6
Management Science	45	5.0
Decision Sciences	39	4.3
Academy of Management Journal	15	1.7
Academy of Management Review	5	0.6
Totals:	899	100

[1]Journal of MIS first appeared in 1984.

Table 2. A breakdown of joint MIS publications

Journal	Number of authors			
	1	2	3	4 or more
Information & Management	49%	39%	10%	2%
MIS Quarterly	46	42	10	2
Journal of MIS	44	43	10	3
Communications of the ACM	36	48	13	3
Sloan Management Review	70	27	2	1
Harvard Business Review	64	34	2	0
Management Science	29	60	9	2
Decision Sciences	36	36	26	2
Academy of Management Journal	47	53	0	0
Academy of Management Review	40	60	0	0
Overall	47	41	10	2

MULTIPLE AUTHORSHIP

The results given above show that a significant number of MIS publications are published jointly. According to Price (1963), in a discipline, a shift towards multiple authorship is a salient feature of a movement from "little science" to "big science." However, multiple authorship raises the issue of how the multiple-authored articles should be treated. Traditionally, each author of an article has received full credit (i.e., if an article has three authors, the paper counts as one publication for each author). Lindsey (1980) calls this "normal count." Lindsey also discusses two other ways of counting number of publications. These counting procedures are discussed below.

The second counting procedure is used when only the senior researcher receives credit for a publication. It is referred to as the "straight count." This approach disregards all other authors except the first author (who receives all the credit). Obviously, the straight count

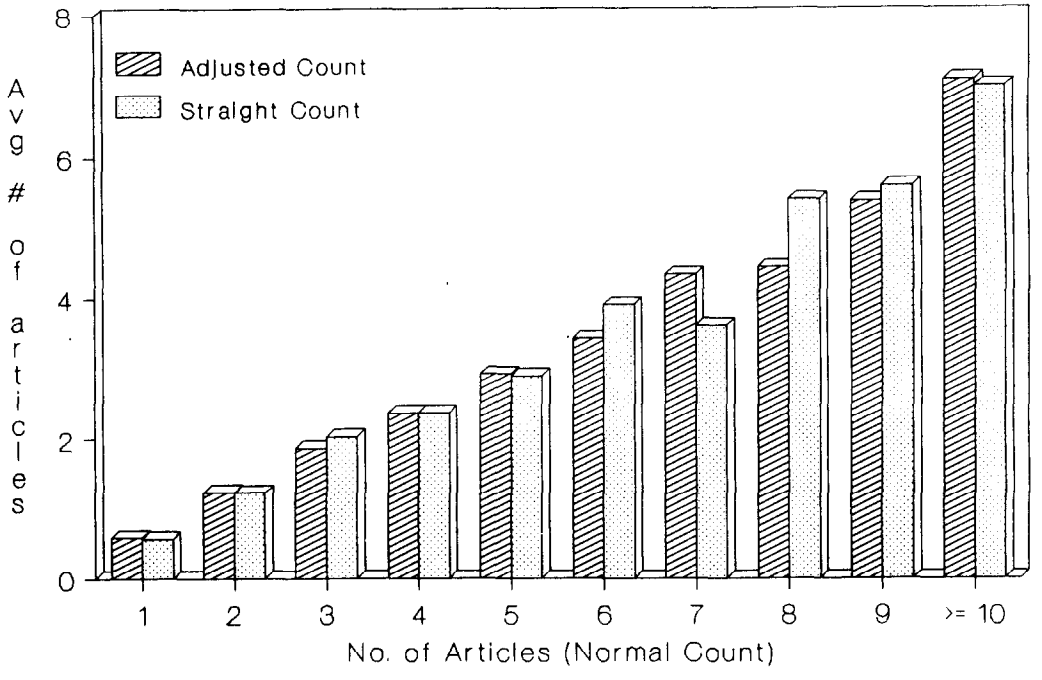

Fig. 1. A comparison of adjusted and straight counts.

is not fair to junior author(s) and thus, in turn perhaps, discriminates against those researchers whose names appear late in an alphabetical listing.

The third counting procedure is named "adjusted count." Each author of a paper receives an equal fraction of the total credit of one. For example, if a paper has four authors, each author is given one-fourth credit. Using this approach an author's total article count can be calculated as:

$$\text{Adjusted article count} = \sum_{i=1}^{k} (1/n_i)$$

where n_i represents the number of authors of article i, and $i = 1, 2, \ldots, k$ represents the articles by the author. This measure ignores the relative contribution (if any) of each author to the article. It assumes that each author contributed equally to the paper and adjusts for coauthorships, unlike normal count.

To compare the three measures, the normal, adjusted, and straight counts for each of the 910 authors were computed. Then the adjusted and straight counts were averaged over all authors having a normal count of one, two, etc. This information is graphically depicted in Fig. 1. Clearly there does not appear to be much difference between the averages of adjusted and straight counts for authors. That means the two measures essentially gauge the same thing and therefore it could be argued that we need not consider adjusted counts and should simply focus on the straight counts (number of solo or first-authored articles).

LOTKA'S LAW AND MIS RESEARCH

Does Lotka's inverse-square law as given by eqn. 1 apply to MIS researchers' productivity? Following Lotka's assertion, we test it only for "straight" count data (senior author receives all credit). Also, the Kolmogorov-Smirnov (K-S) goodness-of-fit test is used to test

Table 3. Lotka's inverse-square law for MIS researchers using "straight" count*

# Papers	# Authors	% Authors	$S_N(X)$[1]	$F_O(X)$[1]	$D(X) = S_N(X) - F_O(X)$
1	439	73.91	.7391	.6079	.1312
2	91	15.32	.8923	.7599	.1324
3	30	5.05	.9428	.8274	.1154
4	14	2.36	.9664	.8654	.1010
5	7	1.18	.9782	.8897	.0885
6	7	1.18	.9900	.9066	.0834
7	3	0.51	.9951	.9190	.0760
8	0	0.00	.9951	.9285	.0666
9	1	0.17	.9968	.9360	.0608
10	0	0.00	.9968	.9421	.0547
11	0	0.00	.9968	.9472	.0496
12	1	0.17	.9985	.9514	.0471
13	1	0.17	1.0002	.9549	.0453
Totals:	594	100.02			

$D = \max |D(X)| = .1324$

$N = 594$

Critical value at the .01 level = .0669.
The K-S test is significant showing that Lotka's inverse-square does not hold.

*316 authors out of a total of 910 who published MIS papers did not have a solo or a first-authored paper.

[1] $F_O(X)$ = The theoretical cumulative distribution function dictated by Lotka's law $f(X) = (6/\pi^2)\ 1/X^2$. For example, for one author $(X = 1)$, $F_O(X) = f(1) = .6079$; for two authors $(X = 2)$, $F_O(X) = f(1) + f(2) = .6079 + .1520 = .7599$; and so on.

$S_N(X)$ = The sample-based cumulative distribution function. For example, for one author $(X = 1)$, $S_N(X) = 439/594 = .7391$; for two authors $(X = 2)$, $S_N(X) = (439/594) + (91/594) = .8923$; and so on.

Table 4. Lotka's inverse-power law for MIS researchers

# Papers	# Authors	% Authors	$S_N(X)$[1]	$F_O(X)$[1]	$D(X) = S_N(X) - F_O(X)$
1	439	73.91	.7391	.7775	−.0384
2	91	15.32	.8923	.9005	−.0082
3	30	5.05	.9428	.9423	.0005
4	14	2.36	.9664	.9618	.0046
5	7	1.18	.9782	.9726	.0056
6	7	1.18	.9900	.9792	.0008
7	3	0.51	.9951	.9836	.0015
8	0	0.00	.9951	.9867	.0084
9	1	0.17	.9968	.9890	.0078
10	0	0.00	.9968	.9907	.0061
11	0	0.00	.9968	.9920	.0048
12	1	0.17	.9985	.9930	.0055
13	1	0.17	1.0002	.9938	.0064
Totals:	594	100.02			

$D = \max |D(X)| = .0384$

$N = 594$

Critical value at the .01 level = .0669. Not significant, indicating that the law applies.

[1] $F_O(X)$ = The theoretical cumulative distribution function dictated by Lotka's law $f(X) = .7775/X^{2.66}$. For example, for one author ($X = 1$), $F_O(X) = f(1) = .7775$; for two authors ($X = 2$), $F_O(X) = f(1) + f(2) = .7775 + .1230 = .9005$; and so on.
Description of $S_N(X)$ is the same as given in Table 3.

the hypothesis that the data should fit Lotka's inverse-square law. Table 3 reports these results. At the .01 level, the K-S statistic is significant, indicating that the data do not conform to Lotka's theoretical distribution. Furthermore, when publications for each journal were individually considered, Lotka's inverse-square law failed to apply in all cases except one. Harvard Business Review was the only journal where it fits.

The next question is whether or not Lotka's inverse-power law holds. If it does, then what are the estimated values of parameters b and c in eqn. 2? Using Pao's (1985) procedure as given earlier in this paper and the data from Table 3, we found $b = 2.66$ and $c = .7775$. In estimating these values, Nicholls' (1986) recommendation was followed and the data were truncated at $n = 9$ (the first $a_n = 1$). Table 4 shows the details of the K-S test. The K-S test is not significant ($p > .20$), implying that the inverse-power law with $b = 2.66$ and $c = .7775$ applies.

Table 5 reports the estimated values of b and c for individual journals. In each case the inverse-power law held as indicated by the K-S test (details of the K-S tests are omitted). As pointed out earlier, in the case of *Harvard Business Review* (*HBR*), the inverse-square law holds. This indicates that unlike other journals, once an MIS researcher publishes an article in *HBR*, the probability of his/her publishing more articles in *HBR* increases. This is attributable to the fact that a selected number of MIS researchers have repeatedly published MIS articles in *HBR*. This can be demonstrated by taking the total number of MIS articles published in *HBR* and dividing it by the total number of distinct

Table 5. Lotka's law for individual journals

Journal	Parameters	
	b	c
Information & Management	3.22	.8593
MIS Quarterly	3.12	.8475
Communications of the ACM	3.82	.9125
Sloan Management Review	2.19	.6680
Management Science	3.20	.8571
Decision Sciences	3.12	.8475

authors writing these articles. For *HBR* this figure turns out to be 1.14 (50 papers/44 distinct authors) papers per author. *Sloan Management Review* has the second highest figure (.97). The lowest figure is for *Decision Sciences* (.57).

SUMMARY AND DISCUSSION

In this study we have considered the problem of bibliometric prediction. By examining 899 MIS articles published in ten journals during the period 1975–1987, the following conclusions are reached:

1. Lotka's inverse-square law predicting the number of authors making a certain number of contributions to the MIS literature is not valid when we consider publications of the researchers in various journals. However, the inverse-power law with parameters $b = 2.66$ and $c = .7774$ appears to provide a good fit.
2. When publications are considered on a journal-by-journal basis, Lotka's inverse-square law still does not fit. An exception to this rule is the publications in *Harvard Business Review*, for which the inverse-square law holds. An explanation for this deviation is that the same authors have repeatedly published MIS articles in HBR.

The results presented here should be interpreted in light of the fact that this study did not consider all journals publishing MIS papers. Only "mainstream" journals, which have emerged as the leading publication outlets for MIS researchers were used. By including other journals, the results or the conclusions of this study could possibly change.

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