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BRADFORD'S LAW IN RELATION TO THE EVOLUTION OF A FIELD. A CASE STUDY OF SOLAR POWER RESEARCH

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Based on the data of growth of literature in the field of solar power, the present paper investigates the stage of evolution at which the scattering of articles over journals is similar to Bradford's curve, i.e. the stage at which Bradford's law is valid. Traces the related changes that take place in the size and elements of the core during the evolution and growth of literature. The study reveals that a curve similar to Bradford's curve is obtained when the field matures. The finding has been supported with the help of a simple mathematical model.

Introduction

Bradford first formulated his law of scattering in 1934,[1] which received wide attention only after the publication of his book *Documentation* in 1948.[2] The law describes a quantitative relationship between the journals and the papers they publish. Two widely recognized formulations of the Bradford's law are: (i) the verbal formulation, derived from the verbal statement of Bradford's conclusions, and (ii) the graphical formulation, derived from the graph of a distribution of papers over periodicals. Bradford's verbal expression as originally stated reads: "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 particularly devoted to the subject and several groups or zones containing the same number of articles as the nucleus, then the number of periodicals in the nucleus and succeeding zones will be as 1: n: n^2 ..... ."

The graphical formulation is obtained by plotting a curve in a plane whose coordinates are the cumulative number of articles (in the y-axis) and the logarithm of the cumulative number of journals of the collection (in the x-axis), where journals are cumulated from most to least productive. This curve has invariably an ascending shape which, after a certain point, approaches to a straight line. *Vickery*[3] was the first to point out that the graph provided by *Bradford* was not necessarily equivalent to his

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verbal formulation of the law. Later, *Wilkinson*[4] discussed the ambiguity of Bradford's law in terms of the two different approaches.

A huge body of literature has since been published on Bradford's[5-15] law. The literature published so far can broadly be classified into three categories. These are: (a) validation of Bradford's law, (b) mathematical formulation of the law, (c) application of the law to the management of library. In all the studies of Bradford's law published so far time has not been taken into consideration and, thus, these are in general time independent studies. The need to consider time in scattering studies arises because in the initial stages the number of papers published increases slowly, reaches a maximum during the mature phase and then start declining. During this phase the journals may also proliferate. Therefore, it is logical to investigate how scattering of papers over periodicals changes with time for a field. The need to consider time in scattering studies has earlier been suggested by *Braga*,[16] *Burrel*[17] and more recently by *Oluvic-Vukovic*.[18] *Jain* and *Garg*,[19] however, have modelled the growth of literature, describing the evolution of literature with time.

In the present study, we investigate the nature of scattering of articles over journals using a time dependent bibliography for different stages of development of a research field (Solar Power) for the years 1971, 1974, 1977, 1980, 1983 and 1986. This study would enable us to identify the stage at which the scattering of articles over journals is similar to Bradford's curve, i.e. the stage at which Bradford's law is valid and the related changes in the size and elements of the core during the growth of literature. The stage at which the Bradford's law is valid has been further confirmed by applying *Bass* model[20] to the growth of literature. Solar power has specifically been chosen because its bibliographic data shows all the three stages of growth we are interested in. For instance, during the years 1971 and 1974 the research activity in this field, as reflected by the number of publications was almost negligible. However, after the energy crisis in 1973, the research activity picked up resulting in a rapid growth of literature between 1977 to 1980. The literature output peaked in 1984 and started declining thereafter.[21] Thus, the data shows all the three stages of evolution, growth and decline.

Data collection and methodology

We prepared bibliographies on solar power research for the years 1971, 1974, 1977, 1980, 1983 and 1986 for the papers published in journals from *Engineering Index*. For each bibliography ranked data tables as suggested by *Bradford* were

prepared. These bibliographies were merged in stages for two years (1971, 1974), three years (1971, 1974, 1977), four years (1971, 1974, 1977, 1980), five years (1971, 1974, 1977, 1980, 1983) and six years (1971, 1974, 1977, 1980, 1983, 1986). For each merged bibliography ranked data tables were prepared and for each such table, graphs were drawn in the usual manner on a semilog graph paper (Fig. 1). We compiled bibliographies in gaps for two years presuming that a new journal published in these years must be covered by the bibliography prepared in the succeeding years.

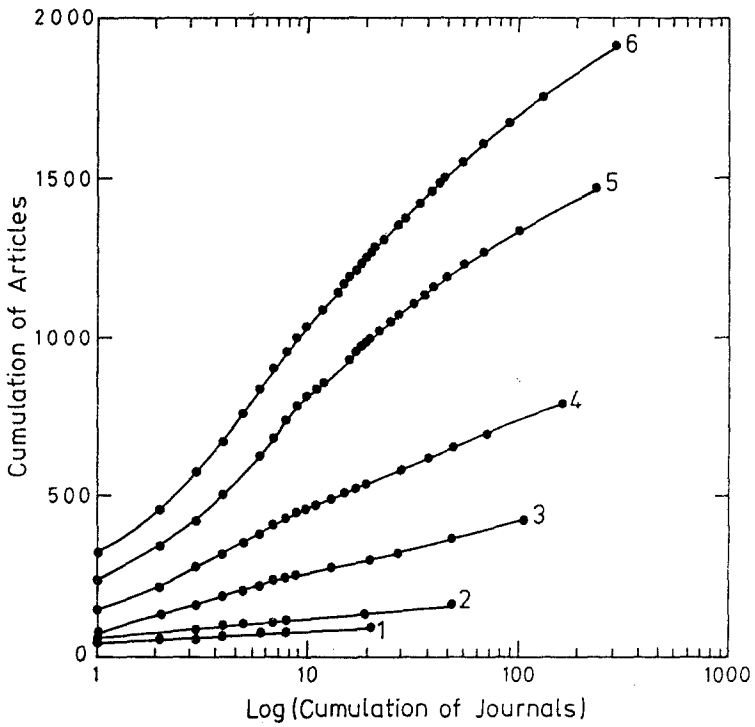

Fig. 1. Scatter of articles over journals for different years. Curves 1 and 2: Scatter of articles over journals for the single year 1971 and the two year (1971, 1974) merged bibliography are linear. Curves 3 and 4: Scatter of articles over journals for the three year (1971, 1974, 1977) and four year (1971, 1974, 1977, 1980) merged bibliographies are also linear with a rising slope. Curves 5 and 6: Scatter of articles over journals for the five year (1971, 1974, 1977, 1980, 1983) and six year (1971, 1974, 1977, 1980, 1983, 1986) merged bibliographies shows a pattern similar to Bradford's curve with a nucleus having 4 core journals

Results

1. For the single year 1971 and the two year (1971, 1974) merged bibliography the nuclear zone is not visible and the curves are linear (Fig. 1 curves 1 and 2).

2. For the three year (1971, 1974, 1977) and four year (1971, 1974, 1977, 1980) merged bibliographies the nuclear zone is not visible and the curves are also linear, with slightly rising slopes. (Fig. 1 curves 3 and 4).

3. For the five-year (1971, 1974, 1977, 1980, 1983) and six year (1971, 1974, 1977, 1980, 1983, 1986) merged bibliographies the curves are Bradfordian with a clear nuclear zone at the bottom and a slight droop at the top and middle portion is a rising straight line. (Fig. 1 curves 5 and 6).

Discussions

For the single year 1971 and the two year (1971, 1974) merged bibliography (Tables 1 and 2), there is only one core journal i.e. *Journal of Geophysical Research* containing 41 and 53 articles, respectively. For these two periods there is no change in the shape of the curves as well as the size and elements of the core, although there is a slight increase in literature during 1974 as compared to 1971.

Table 1
Scatter of Solar Power literature in 1971

A (No. of journals)	B (No. of papers)	C (Cumulation of A)	D (Cumulation of B)
1	41	1	41
1	9	2	50
1	8	3	58
1	5	4	63
2	8	6	71
2	4	8	75
12	12	20	87

Table 2
Scatter of Solar Power literature in 1971 and 1974

A	B	C	D
1	53	1	53
2	28	3	81
1	13	4	94
1	5	5	99
2	8	7	107
1	3	8	110
11	22	19	132
30	30	49	162

When the literature grows further and the number of papers become more than twice the previous years as seen from the three year (1971, 1974, 1977) and four year (1971, 1974, 1977, 1980) merged bibliographies (Tables 3 and 4) there is a slight change in the shape of curves as well as in the size and elements of the core. In the single year 1971 and the two year (1971, 1974) merged bibliography there was only one core journal, while for the three year (1971, 1974, 1977) and four year (1971, 1974, 1977, 1980) merged bibliographies, the number of core journals become three, i.e. two new journals have been added in the list of core journals. The core journals are *Solar Energy, Journal of Geophysical Research* and *IEEE Transactions on Electronic Devices* containing 162 and 277 articles respectively. The ranking has also changed with *Solar Energy* being the first among core journals.

Table 3
Scatter of Solar Power literature in 1971, 1974 and 1977

A	B	C	D
1	70	1	70
1	61	2	131
1	31	3	162
1	27	4	189
1	19	5	208
1	17	6	225
1	15	7	240
1	8	8	248
1	6	9	254
4	20	13	274
7	28	20	302
7	21	27	323
22	44	49	367
59	59	108	426

Table 4
Scatter of Solar Power literature in 1971, 1974, 1977 and 1980

A	B	C	D
1	141	1	141
1	75	2	216
1	61	3	277
1	40	4	317
1	34	5	351
1	29	6	380
1	27	7	407
1	20	8	427
1	18	9	445
1	12	10	457
1	11	11	468
2	20	13	488
2	18	15	506
2	14	17	520
2	12	19	532
9	45	28	577
10	40	38	617
12	36	50	653
22	44	72	677
92	92	164	789

Further growth in literature as evidenced by five year (1971, 1974, 1977, 1980, 1983) (Table 5) and six year (1971, 1974, 1977, 1980, 1983, 1986) (Table 6) merged bibliographies, the growth of solar power literature matures[21] and the shape of the curves become Bradfordian. This has also earlier been pointed out by Braga,[16] according to whom "droop is a function of maturity of the subject area". At the stage of maturity, there is a change in the size and elements of the core. The core comprises four journals containing 499 and 666 articles respectively (Fig. 1 curves 5 and 6). The core journals for the five year (1971, 1974, 1977, 1980, 1983) merged bibliography are *Solar Energy*, *Solar Energy Materials*, *IEEE Transactions on Electronic Devices* and *Applied Solar Energy*. However for the six year (1971, 1974, 1977, 1980, 1983, 1986) merged bibliography, although the core size remains constant, but the elements of the core changes. The core comprises of *Solar Energy, Solar Energy Materials, Applied Solar Energy* and *Solar Cells*. The change in the elements of the core during this phase can be explained on the basis of changing emphasis in the research field.

Table 5
Scatter of Solar Power literature in 1971, 74, 77, 80 and 83

A	B	C	D
1	233	1	233
1	111	2	344
1	79	3	423
1	76	4	499
2	124	6	623
1	56	7	679
1	54	8	733
1	46	9	779
1	27	10	806
1	23	11	829
1	21	12	850
4	80	16	930
1	19	17	949
1	18	18	967
1	16	19	983
1	13	20	996
2	22	22	1018
3	30	25	1048
2	18	27	1066
5	40	32	1106
4	28	36	1134
4	24	40	1158
6	30	46	1188
10	40	56	1228
13	39	69	1267
33	66	102	1333
134	134	236	1467

To verify the fact that Bradford's shape is obtained only at the stage when the field matures, we drew the graph for the individual bibliography of 1983 and a curve similar to Bradford's shape was obtained (Fig. 2). Thus, the characteristic Bradford shape is associated with the emergence of "mature" phase of the development of the field.

Table 6
Scatter of Solar Power literature in 1971, 74, 77, 80, 83 and 86

A	B	C	D
1	316	1	316
1	137	2	453
1	119	3	572
1	94	4	666
1	90	5	756
1	76	6	832
1	62	7	894
1	56	8	950
1	46	9	996
1	31	10	1027
2	60	12	1087
2	54	14	1141
1	25	15	1166
1	23	16	1189
1	22	17	1211
1	20	18	1231
1	19	19	1250
1	17	20	1267
1	16	21	1283
2	24	23	1307
4	44	27	1351
2	20	29	1371
5	45	34	1416
5	40	39	1456
4	28	43	1484
2	12	45	1496
10	50	55	1546
14	56	69	1602
22	66	91	1668
42	84	133	1752
160	160	293	1912

Mathematical model for growth pattern

We now proceed to relate the above finding on Bradford's law with the model for growth of publications with time using Bass model as used by *Jain* and *Garg*[19] to model the growth of laser literature. The cumulative growth curve is generally S-shaped, with the number of articles increasing annually up to the point of inflection, which is a point at which the curve is changing from concave upward to concave downward. After this the annual growth of publications gradually decline. The point of inflection has been taken by the authors to be an indicator of maturity of a field, since it is the point at which publication activity is at the peak.

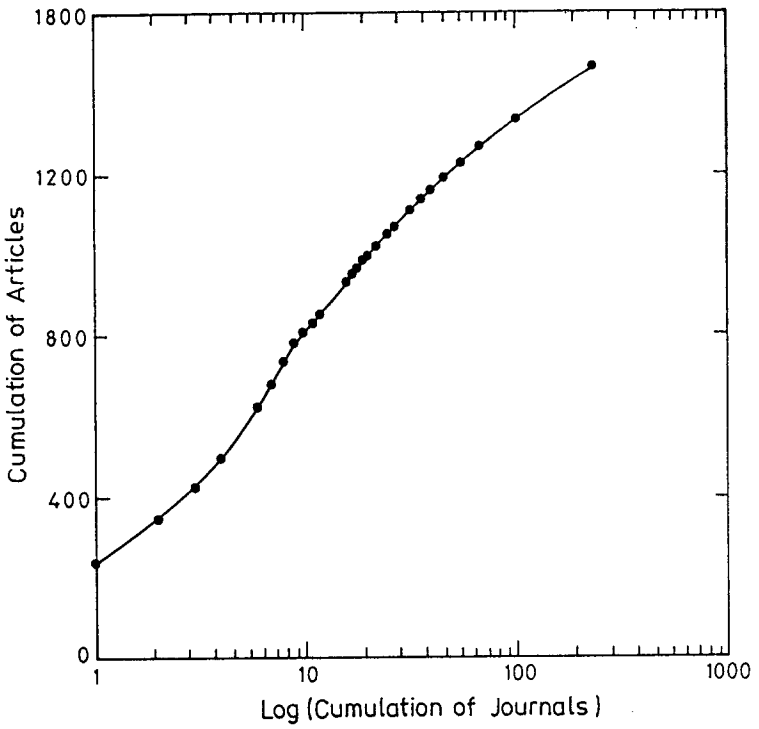

Fig. 2. Scatter of articles over journals for 1983. The curve shows a pattern similar to Bradford's curve at the stage of maturity

According to Bass model[20] the rate of growth of publications is:

$$dN/dt = [P + q \cdot N(t)]\,[M - N(t)]$$

Where $N(t)$ is the number of papers published upto time t, M is the maximum number of papers that can be produced in a field of knowledge, parameter P is taken to represent the intrinsic character of the field which helps is converting $[M-N(t)]$ to published papers and q is the interaction factor between number of scientists in the field and papers produced. The parameter values obtained from the publication data (Table 7) using regression with the help of SYSTAT package for statistical analysis are:

P = 0.003 with standard error = ±.003,

q = 0.403 with standard error = ±.022 and

M = 7372 with standard error = ±170.

The values of R^2 and F which indicate the goodness of fit of the model are $R^2 = 0.979$ and $F = 270.09$.

Table 7
World output of Solar Power literature from 1970 – 1990

Year	No. of publications
1970	73
1971	87
1972	33
1973	51
1974	75
1975	116
1976	214
1977	264
1978	322
1979	310
1980	363
1981	555
1982	715
1983	678
1984	734
1985	561
1986	445
1987	558
1988	399
1989	264
1990	482
Total	6326

The real data (Table 7) indicates that the output is maximum in 1984, which, is also confirmed by the model. After this the literature enters in the declining phase as indicated by the real data (Table 7) as well as by the model (Fig. 3). The projected values for publication output for 1990 are different than the real values of the publication output. The actual number of papers published in 1990 are 482 while the estimated number of papers are 186. It is because the research activity on solar power has again picked up in 1990. This is also reflected by more than 300 conference papers included in *Engineering Index*, while in earlier years the number of conference papers were quite small.[21]

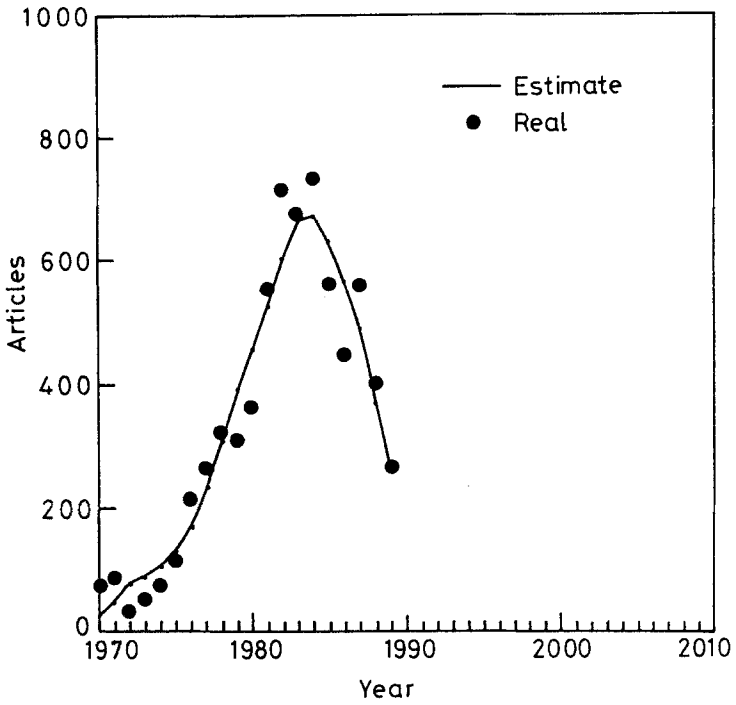

Fig. 3. Model fit for solar power research publications for 1970–1989. Continuous line indicates model estimates and solid points indicate the real values. The model curve shows that the field matures in 1984

Conclusions

(i) The Bradford type of curve is obtained only after the field of knowledge matures.
(ii) The size and elements of the core keep on changing with time, presumably these become stable once the field matures.
(iii) The rank list of journals in the core keeps changing even after the maturity of the field because the emphasis in the field keeps on changing.

The study reveals that the shape of the curve as well as the size and elements of the core changes at various periods of growth of a research field. However, this needs further investigation by using bibliographies of emerging research fields.

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