A Bibliometric Study of Agent Based Modeling Literature in SSCI Database

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Abstract. The purpose of this study is to investigate the characteristics of international literature using Agent-Based Modeling (ABM) in SSCI during 1997-2008. The results of this study reveal the fact that the growth of international literature using ABM is still well perceived. Most of the literature came from various institutions in USA. However, non-American authors including those from Taiwan, Italy, Netherlands, and England still achieve top 4 individual author productivity ranks. According to Bradford's Law, eight core journals in ABM are identified and analyzed. Moreover, the frequency distributions of the author productivity match the generalized Lotca's Law. Aapplications of ABM are mainly found in the fields of social science/interdisciplinary studies, economics, and environmental studies.

Keywords: agent-based modeling, Lotka, Bradford, author productivity, bibliometrics.

1 Introduction

Since the first paper in Agent-Based Modeling (ABM) was published in 1971, exploration of the ABM literature has seen a vigorous development, especially in the last decade owing to the well usage of ABM tools. This paper employs a bibliometric methodology towards a review of literature productivity, and an observation of the trend in ABM. In order to have a better understanding of the quantitative aspects of recorded information and discover literature features and forecasting the research tendency in the near future, finally proceeding by Lotka's law to perform author productivity analysis and Bradford's Law on the core journals in this field within 1997 and 2008.

2 Agent-Based Modeling description

Agent-Based Modeling (ABM) refers to the computer simulation of agents (representing individual roles) in a dynamic social system. Here, agents mean different "representatives" which interact with each other or the environment based on pre-set rules. Through these representatives, we may be able to observe the emergence of certain macro behaviors. Derived from Schelling Segregation Model (SSM), ABM has been applied in economics, physics, biology and ecology to explore the phenomena of Complex Adaptive Systems (CAS), and gradually more widely used in almost every field of study for deeper understanding of its particular phenomena. For instance, Chen (2008) points out that the economic system in agent-based economics is composed of heterogeneous agents, and that summation variables are the results of these heterogeneous agents' interaction. ABM serves as an ideal tool for us to advance our thinking from the micro to the macro perspectives, and to observe the links and relations between these two levels. Unlike the "top-down" mode of thinking in traditional macro economics, ABM introduced a "ground-up" style of thinking to macro-economics under a new paradigm, which presents a challenge to most economists.

There is also a growing trend of ABM application in political studies, for it does not focus on the causal relations between variables, as statistics and econometrics do. Instead, it is mainly concerned with addressing "how" or "what-if" questions—observing how the complicated social/political phenomena in question have been formulated through the interaction between the simulated agents. And the patterns being discovered through such observations may be used either to test existing theories, or to explore new ones. (Axelrod, 2006). Axelrod also argues that ABM can be used to describe certain fundamental questions in many fields, thereby promoting inter-disciplinary cooperation. Moreover, when existing mathematic methods fall short, ABM presents itself as a useful tool to reveal the underlying unity behind various academic fields.

3 Overall Analysis of ABM literature

This paper utilizes the Social Sciences Citation Index (SSCI) of Web of Science created by the Institute for Scientific Information. An empirical method of retrieval was used by Topic = ("agent based(*)") OR Topic=("multi-agent simulation") to retrieve data related to ABM. A total of 788 papers in ABM published during 1997-2008 were found. Fig. 1 indicates the number and growth of published paper in ABM. According to the numerical data, a large amount of research papers published during 2005-2008 have been catalogued in the SSCI database, with the distribution rate of 93(11.71%), 112(14.11%), 157(19.77%), 142(17.88%) against the total number of papers each year. Meanwhile, Fig. 2 shows annual citations of the published papers in ABM. The results appear to suggest that the number of papers in ABM has distinctively increased since 2001, and that respective citations have also increased each year. It appears that ABM has received much attention from researchers, which leads to a rapid growth of related papers and their citations.

With regard to the 788 distributed papers among the countries, the top ten countries ranked in the most publicized catalogues in SSCI database during 1997-2008, are illustrated in Fig. 3. The figure shows that the US is the dominant country (316 papers; 39.8%) in terms of number of published paper in ABM, followed by England (92 papers; 11.59%), Germany (64 papers; 8.06%) and so on.

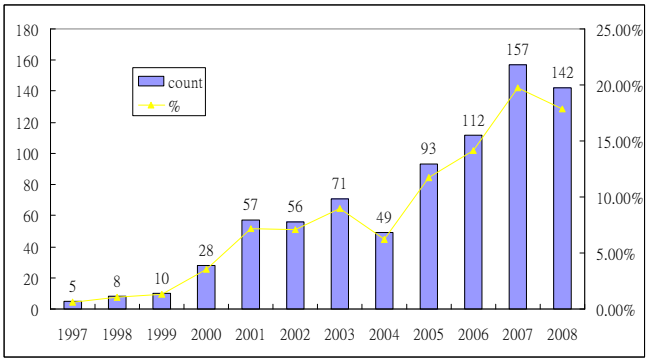

Fig. 1. Number of published papers in ABM

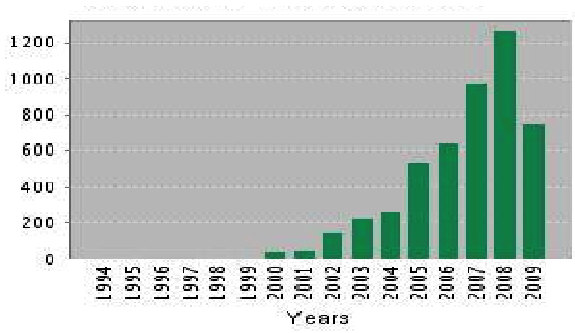

Fig. 2. Citation in each year (Source: SSCI database)

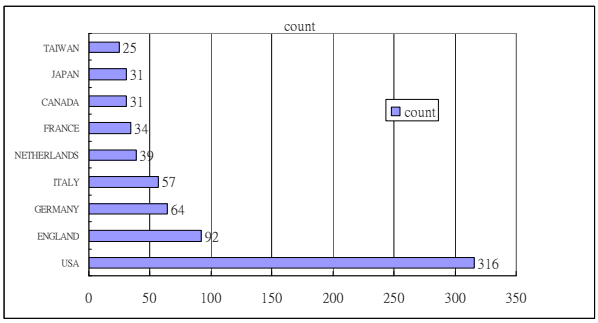

Fig. 3. The Top ten Number of published papers in ABM based on country during 1997-2008

Table 1 offers a closer look at the distribution of academic institutions by which the indexed papers were submitted. It is observed that, among the 27 institutions whose record counts of indexed papers are greater than eight, 12 are located in USA, followed by England and Germany. The data shows that USA is the most productive country in the study of ABM. Taiwan is also among the top ten. (25, 3.15%). And its institution National Chengchi University ranks No.4, holds 12 published papers as that of Harvard University (USA), Santa Fe Institution (USA) and University Groningen (Netherlands).

Table 1. Leading institutions with the most published papers in ABM during 1997-2008.

Rank	Institution Name	Count	%	comprising % of the country	Country
1	Univ Michigan	22	2.77%	23.91%	USA
2	Univ Penn	16	2.02%	17.39%	USA
3	Indiana Univ	13	1.64%	14.13%	USA
4	Harvard Univ	12	1.51%	13.04%	USA
5	Natl Chengchi Univ	12	1.51%	48.00%	Taiwan
6	Santa Fe Inst	12	1.51%	13.04%	USA
7	Univ Groningen	12	1.51%	30.77%	Netherlands
8	Ucl	11	1.39%	17.19%	England
9	George Mason Univ	10	1.26%	10.87%	USA
10	London Business Sch	9	1.13%	14.06%	England
11	Univ Calif Los Angeles	9	1.13%	9.78%	USA
12	Univ Calif Santa Barbara	9	1.13%	9.78%	USA
13	Univ Illinois	9	1.13%	9.78%	USA

Table 2 offer an investigation into the authors who have written more than six papers in ABM during 1997-2008. The top 3 authors are Jager, W (10, Netherlands), Chen, SH（9, Taiwn)、Gallegati, M (9, Italy). The data show that the comprising ratio of the country in Netherlands, Taiwan, Italy, Spain is much greater than that of USA, point that these author in their country dominate the academic research in ABM field. Table 2 shows that the research in economics and management using ABM is the mainstream. This may result from the fact that ABM offers the macro-view of evolution through the micro-view of agents' interactions.

With respect to the future directions of ABM research, the emphasis of the discussion here is on the ABM applications. Based on our retrieving SSCI database results, Table 3 provides the top 10 subject areas in which ABM are most widely utilized. The first rank of subject area is comprised of 155 papers in Social Sciences/interdisciplinary, which takes the lead with 19.52% against the total of 788 papers retrieved. The second rank is Economics, with 118 papers recorded (14.86%) followed by Management with 63 papers (7.93%) related to ABM. Referring to Fig. 4, Economics, Management, Mathematics and Environmental Study are gradually growing year by year within these subject areas; however, Social

sciences/interdisciplinary gradually declines after 2007. If we summarize the three subject areas of computer science as one subject area, it is obvious that the publish paper in computer science are more than that of the other subject area because ABM itself is a computer program to simulate for the other field.

Table 2. The top ranking of published papers in ABM based on authors during 1997-2008

author	count	%	Comprising % of the country	country	institution	subject area
Jager, W	10	1.26%	25.64%	Netherlands	Univ Groningen	Economics
Chen, SH	9	1.13%	36.00%	Taiwan	Natl Chengchi Univ	Economics
Gallegati, M	9	1.13%	15.79%	Italy	Univ Politecn Marche	Economics
Janssen, MA	8	1.01%	2.53%	USA	Arizona State Univ	Ecology
Bunn, DW	7	0.88%	7.61%	England	London Business Sch	Management
Boero, R	6	0.76%	10.53%	Italy	Univ Turin	Economics
Izquierdo, LR	6	0.76%	33.33%	Spain	Univ Burgos	Social Sciences
Lebaron, B	6	0.76%	1.90%	USA	Brandeis Univ	Economics
Mayer, RE	6	0.76%	1.90%	USA	Univ Calif Santa Barbara	Management
Rivkin, JW	6	0.76%	1.90%	USA	Harvard Univ	Management
Squazzoni, F	6	0.76%	10.53%	Italy	Univ Brescia	Computer Science
Tesfatsion, L	6	0.76%	1.90%	USA	Iowa State Univ	Economics

In summary, ABM literature is still under development based on the retrieval performance observed over the SSCI database. The top 3 countries with most published papers in the field of ABM are USA, England, and Germany. In recent years, the published papers using ABM methodology are still growing because the maturity and easy-using of some ABM simulation platform such as SWARM of SFI, Starlogo of MIT, Netlogo of Northeastern University, REPAST of Chicago University. ABM tools enable the subject area such as Social Science/interdisciplinary study, economics, management, Mathematics, Interdisciplinary Applications and Environmental Studies to do research about natural and social science in order to provide human being knowledge.

4 Bradford's law and journal literature

Samuel C. Bradford in 1934 introduced Bradford's Law which is a pattern to estimates the exponentially diminishing returns of extending a search for references in science journals. The law principle impose a formulation that if journals in a field are sorted by number of articles into three groups, each group approximate to one-third of all articles, then the number of journals in each group will be proportional to $1:n:n^2$.

There are various formulations associated with the principle as shown in Fig. 5. (Tsay, 2003)

Table 3. The top ranking of published papers in ABM based on subject areas during 1997-2008

Subject Area	Count	%
Social Sciences/Interdisciplinary	155	19.52%
Economics	118	14.86%
Management	63	7.93%
Mathematics/Interdisciplinary Applications	61	7.68%
Environmental Studies	60	7.56%
Computer Science/Information Systems	55	6.93%
Computer Science/Interdisciplinary Applications	53	6.68%
Computer Science/Artificial Intelligence	52	6.55%
Operations Research & Management Science	52	6.55%
Business	45	5.67%
Information Science & Library Science	45	5.67%

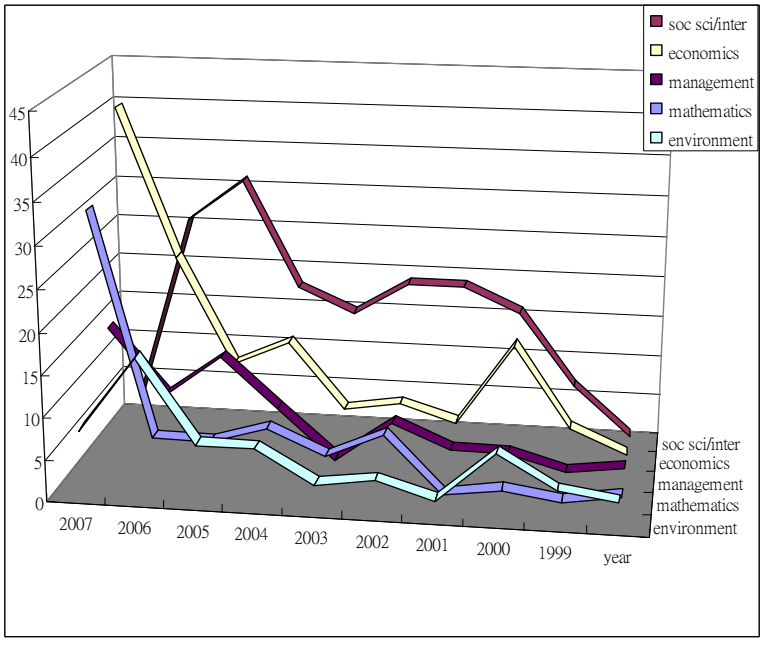

Fig. 4. Yearly Distribution of Top 5 Subject Areas during 1997-2008

The 788 publish papers in this study distributed in 271 journals. Table 4 provide the number of publish paper each journal and other information ranking by the number of publish paper according to the zoning of Bradford Law. Besides, the

number of published paper in the top 31 journals is more than a half of 788 published papers (431, 54%). The other published papers (46%) are distributed in 240 journals, including 1 published paper of 163 journals. The result shows that distribution of published papers in ABM is decentralized.

Table 4. The distribution of ABM journals during 1997-2008

	No. of articles(A)	No. of journal(B)	Accumulated Journals (C)	(D)=(A)*(B)	(E) = Accumulated (D)	log(acc. Journals)
(A) Core	120	1	1	120	120	2.0792
	27	1	2	27	147	2.1673
	23	1	3	23	170	2.2304
	22	1	4	22	192	2.2833
	21	1	5	21	213	2.3284
	18	1	6	18	231	2.3636
	17	1	7	17	248	2.3945
	11	1	8	11	259	2.4133
(B) Relevant	10	3	11	30	289	2.4609
	9	2	13	18	307	2.4871
	8	5	18	40	347	2.5403
	7	6	24	42	389	2.5899
	6	7	31	42	431	2.6345
	5	5	36	25	456	2.6590
	4	10	46	40	496	2.6955
(C) marginal	3	17	63	51	547	2.7380
	2	39	102	78	625	2.7959
	1	163	265	163	788	2.8965

Table 5 also provides the ratio comparisons of 3 zones, that is ratio of published paper each zone of zone A, B, C, 8:38:214. It almost equal to 8:40:200 as $1 : 5 : 5^2$. That is, A: B: C = 1: n: n^2. The result matches the explanations of Bradford Law. Table 6 specifies eight leading journals which have published the most research papers in ABM. According to the data, published ABM papers in these journals take up nearly one-thirds of the total amount. JASSS, which tops the list, has 120 published papers in ABM. It largely outnumbers that of the second journal on top, PHYSICA A (27 papers, 3.4%). It is also observed that the main subject areas of the listed eight journals are Economics and Social Science/ Interdisciplinary.

Table 5. The literature brief distribution in ABM based on journal

	(1) No. of journal	(2) No. of articles	(3) Range of No. of articles	(4) Average articles
A	8	259	11~120	32
B	38	237	4~10	6
C	219	292	1~3	1

Table 6. The eight core journal titles and their statistics in ABM

Title	count	%	Acc. %
JASSS-The Journal Of Artificial Societies And Social Simulation	120	15.11%	15.11%
PHYSICA A-Statistical Mechanics And Its Applications	27	3.40%	18.51%
Journal Of Economic Dynamics & Control	23	2.90%	21.41%
Journal Of Economic Behavior & Organization	22	2.77%	24.18%
Environment And Planning B-Planning & Design	21	2.64%	26.82%
Advances In Complex Systems	18	2.27%	29.09%
Social Science Computer Review	17	2.14%	31.23%
Adaptive Behavior	11	1.39%	32.62%

5 Lotka's law and Author productivity

5.1 Distribution of scientific productivity of authors with equality of chances of participation

With 788 retrieved literatures based on the Equality method, the sum of accumulated authors who jointly contributed to a published paper altogether 1,407 authors, with an average of 0.56 papers per author. Within these retrieved literatures, one author per paper (with no jointly accumulated authors) is the majority, which comprised a total of 1,149 persons, or 81.66%. Meanwhile, six or more accumulated authors per paper consist of 12 persons. In assuming each accumulated author exerted one paper, there will be 1,838 accumulated papers, as shown in Table 7, as in actual fact only 788 papers. As a result, the overall estimated authors per paper will be 2.33, that's mean the research teams will be usually with the sizes of two or three persons.

Table 7. Distribution of author productivity of ABM papers

Publish(s)	Author(s)	Sum of Record Count	Accumulated Record Count	% of Accumulated Record Count	Accumulated Author(s)	% of Auther(s)	% of Accumulated Author(s)
10	1	10	10	0.54%	1	0.07%	0.07%
9	2	18	28	1.52%	3	0.14%	0.21%
8	1	8	36	1.96%	4	0.07%	0.28%
7	1	7	43	2.34%	5	0.07%	0.36%
6	7	42	85	4.62%	12	0.50%	0.85%
5	13	65	150	8.16%	25	0.92%	1.78%
4	11	44	194	10.55%	36	0.78%	2.56%
3	51	153	347	18.88%	87	3.62%	6.18%
2	171	342	689	37.49%	258	12.15%	18.34%
1	1149	1149	1838	100.00%	1407	81.66%	100.00%

5.2 Lotka's law

Lotka's law of scientific productivity of authors is a good example with respect to such empirical laws. Lotka (1926) deduced an inverse square law relating the authors of published papers to the amount of papers written by each author. The data represented in the decennial index of Chemical Abstracts specifically and the Auerbach's Geschichtstafeln der Physik as the name index, Lotka plots the number of authors against the number of contributions made by each author on a logarithmic scale. Lotka proposes that these points are closely scattered around a straight line having a depth slope of approximately negative two. This empirical observation as Lotka concludes provided the following equation (Chung and Cox, 1990).

$$\mathbf{a_n = a_1/n^c,\ n = 1, 2, 3,..,} \qquad \mathbf{(1)}$$

where

a_n = the number of authors publishing n papers,
a_1 = the number of authors publishing one paper, and
c = a constant. (in Lotka's case, c = 2)

Taking the log of both sides of (1), we obtain

$$\mathbf{\log(a_n) = \log(a_1) - c\log(n).} \qquad \mathbf{(2)}$$

In the computation of the "best empirical value", the constant c for data related to ABM by fitting a line to the empirical frequency distribution. The regression results show that c = 3.20. If the estimated a1 is 0.8573, then the equation (1) will be stated as follows:

$$\mathbf{a_n = 0.8573 / n^{3.2}}$$

It is possible to check whether ABM literature matched the Lotka's Law by K-S statistical test. According to K-S test, as demonstrated in Table 8, as if Dmax=0.0407 and the sampling number is bigger than 35, then the threshold value

will be $1.63/1407^{1/2} = 0.0435$, while the number of accumulated authors will be 1407. In spite of the fact that Dmax is less than the threshold value, the result matched the generalized Lotka's law, which indicated that the Lotka's law is author productivity distribution data in ABM literature.

Table 8. Author distribution of Lotka's Law

record count	% of author(s)	Accumulated % of Author(s) Sn(X)	Expected % of author(s)	Accumulated Expected % of author(s) Fo(X)	Absolute Value |Fo(X)-Sn(X)|
1	0.8166	0.8166	0.8573	0.8573	**0.0407(Dmax)**
2	0.1215	0.9381	0.0932	0.9505	0.0123
3	0.0362	0.9744	0.0254	0.9759	0.0015
4	0.0078	0.9822	0.0101	0.9860	0.0038
5	0.0092	0.9914	0.0050	0.9910	0.0005
6	0.0050	0.9964	0.0028	0.9937	0.0027
7	0.0007	0.9971	0.0017	0.9954	0.0017
8	0.0007	0.9978	0.0011	0.9965	0.0013
9	0.0014	0.9993	0.0008	0.9973	0.0020
10	0.0007	1.0000	0.0005	0.9978	0.0022

6 Conclusion

The purpose of this study is to investigate the characteristics of international literature using agent-based modeling (ABM) in SSCI, 1997-2008. The results of this study reveal the growth of international literature using ABM is still well perceived. Most of the literature came from various USA institutions, but the non-USA authors including Taiwan, Italy, Netherlands and England are still achieving top 4 individual author productivity rank. According to Bradford's Law, the eight core journals in ABM are identified and analyzed. Moreover, the frequency distributions of the author productivity match the generalized Lotca's Law. The three applications of ABM are mainly in the fields of social science/interdisciplinary studies, economics, and environmental studies.

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