Malaysia's Computer Science research productivity based on publications in the Web of Science, 2000-2010

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ABSTRACT

A number of studies have appeared that evaluate the productivity of computer science scholars and their institutions. The aim of this work is to estimate the research productivity of Malaysia's computer science researchers and their affiliated institutions. To achieve the objectives of the study, we employed the bibliographic repository that is made available to the world's scientific research, which is the Thomson's Web of Science (denoted as CWTS-WoS) database. The 903 research works produced by Malaysia's computer science researchers, published as journal article (74.8 percent) and proceedings (25.2 percent) covered by the database from 2000 to 2010 were evaluated. The productivity of authors and core journals they published in have been determined using Lotka's and Bradford's Law. Some of the important findings are that most articles (54.9 percent) are multi-authored, author productivity is not in agreement with Lotka's law, the maximum number of articles were published in the Lecture Notes of Computer Science, distribution of articles is quite close to Bradford's Law, and the Multimedia University ranked first for the maximum number of publications (22.3% percent).

Keywords: Bibliometrics; Research productivity; Computer science; Scholarly publications; Malaysia

INTRODUCTION

The assessment of research performance in the scientific disciplines has caught the attention of the university community for a long time. The most crucial asset of a university is its reputation, and research is the playing field where reputations are made. With a high reputation, a university's ability to attract and retain high-performing staff and outstanding research students, both nationally and internationally, grows. It is important to study trends in research productivity because universities account for basic research which is one of the mainsprings of industrial innovations (Adams and Griliches 2000). The Ninth Malaysia's Plan (9MP), which runs from 2006 to 2010 calls for "producing more researchers, scientists and engineers (RSEs)" and the RM14.1b (USD4.2b) allocated to the Ministry of Higher Education in 2009 (Malaysia 2009) was a further indication of the importance that the government places on research. As far as the number of universities is concerned, Malaysia has prospered starting with 3 public universities in 1970 to 20 public and 25 private universities in 2009 (Malaysia Ministry of Higher Education 2009) registering

a manifold increase. Growth in numbers is expected to cater to the increasing number of students; and at the same time, it is important to assess the performance of faculty in terms of research contribution in their respective fields of study.

A systematic assessment of Malaysia's research performance is not available. This paper focuses on the research productivity of universities in Malaysia in the area of computer science (CS). Bibliometric techniques have been employed to conduct the research. The study of scientific publications based on international bibliographic data is one of the most widely used methods to measure scientific achievement, and this usually includes the use of publication and citation counts. Established as a field of study during the 1960s, bibliometrics has become a generic term for a whole range of specific measurements and indicators; its purpose is to measure the output and impact of scientific and technological research through different databases (Thackray 1978). As a tool it is often used for analyzing and situating a country in relation to the world, an institution in relation to a country, and individual scientists in relation to their research communities. Using data from the Web of Science (WoS), the present study aims at identifying those institutions and researchers publishing in the different subject areas of CS in Malaysia.

RELATED LITERATURE

There have been several previous works on bibliometric studies of CS. One of the earliest was Hirsch and Talent (1997) who studied CS journals; Culnan (1978), and Salton and Bergmark (1979) who analysed citations on CS literature. Subramanyam's (1984) analysis of core journals in CS investigated the relationship between research productivity of computer scientists, as indicated by the number of papers published, and the breadth of research interests. Over the past two decades, there have been studies that addressed the most widely cited CS papers (Franceschet 2010) or the most prolific researchers in specialty areas within the CS discipline, such as management information systems (Nath and Jackson 1991), decision support systems (DSS) (Holsapple and Luo 1995; Forgionne and Kohli, 2001), e-commerce (Bharati and Tarasewich 2002), artificial intelligence (van den Besselaar and Leydessdorf 1996), expert systems (Cheng, Holsapple and Lee 1994), data mining (Li and Ke 2009) and human-computer interaction (Meho and Rogers 2008). There are also reviews of the top researchers or journals in CS (Katerattanakul, Han and Hong 2003), or analysis of publication patterns and citations of single journal in this discipline (Zainab, Anyi and Anuar 2009; Bakeri and Willet 2009). CS researchers have even identified CS scholars' views of the best practitioner journals (Hsieh, Lu and Lin. 2001), and have developed sophisticated mathematical procedures for identifying the highest-quality CS journals (Kleijnen and van Groenendaal 2000; Forgionne and Kohli 2001). The most recent study is by Merlo et al. (2011) who investigated the productivity of first authors using data from 5,274 articles in five leading journals in CS education using Lotka's law.

The evolution of a nation's publication activity and citation impact in the field of CS has also been studied such as for China (He and Guan 2009; Kumar and Garg 2005) and India (Kumar and Garg 2005). Using the Essential Science Indicator (ESI) database of Thomson Scientific as the data source with a time span of more than ten years, Ma, Ni and Qiu (2008) evaluated the scientific research competitiveness of world universities in CS. The authors established a hierarchical indicator system to establish the university ranking which incorporates the following bibliometric indicators: number of papers, total citations, highly cited papers, hot papers, average citation per paper and the ratio of highly cited papers to papers.

Previous bibliometric studies of Malaysian work in CS have been limited to the work of Gu and Zainab (2000) who looked at the publication channels used by Malaysia's computer scientists, as well as Gu and Zainab (2001) and Gu (2002) who explored the Malaysian CS publication productivity, based on three CD-ROM databases, *COMPENDEX* (1987-1999), *IEL* (IEE/IEEE Electronic Library) (1988-1999) and *INSPEC* (1990-1998). This research extends Gu and Zainab's study in two ways. First, it looks into the research performance of Malaysia's CS researchers as reflected by their publications in international refereed journals and proceedings for the past 11 years (2000-2010). Second it exclusively covers international scholarly publications indexed by WoS which publishes a list of highly cited researchers, one of the factors included in the Times Higher Education World University Ranking and Academic Ranking of World Universities (ARWU).

OBJECTIVES, MATERIALS AND METHOD

The objectives of this study are to ascertain:

a) the most productive Malaysian institutions in the field of CS as determined by the institutional affiliations of authors for the period 2000 to 2010;
b) Malaysia's prolific authors / researchers in the field of CS for the period 2000 to 2010;
c) author productivity and authorship patterns among Malaysia's CS researchers over the studied period;
d) the core journals which Malaysia's CS researchers publish in.

The focus on international scholarly publications means that national or regional publications that are not indexed by WoS (denoted as CWTS-WoS database, the source of the Science Citation Index) are not considered in this study. Corrections, editorial materials, letters, news items, notes and reviews were excluded.

The units of analysis are all articles in the CS field by Malaysian scholars and published during the time period 2000-2010. This field comprises all journals assigned to journal categories related to Computer Science, and the conference proceedings published by the Association of Computing Machinery (ACM), Lecture Notes in Computer Science (LNCS) and Institute of Electrical and Electronics Engineers (IEEE) covered by the CWTS-WoS database. The following steps to retrieve the relevant data were followed:

a) Using Advanced search feature, the country field tag Malaysia (CU= (Malaysia)) was used as the query command and the period of analysis covered (time span) was from 2000 to 2010. The citation database "Science Citation Index Expanded (SCI-EXPANDED)" was checked.
b) From the search results, the four subject areas in CS (artificial intelligence, information systems, computer science theory and methods, and interdisciplinary applications) were chosen to refine the search.
c) The analysis was further limited to only journal articles and conference proceedings.
d) To get the top 100 authors, the 'authors' heading was selected, and the "more options / values" hypertext was used to refine the search. The same procedure applies to obtain the top institutions.

The search retrieved a total number of 903 articles for the eleven-year period. Of these, 675 (74.8 per cent) were published in journals, and 228 (25.2 per cent) in proceedings. The indices of productivity indicators calculated in this study are:

a) Productivity (P): This refers to institution productivity and author productivity as reflected by the respective number of published articles in journals and proceedings covered by WoS. The data on author productivity data provide the basis for the application of Lotka's Law.
b) The Impact Score (I): Institutional impact or authors impact refers to the sum of the number of articles calculated by n^{-1} authorship. For each article, the institutional affiliations of contributing authors were noted. For the articles with n co-authors, each author's institution assumed to get a credit for n^{-1} articles without regards to order of authorship. In the case of a single author with two institutional affiliations, the article is credited to the institution where the research was carried out. This is termed as adjusted count where it assumes that each author contributed equally to a paper and adjusts for authorship.

RESULTS

Research Productivity by Institutional Affiliation

The institutions contributing 10 or more articles in the period 2000-2010 were included in the list of major institutions. Out of the 45 universities in Malaysia, ten universities appear to be actively contributing to the scholarly literature in CS (89.7% of the total publications). Table 1 depicts the yearwise distribution of their research productivity (P) output in this field. It is observed that the overall output has grown steadily during the period of study, from 23 in 2000 to 142 in 2010. However, there was a decrease observed in 2007 for almost all universities, except for University of Malaya (UM), Universiti Putra Malaysia (UPM), Universiti Kebangsaan Malaysia (UKM), Monash University, Universiti Teknologi Petronas and University of Nottingham, as shown in the time series analysis of research productivity based on the universities' publication counts (Figure 1).

The rankings and scores on research productivity of the Malaysian universities in relation to their contribution in CS research during the period 2000 to 2010 were calculated and presented in Table 2. The institutional total score of those institutions contributing 10 or more articles in the period 2000-2010 indicate that Multimedia University (MMU) contributed 25.4% with an impact value of 157.41 is positioned first. The highest impact value, in the case of MMU (a private university) speaks of the consistent performance of its faculties throughout the period of study. However, MMU's publication productivity dropped by 50% in 2007, and was ranked third with UM in 2010. The cumulative share of the five research intensive universities comes to 54% with Universiti Sains Malaysia (USM) is placed second, followed by University of Malaya (UM), Universiti Putra Malaysia (UPM), Universiti Teknologi Malaysia (UTM) and Universiti Kebangsaan Malaysia (UKM). Other private universities such as Swinburne University of Technology, Monash Malaysia, Universiti Teknologi Petronas and Nottingham Malaysia found place in the top ten positions. The contribution of each of the remaining universities was less than one percent of the total research output.

Table 1: Yearwise Distribution of Malaysia's Computer Science Publications by Institutions: 2000-2010

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	P
ALL	23	16	26	66	75	97	93	65	96	111	142	
MMU	3	2	5	24	23	37	43	21	26	24	21	229
USM	4	4	7	9	21	15	10	4	18	15	30	137
UM	6	3	5	11	9	8	7	7	9	14	21	100
UPM	4	3	5	4	8	10	7	7	12	18	16	94
UTM	3	1	2	3	9	9	9	8	7	15	22	88
UKM	2	2	2	9	4	7	3	4	12	12	13	70
Monash	1	1	0	5	0	1	2	4	5	3	5	27
Swinburne	0	0	0	0	1	8	6	4	1	2	3	25
Tek. Petronas	0	0	0	0	0	2	4	4	4	2	7	23
Nottingham	0	0	0	1	0	0	2	2	2	6	4	17

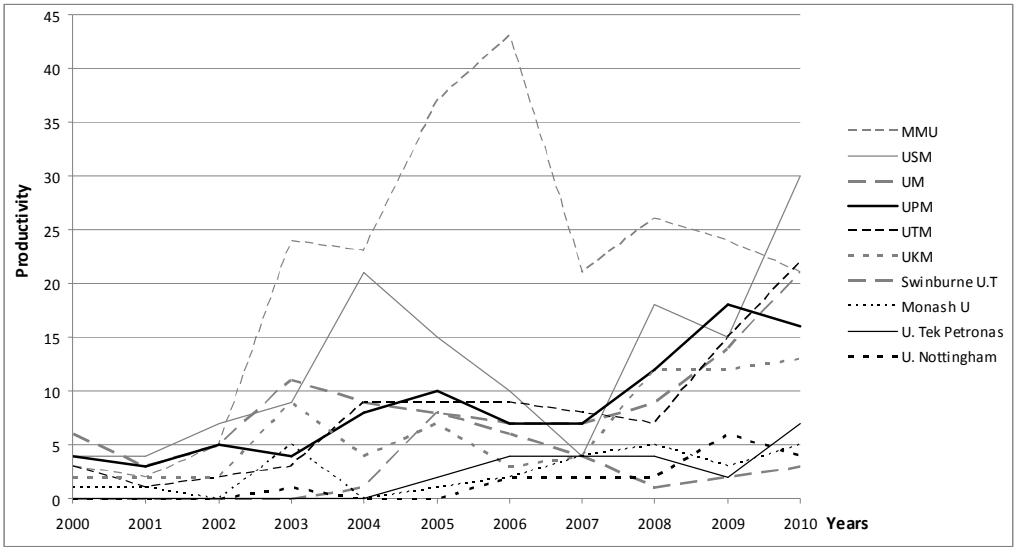

Figure 1: Time Series Analysis of Institutional Productivity based on Publication Counts: 2000-2010

Table 2: Publication Productivity and Impact grouped according to Institutions: 2000-2010

Rank	Institution	Number of publication (Percentage)	Institutional total score[a]
1	MMU	229 (25.4%)	157.41
2	USM	137 (15.2%)	96.60
3	UM	100(11.1%)	81.43
4	UPM	94(10.4%)	68.70
5	UTM	88(9.7%)	64.00
6	UKM	70 (7.8%)	52.00
7	Swinburne Univ. Technology	25 (2.8%)	17.33
8	Monash University	27(3.0%)	13.33
9	Uni. Teknologi Petronas	23(2.5%)	11.65
10	University of Nottingham	17(1.9%)	10.75

[a] Sum of the number of articles calculated by n^{-1} institutional authorship.

Research Productivity in Subject Orientation

Institutions' productivity in the five sub-domains of CS for the period 2000-2010 is given in Table 3. Findings indicate that the top 10 productive institutions were consistently ranked in all the sub-domains. MMU is the most productive institution in all five sub-domains. The results also indicate considerable difference in institutional scores in different sub-domains of CS. For example, UM and UTM produce more papers in the sub-domain engineering, electrical and electronics (more than 14 percent respectively), whereas USM contributes 18.6 percent papers in the area of artificial intelligence. This is expected as institutions often specialise in a few or even single sub-domain and publish overwhelmingly in one or two journals.

Table 3: Ranked Institutions in Productivity by Main Sub-Domains of Computer Science

Rank	Institution	Institutional Impact Score (Percentage)				
		Computer science, theory & methods	Engineering, electrical & electronic	Artificial Intelligence	Inter-disciplinary Application	Information Systems
1	MMU	25.2	23.5	27.0	17.8	23.4
2	USM	14.9	8.2	18.6	15.9	10.1
3	UM	15.3	14.1	13.6	13.3	10.1
4	UPM	7.3	12.4	6.1	14.9	12.8
5	UTM	6.1	14.7	10.4	11.3	9.0
6	UKM	8.8	7.1	6.1	6.8	8.5
7	Swinburne	6.5	2.9	0.6	0.6	2.7
8	Monash	0.8	1.8	2.3	3.0	6.4
9	Tek. Petronas	1.1	3.5	3.5	5.2	0.5
10	Nottingham	0.4	4.1	2.9	1.9	1.6
Cumulative %		86.4	92.3	91.1	90.7	85.1

Research Productivity by Authors

Author Productivity

A total of 1662 Malaysian authors contributed to the 903 papers in CS during 2000 to 2010. The ratio of the number of authors to articles is 1662 : 903 or 1 : 0.54. Table 4 presents active authors who have produced at least 5 articles in CS during the period of study and their respective author score, which yielded a list of 74 individuals. It is observed that from the 1662 authors, a total of 1237 (74.4 percent) published only one article whereas only 14 authors contributed 10 or more articles. This indicates that many Malaysia's CS researchers write only one paper, and a few write many papers. The most prolific author is Lim CP from USM with 34 papers, followed by Teoh ABJ and Ngo DCL, both from MMU, with 33 and 29 papers respectively. A high number of active authors among those who contributed at least five papers are from MMU (22 authors), followed by UPM (13 authors), USM (9 authors), UTM and UM (7 authors respectively) and UKM (5 authors).

Table 4: Malaysia's Computer Science Researchers who Contributed at least Five Articles During 2000-2010

No	No. of Publication	Author (with variant names)	Affiliation	Author total score[a]
1.	34	Lim C P	USM	12.12
2.	33	Jin ATB or Teoh ABJ; or Teoh A	MMU	11.26
3.	29	Ling DNC or Ngo DCL or or Ngo D	MMU	10.01
4.	27	Rao, M. V. C. or Rao MVC	MMU	9.83
5.	23	Raveendran, P. or Paramesran, Raveendran	UM	8.75
6.	21	Phan RCW (Phan, Raphael C. -W.)	Swinburne	12.03
7.	14	Hussain, A	UKM	3.97
8.	14	Loo, Chu Kiong	MMU	4.42
9.	14	Othman, Mohamad	UPM	3.65
10.	14	Goi BM (Goi, Bok-Min)	MMU	4.99
11.	11	Goh A (Goh, Adrian)	*(ClinkRes Sdn Bhd)*	4.42
12.	11	Mohamed, Azah	UKM	3.32
13.	11	Heng SH	MMU	4.00
14.	10	Vasant Pandian	Tek. Petronas	2.71
15.	9	Ewe HT	MMU	5.83
16.	8	Khalid M	UTM	2.14
17.	8	Ali, Borhanuddin Mohd. (Ali, BM)	UPM	2.12
18.	8	Deris, Mustafa Mat	UTHO	2.20
19.	8	Eswaran, Chikkannan	MMU	3.67
20.	8	Ho CK	MMU	3.00
21.	8	Ibrahim Z (Ibrahim, Zuwairie)	UTM	2.42
22.	8	Ong SH	UM	3.36
23.	8	Ooi KB	MMU	2.03
24.	8	Palaniappan, Ramaswamy	UM	3.17
25.	8	Phon-Amnuaisuk S	MMU	1.33
26.	7	Deris, Safaai	UTM	1.92
27.	7	Hamouda AMS	UPM	2.50
28.	7	Ismail N	UPM	1.92
29.	7	Lai WK	MIMOS	2.12
30.	7	Logeswaran R	MMU	5.33
31.	7	Mustafa, A.	USM	2.12
32.	7	Wee CY	UM	2.92
33.	6	T Connie, Connie T	MMU	1.45
34.	6	Abdullah R	USM	1.7
35.	6	Abidi SSR	USM	3.33
36.	6	Arumugam MS	MMU	2.33
37.	6	Chong AYL	INTI	4.45
38.	6	Chong CW	MMU	2.00
39.	6	Chong SC	MMU	1.75
40.	6	Hashim, I	UKM	2.00
41.	6	Khatun, Sabira	UPM	1.50
42.	6	Larbani M	IIUM	4.98
43.	6	Noorani, MSM	UKM	2.17
44.	6	Rajeswari M	USM	2.11
45.	6	Salam, RA	USM	1.70
46.	6	Salleh, S	UTM	1.65
47.	6	Sembok, TMT	UKM	1.74
48.	6	Subramaniam, Shamala	UPM	1.58
49.	6	Tan, SC	MMU	2.17
50.	6	Wong KY	UTM	3.50

51.	6	Yusuf Rubiyah	UTM	1.55
52.	5	Sulaiman, MN	UPM	0.70
53.	5	Lee CS (Lee, Chien-Sing)	MMU	5.67
54.	5	Ahmad, F	UPM	1.33
55.	5	Aris, I	UPM	1.02
56.	5	Budiarto, R	USM	1.33
57.	5	Ibrahim, F	UM	1.37
58.	5	Ibrahim, H	UPM	1.10
59.	5	Isa, D	Nottingham	2.08
60.	5	Isa, Nam	USM	1.75
61.	5	Low, Aly	MMU	1.02
62.	5	Mashor, MY	UniMAP	2.78
63.	5	Nagarajan R	UMS	1.62
64.	5	Omar M	UM	2.17
65.	5	Othman AT	UPM	1.65
66.	5	Rahman NA	UM	1.63
67.	5	Ramli AR	UPM	1.53
68.	5	Sahoo NC	MMU	1.92
69.	5	Salim N	UTM	2.03
70.	5	Tan SW	MMU	1.45
71.	5	Teo J	UMS	3.33
72.	5	Wahab, Habibah A	USM	1.62
73.	5	Wong EK	MMU	1.42
74.	5	Wong SV	UPM	1.28

[a] Sum of the number of articles calculated by n^{-1} individual authorship.

Table 5: Malaysia's First Authors Producing Four or More Papers During 2000 – 2010

First Author	2000 - 2002	2003	2004	2005	2006	2007	2008	2009	2010	Occurrences
Phan RCW	1	0	3	7	6	0	1	0	0	18
Jin ATB	0	1	5	2	3	1	1	0	2	15
Loo, CK	0	0	5	1	2	0	0	0	0	8
Wee CY	0	0	1	0	1	3	1	1	1	8
Vasant Pandian	0	0	0	1	2	2	0	1	1	7
Chong CW	0	4	1	0	0	0	0	0	1	6
Ibrahim Z	0	0	1	2	2	1	0	0	0	6
Tan, SC	0	0	0	0	1	1	2	1	1	6
Wong KY	0	0	0	1	1	1	0	1	2	6
Abidi SSR	2	1	1	1	0	0	0	0	0	5
Arumugam MS	0	0	0	1	0	1	2	1	0	5
Deris, MM	0	0	2	2	0	0	1	0	0	5
Lim CP	0	2	0	1	0	1	0	0	1	5
Logeswaran R	1	0	1	0	1	1	1	0	0	5
Teo J	0	1	1	2	1	0	0	0	0	5
Goh A	0	4	0	0	0	0	0	0	0	4
Ho CK	0	1	0	1	1	0	0	1	0	4
NgoDCL	1	2	1	0	0	0	0	0	0	4

From the 903 articles published by the 1662 Malaysian authors, a total of 52 first authors were identified. First authors are those authors whose name appears first in an article's citation. Table 5 provides the distribution of first author productivity, as measured by the number of papers. These data provide insights into author productivity within the field of

CS. The most number of articles was authored by Phan RCW (Swinburne, first author of 18 out of 21 papers) followed by Jin ATB (MMU, first author of 15 out of 33 papers). Sixteen other first authors wrote as many as four articles (Table 5) and 12 of the 52 first authors wrote only one article. It seems that the research fronts in the field of CS in Malaysia are being led by a small group of active first authors. These data provide the basis for the application of Lotka's Law.

Author Productivity Using Lotka's Law

The researchers checked whether Malaysia's CS literature in WoS is in compliance with Lotka's Law, which is applicable to author's productivity. Many researchers have used the method of calculating by Pao (1985), however this study employed Sen's (2010) method as it is "simpler and the former may not prove to be very good for all data sets" (Sen 2010). Sen demonstrated a simpler equation to represent Lotka's inverse square law which is mathematically expressed as:

$$x^{à} y = c \qquad \text{(Equation 1)}$$

where x stands for the author's contribution, y stands for the number of authors and c is a constant. The value of c was determined by putting in the value of the pair of data in the first row of Table 6 into Equation 1. Considering the fact that 1237 authors (considering all authors) have produced one article each, the value of constant c can be easily obtained:

$$1^{à} y = c \quad (1^{a} = 1) \qquad \text{(Equation 2)}$$
$$y = c$$
$$c = 1237$$

The value of à can be determined by using the pair of data in the second row into Equation 2:

$$2^{à} y = c$$
$$2^{à} = 1237 / 210 = 5.89$$
$$à = \log 5.89 / \log 2 = 0.7701 / 0.3010$$
$$à = 2.56$$

Comparing the data set appearing in the column 2 and 3 of Table 6, it may be said that the data sets do not follow Lotka's Law (the difference between the observed values and the expected values is wide for x=3). Lotka's Law indicates that " . . . the number (of authors) making *n* contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60 percent" (Lotka 1926, cited in Potter 1988). This means that out of all the authors in a given field, 60 percent will have just one publication, 15 percent will have two publications ($1/2^2$ times .60), seven percent of authors will have three publications ($1/3^2$ times .60), and so on. According to Lotka's Law of scientific productivity, only six percent of the authors in a field will produce more than 10 articles. Lotka's Law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general, but not statistically exact. Radhakrishnan and Kerndizan (1979) observed that Lotka's inverse square law relating the number of authors of papers to the number of papers written by each author does not apply to CS literature. Similar findings were obtained in Nath and Jackson (1991) and Merlo et al. (2011) in the CS sub-domain of Management Information Systems and CS journals respectively.

Table 6: Observed Values and Expected Values of Author Productivity using Lotka's Law

Contribution (x)	Contributors (y) (Observed values)	Observed % of authors	Number of authors (y) with the values à = 2.56 (Expected values)	Expected % of authors
1	1237	74.43	1237	74.43
2	210	12.64	210	12.64
3	103	6.20	74	4.45
4	38	2.29	36	2.17
5	23	1.38	20	1.20
6	19	1.14	13	0.78
7	7	0.42	9	0.54
8	10	0.60	6	0.36
9	1	0.06	5	0.30
10	1	0.06	3	0.18
More than 10 papers	13	0.78	49	2.95
Total	1662	100.00	1662	100.00

Authorship Pattern

Bibliometrics studies have shown that research in the sciences is predominantly carried out by group of researchers rather than by a single researcher. Through collaboration, researchers share and exchange knowledge and techniques, that results in the derivation of positive scientific thoughts and decrease research cost (Katz and Martin 1997). This study attempts to identify the nature of authorship pattern in scientific research output made by the CS researchers in Malaysian universities.

Distribution of papers according to number of authors is given in Table 7. These papers have been divided into four categories, namely single authored papers, two authored papers, multi-authored and mega authored papers. Multi-authored papers included papers with three and four authors, while mega authored papers included papers with five or more authors. It is evident that multi-authored papers rank first sharing 54.9 per cent (n=496) of the total research output and the trend drastically increases from 2008 onwards.

Table 7: Distribution of Authorship Pattern during 2000-2010

Authorship pattern	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	TOTAL
Single author	1	4	3	5	6	7	7	4	3	8	8	56
Two author	8	6	8	25	25	31	37	31	34	38	29	272
Multi author	11	10	21	37	49	47	49	33	62	61	116	496
Mega author	1	0	1	4	11	13	5	6	6	16	16	79
Total	21	20	33	71	91	98	98	74	105	123	169	903

We study the trend of collaborative research between Malaysia's CS researchers and investigators from other countries, by using the first top 100 authors list (sorted by record count). Malaysia's CS researchers have worked with at least 20 international collaborators resulting in at least 79 papers based on normal count. The percentage of international collaboration is found to be rather low. The maximum collaborative activity is found with Mukundan R (New Zealand, 9 papers) followed by Omatu S (Japan, 8 papers). Table 8

presents a list of major international authors who have collaborated with Malaysia's CS researchers, producing at least 5 papers. Co-authorship maps have been used in Glänzel and de Lange's (2002) study to reveal international collaborations as an indicator of quality and revealed that scientists who cooperate with their colleagues internationally are more likely to do quality research.

Table 8: Distribution of Major International Collaborators

No	Collaborators	Institutions (Country)	Paper counts
1	Mukundan, R	Univ Canterbury (New Zealand)	9
2	Omatu S(Omatu, Sigeru)	Osaka Prefecture Univ (Japan)	8
3	Ono S(Ono, Osamu)	Meiji Univ (Japan)	6
4	Tsuboi Y	Meiji Univ (Japan)	6
5	Kurosawa K (Kurosawa, Kaoru)	Univ Ibaraki (Japan)	6
6	Hanmandlu M	Indian Inst Technol (India)	6
7	Abawajy, JH.	Deakin Univ (Australia)	5
8	Bhattacharya, A	Bouddhik Sampada Bhawan. (India)	5
9	Olariu, S	Old Dominion Univ, Norfolk (USA)	5

Identification of Core Journals

The literature in CSs covered in the present study (2000-2010) comprises a total of 903 articles published in 191 journals and 150 proceedings. The largest number of papers were in *Lecture Notes of Computer Science* (172 papers), followed by *Lecture Notes in Artificial Intelligence* (32 papers). Table 9 illustrates the distribution of the articles in journals with JCR 2009 impact factor, a measure of quality. A significant number of articles (209, 23.1%) were published in 17 international journals with significant impact factor, including titles such as *Information Sciences, Expert Systems with Applications, International Journal of Innovative Computing Information and Control*, and *Applied Soft Computing*. Among the journals, 19 articles were published in the country's very own *Malaysian Journal of Computer Science*, which was first published in 1985 and indexed by WoS in 2008. This is definitely not an indication of national bias, which may be seen in scientists from many other countries of the world. The highly widespread field of research of the scientist is clearly discernible from the titles of journals (Table 9) which belong to varied fields such as expert systems, soft computing, neural computing, pattern recognition, computers and mathematics, chemical engineering, biology, education, industrial management as well as industrial engineering.

In total, the 675 articles are published in 191 journals. It is found that 71 journals published only one article each, 35 journals published two articles each, 26 journals published 3 articles each, 12 journals published 4 articles each, 15 journals published 5 articles each and the rest of 32 journals published more than 5 articles each. The journal publishing the maximum number of papers in any discipline is considered a core journal. Bradford's Law states that if a large collection of papers is ranked in order of descending productivity of journals relevant to a discipline, three zones can be identified so that each zone produces one third of the total relevant papers. As such, each zone should account for roughly one third of this number, i.e. 225.

Table 9: Articles Published in Journals with Impact Factor

Source title	No. of Articles	Impact factor from JCR 2009	Country
Expert systems with applications	29	2.908	United States
Industrial management & data systems	19	1.535	England
Applied soft computing	14	2.415	Netherlands
Computers in biology and medicine	14	1.269	United States
International journal of innovative computing information and control	12	2.932	Japan
Computers & chemical engineering	12	1.808	United States
Pattern recognition	12	2.554	England
Computers & education	11	2.059	England
Computers & industrial engineering	11	1.491	England
Computer communications	11	0.933	Netherlands
Information sciences	11	3.291	United States
Neural computing & applications	11	0.812	United States
Simulation modeling practice and theory	10	0.799	Netherlands
Computers & mathematics with applications	10	1.192	England
Advances in engineering software	8	1.045	England
Fuzzy sets and systems	8	2.138	Netherlands
Mathematical and computer modeling	6	1.103	England
Total	209	1.781*	

* Average Impact Factor

Table 10: Fitting Bradford's Law to the Distribution of Journals Publishing Malaysia's Computer Science Papers

Zones	No of articles	No of journals	Accumulated Journals	Accumulated articles
(A) Core (16 journals)	29	1	1	29
	19	3	4	86
	14	2	6	114
	12	3	9	150
	11	5	14	205
	10	2	16	225
(B) Relevant (43 journals)	9	2	18	243
	8	2	20	259
	7	3	23	280
	6	9	32	334
	5	15	47	409
	4	12	59	457
(C) Marginal (132 journals)	3	26	85	535
	2	35	120	605
	1	71	191	675

Table 10 provides the number of publication in each journal and relevant information ranking by the number of published paper according to Bradford's Law zoning. It shows that 16 journals (8.3 per cent) published maximum segment with 33.3 percent of articles while the second larger group of 43 journals (22.5 percent) provided the next 34.5 per cent

articles. The third largest of 132 (69.2 per cent) journals published the next 218 articles (32.2 per cent). According to Bradford's Law of distribution the relationship between the zones is 1: n: n^2. The relationship between the zones in the present study is 16: 43: 132 (quite close to 1:3:3^2), and it can be inferred that the distribution of journal articles is quite close to Bradford's distribution.

DISCUSSION AND CONCLUSION

Evaluating the productivity of institutional research and developmental activities highlights the contribution of the institution and the individual scientists engaged in research, as well as providing some insights into the dynamics of research activity and directs the research activities in a proper direction. This study looked at research productivity of Malaysia's CS researchers. The results appearing in this paper represent the publication productivity of 1662 Malaysia's CS researchers based on 903 records retrieved from WoS for the period 2000 to 2010. This analysis provides an understanding of the state of CS research in Malaysia and examines publication productivity at the individual and institutional level. Both the normal and fractional counts were used in our evaluation. In brief, the following findings are highlighted:

a) The number of Malaysia's CS papers in WoS keeps growing in the studied period. This may reflect the high priority that has been given to publishing research output in highly-ranked scholarly publications in recent years.
b) At the institutional level, MMU exceeds other Malaysian universities in CS research productivity (25.4%) for the period studied, followed by USM (15.2%), and UM (11.1%). This may be partially explained by the fact that these universities have a long tradition to publish in highly-ranked scholarly publications. Gu and Zainab's (2001) earlier study on the other hand found that active authors were affiliated to a few institutions, with UTM, USM and UM accounting for the highest number of CS publications, either in the form of journal articles or papers in conference proceedings.
c) The three most productive authors were Lim CP (USM, 34 papers), followed by Teoh ABJ (MMU, 33 papers) and Ngo DCL (MMU, 29 papers). The results suggest that the number of new and prolific authors entering into the pool of total publication within the period under study is high, as compared to Gu and Zainab (2001). In the case of author productivity, it can be concluded that a small number of scholars are responsible for a significant number of publications.
d) The papers were predominantly contributed by multi-authors indicating that research teams rather than individual authors are active in the field of CS research in Malaysia.
e) In spite of the increasing number of Malaysian papers in WoS, the percentage of international collaboration is found to be low. It is concluded that CS publications from Malaysia are mostly the result of local collaboration. This shows that Malaysia's CS researchers are more likely to collaborate with domestic fellows. This concurs with Bakeri and Willet's (2009) analysis of publication and citation patterns in the *Malaysian Journal of Computer Science (MJCS)* from 1996-2006 where they found that the articles in *MJCS* are mostly written by Malaysian academics, with only limited inputs from international authors.
f) A total of 74.8 percent of the Malaysia's CS papers indexed in WoS are in the form of journal articles. With regard to the standing of the journals used by the CS researchers, 209 (23.1%) articles were published in journals with current Impact Factor. This indicates that the visibility of Malaysia's contribution throughout the

period is low. *Expert Systems with Applications* contributes the highest number of articles.

g) With respect to conference proceedings, this study found that about 25.0% made their way to WoS. This seems to corroborate with earlier literature that suggests a role of conference papers to computers scientists: as a substitute for journal article (Goodrum et al. 2001). This view of the communication value of conference proceedings in CS has also been noted by Kling and McKim (1999).

h) The frequency distribution regarding author productivity did not match Lotka's Law, however it should be stressed that Lotka's inverse square law is a general, theoretical estimate of productivity, and is not a precise statistical measurement (Potter 1981). On the other hand, the scattering of articles distributed in journals publishing Malaysia's CS research is quite close to Bradford's distribution.

This study is not without limitation. It used WoS exclusively as a source of bibliometrics data in the CS domain where conference proceedings represent a major channel of written communication. Articles published in non-SCI indexed publications were not included although they contributed to scientific production. As such more studies are needed to compare the research productivity of Malaysia's CS researchers based on their publication coverage in non-SCI databases such as Scopus and Google Scholar. In addition, we searched journals included only in the five sub-domains of CS, although many articles regarding CS and information technology are published in journals of fields such as engineering, telecommunications and robotics. Furthermore, it does not delve into the possible explanations for the Malaysian publication pattern of low volume, and the low level of publications in top journals. However, we believe that this work can be a basis for future studies aimed to create a clear picture of the nature of communication and scientific contributions of CS researchers in Malaysia.

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