Analysis of academic research performance from publications in the field of Computer Science

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ABSTRACT
Research performance in academia is treated as one of the metrics for national competency. Many countries devote a high level of commitment and resources to improving their research performance. This paper illustrates computer science research covering a ten year period (2001-2010) in several countries in Asia and prominent countries represented by the Group of Eight (G8). The study used different indices to analyze aspects of scientific publications, such as publication quantity, popular subjects and research quality, to evaluate a country’s academic performance. We generalize the previous indexes and create novel indexes to construct an integrated study to evaluate and gain a clear view of countries’ research performance. Our research found that countries with the highest productivity seldom have the strongest impact on research. Some countries, such as Malaysia, have a greater impact than many other countries even though they demonstrate lower production. Our research suggested that scholars in countries with lower production can pay more attention to interdisciplinary applications to increase their competency in the area of computer science.

KEYWORDS: Scientometric analysis; Bibliometrics; Research productivity; Research impact; Computer science research;

INTRODUCTION

With the increase in worldwide dissemination of research, academic research performance is being treated as one of the indexes of national competency; as a result, countries worldwide are paying more attention to their academic research productivity and impact (van Damme 2001). A comprehensive method of analysis would help scholars who are already involved in or who wish to get involved in scholarly communication to evaluate and understand research performance in a given discipline. Evaluating a country’s research
performance within a specific discipline can give scholars a point of reference for their research performance. There are two ways to assess a country’s academic research performance. The first is to observe the number of papers produced and the overall contribution of the papers in a discipline; the second is to observe the impact of the papers on the discipline or refer to citation counts or indexes (Bordons, Fernandez and Gomez 2002).

Bibliometric analysis is a mathematical or statistical method that can be used to organize, classify and quantize any kind of publication (Sengupta 1985). Similar to bibliometric analysis, scientometric analysis is a process used to evaluate scientific research performance. Scientometric analysis classifies disciplines and compares the quantity and characteristics of research performance in one country with those of other countries (van Raan 2008). Therefore, both bibliometrics and scientometrics are methods of analysis that use publications to evaluate scientific output. Both methods can examine research performance within a specific discipline and compare different countries’ scientific production.

To evaluate scientific production, this study first collects previous indices to assess different aspects of research performance, such as production quantity, collaborative character and research impact, and then chooses suitable indices for the purpose of our metastudy. However, if the current indices pay insufficient attention to, for example, the impact of popularity, Gross Domestic Product (GDP) or other external factors on a country’s quantity of production, we note this concern and develop novel indices. Our analysis targets the academic research performance for a country or regional groups in the computer science discipline, observes its development over the years and compares it with prominent countries that serve as examples of strength and weakness in this area.

**LITERATURE REVIEW**

Raising (1962) defines bibliometrics as the statistics related to both journal and bibliography, which aims to study the condition of national and global journals. Nevertheless, some scholars offer different definition – for example, the statement and relative behavioral research by dealing with record format in quantification way (Fairthorne 1969); communication models (Potter 1981); or the quantified research which used statistical analysis to get further information (Boyce and Kraft 1985). Bibliometrics is categorized into two major research scopes, descriptive bibliometrics and evaluative bibliometrics (Steven 1983) Discriptive bibliometrics is mainly used to calculate the
productivity such as the production of published works of a country or an institution in a particular period of time, including journals, books, conference papers and research papers. It also includes the language, information type, the composition and distribution of the literature, and the research approaches. On the other hand, evaluative bibliometrics which can evaluate the quality and influence of the literature takes advantage of references and citations to analyze the amount of literature use (McBurney and Novak 2002). In addition, citation analysis can be one of the tools to evaluate the influence of journals (Garfield 1972; Meho 2007). In terms of the citation times of literature (evaluative viewpoint), the common issues are cited frequency, cited percentage, self-citation, co-citation issues and their relativity (i.e. regionalism and subject matters).

Bibliometrics has also an application on the investigation of the literature distribution. For instance, the well-known Bradford’s law can find out the core academic journals of the subject (Gu 2004). Furthermore, for exploring the scientific productivity, Lotka (1962) conducted a research about the frequency distribution of scientific productivity. He proposed that the number of the author publishing $x$ of articles is approximately equivalent to $1/x^2$ of those publishing one article. In addition, Zipf (Zhang 2009) made vocabulary distribution statistics on literatures and found that there showed No. $n$ common word in every $10^n$ words, which aroused many discussions. Bradford’s Law, Lotka’s Low and Zipf’s Law are therefore regarded as three major principles in bibliometrics.

Scientometric analysis, on the other hand, is a measurement method which can process scientific information and its core is to utilize mathematical patterns to analyze scientific activities. The term “scientometrics” can be traced back to 1969 when Dobrov and AKarennoi proposed it in the published item of the Federation Internationale de Documentation (FID) (Dobrov and AKarennoi 1969). It got widespread recognition in 1978 when Tibor Braun established a journal named *Scientometrics*, in Hungary. As to research content, there are some overlaps between scientometrics and bibliometrics. In deeper meanings, however, the targets of bibliometrics include bibliographies and published items, while the discussion of scientometrics extends to all fields associated with information including sociometrics, econometrics and biometrics, viewed as having much more potential than econometrics, sociometrics and even bibliometrics (Price 1978). Trofimenko (1987), who thought that scientometrics took advantage of various information such as publication quantity, literature citation, expert’s opinion and literature content analysis, used statistics and theme analysis to explore the growth of scientific field. Van Rann (2008) emphasized that scientometrics is a process of evaluating research performance by comparing different fields in different countries and evaluating the influence and contribution of research results and also observing the research scale and feature of the
target in this field.

Dobrov (1978) explained that the scope of scientometrics was to study the scattering and aging of information, the structure of information flows, citation analysis and features. Since some part of research in scientometrics overlaps with bibliometrics, it is similar to bibliometrics in some sense, and can also be applied to both quantitative research of Library and Information Science and the production research of author’s articles (Rao 1998). The evaluation of the research result could be reviewed from the angles of an individual, an organization and a country. This study takes bibliometrics as the basis and uses scientometrics to increase other considerations to find information that differs from the past.

**MATERIALS AND METHOD**

This paper used data abstracted from the Institute for Scientific Information’s (ISI) Web of Science database. The ISI offers a large amount of scholarly literature in the sciences, social sciences and humanities; most of the articles are published in the English language. Our research accessed the raw materials sorted by nations and gathered articles indexed in the Science Citation Index (SCI) or the Social Science Citation Index (SSCI). The subject area follows the Web of Science category, and the analysis covers the past ten years (2001-2010).

In East Asia, we analyzed publications from China, Hong Kong, Japan, Korea, India, Malaysia and Singapore. We separated Hong Kong from China for historical reasons. We considered India and Malaysia because of their potential impact in computer science research (Garg and Kumar 2005; Abrizah and Wee 2011). Our research assumed that prominent countries influence research trends, and we took the Group of Eight (G8) countries as representatives of prominent countries. The G8 countries are England, the USA, Germany, France, Japan, Russia, Italy and Canada, giving us a total of 15 observations.

We chose computer science as our target discipline for the following reasons. First, many countries place a high priority on the development of computer science and the discipline requires many individuals who are talented in hi-tech fields (Indjikian and Siegel 2005). Thus, there are many computer science-related departments in colleges and universities, and most students major in science or related subjects rather than the humanities and social sciences (Marina 2008). Second, production is increasing in many academic fields, and the growth rate in computer science is accelerating rapidly (Crespi et al. 2011).
Figure 1 shows the research procedure for processing and analyzing research performance indicators to track the development of research trends in computer science discipline. We also analyze the research performance of neighbouring countries to compare the research preference in the region, and that of prominent countries to understand the differences among them and the recent research trends. The system used for analysis is composed of three modules: data retrieval, index calculation, and comparison and analysis. Collection and classification are included in the data retrieval module. We download and parse abstracts of articles from public databases and process them for the next stage. In the index calculation, we compute statistical information using scientometrics and bibliometrics methods. This information is used in the next stage to compare and analyze single or regional targets to trace the countries’ research development over the years.
Data Retrieval

In the first stage, we download and filter data to retrieve the required sources. Through a retrieving programme, we abstract key information, such as journal name, author list, article category, nationality, organization list, and keywords. We process the article data by attributes, such as nationality or journal category, and store them in a local database. During this process, our research allows multi-subject categories for articles. That is, if an article belongs to three categories, the local warehouse can search and find articles from all three categories.

Index Calculation

In this stage, the abstracted literature data are used to analyze the quantity and quality of the literature. We divide the analysis into four sub-modules: production, collaboration, popular topics and impact analysis. We integrate and choose suitable indices for our study and create novel indexes if the existing ones are insufficient.

(a) Productivity

The first task is to observe research productivity and calculate the following indicators:

i) Total number of papers published per year in the nation.

ii) Average number of papers per author.

iii) Average number of authors per paper.

iv) Article type.

v) Transformative Activity Index (TAI). TAI can analyze a country’s production compared with other countries using the following formula (Karki and Garg 1997):

\[
\text{TAI} = \frac{C_i}{W_i} \times 100, \quad (1)
\]

where \(C_i\) represents the number of papers published in the country and in a given field in year \(i\), \(C_o\) represents the number of papers published in the country and in the given field for all of the years, \(W_i\) represents the number of papers published globally in the field in year \(i\) and \(W_o\) represents the number of papers published globally in the field for all of the years. A country is considered to be active in the given discipline if its TAI is greater than 100.

vi) Population Performance Index (PPI): Research performance can be observed through production over the years; however, considering productivity as the only indicator introduces bias. This paper is concerned with other factors that affect a country’s productivity, such as national population and GDP. Our research attempts to measure those factors and create novel indices if possible to account for them. First, we examined the relationship between production and population from 2002 to 2006; second, we analyzed the relationship between production and GDP and between
production and population. The relationships are shown in Figure 2. We found that:

- A country’s production and GDP are highly positively correlated. In other words, the higher a country’s GDP, the higher its scientific production.
- There is little or no relationship between a country’s production and its population. Therefore, we designed an indicator to determine the country in which people have highest research production.

![Figure 2: Relationship between production, GDP and population](image)

The level of a country’s production might be influenced by its geographical area. For example, Taiwan and Singapore are crowded but geographically small. However, the lower production of these countries does not correspond with a less significant contribution to the discipline. We designed a novel index to account for population:

$$PPI = \frac{P_{ij}}{P_{io}},$$  \hspace{1cm} (2)

where $P_{ij}$ represents the number of authors in country $i$, $P_{io}$ represents the population of country $i$, $P_{oj}$ represents the global number of authors, and $P_{oo}$ represents the global population. This index measures the percentage of authors in a given country’s population relative to the world average. A PPI greater than 1.0 indicates that the proportion of authors in the given country is greater than the world average.

vii) Normalized Productivity Index (NPI), another proposed index that is also based on population, is calculated as the ratio of the number of papers per author to the global average. The formula is as follows:

$$NPI = \frac{D_{ik}/P_{ij}}{D_{ok}/P_{oj}}.$$  \hspace{1cm} (3)
where $D_i$ represents the number of papers published from country $i$, $P_i$ represents the number of authors in country $i$, $D_{ok}$ represents the total number of papers published globally, and $P_{oj}$ represents the total number of authors globally. An NPI greater than 1.0 indicates that the country's scientific productivity is greater than the world average. This index adjusts for the influence of population density and emphasizes countries with a larger population in a small geographical area or those with a large geographical area but a smaller population.

b) Impact analysis

To analyze countries' scientific output, it is necessary to examine not only quantity but also impact analysis. Based on the principle that “the more often a country is cited, the more influence it has in the specific area,” we evaluate different countries’ influence based on citation counts. Common indices for impact analysis include the Impact Factor (IF; Garfield 1955), Article Impact Factor (AIF; Sombatsompop et al. 2006), Normalized Impact Factor (NIF; Sen 1992), PEI (Nagpaul 1995), H-index (Hirsch 2005), and CPP/FCSm (Moed, De Bruin and Van Leewen 1995). However, some indices are not suitable for our purposes. For example, the IF is used to evaluate journals, and the H-index is used to evaluate personal impact (some authors have adapted the H-index to examine journal or conference influence, but generally, this has been neglected over time). Another index, the PEI, is calculated using the NIF, and both are more suitable for cross-disciplinary studies. Our study focuses on one category: computer science. Therefore, we choose the following two indices for our impact analysis:

i) Article Impact Factor (AIF): The AIF is an index that calculates the number of citations originating from each country. The larger the AIF is, the more influence the country has in that area. The formula for the AIF is as follows:

$$\text{AIF} = \frac{\text{the total citation counts of the articles authored by country } i}{\text{the number of articles published by country } i}.$$  

ii) CPP/FCSm: The AIF can only calculate the percentage of citations for each country; our study further examines the status of countries in the target discipline using the CPP/FCSm. The FCSm calculates the mean citation counts; if a country's citation counts are greater than the world average, then the CPP/FCSm is greater than 1.0, indicating that the country is more powerful in the target discipline. The formula for the CPP/FCSm is as follows:

$$\text{CPP/FCSm} = \frac{\text{citations per paper}}{\text{mean of field citation scores}}.$$  

So far, this paper has presented evaluation methods such as productivity and impact analysis. The question is whether a large quantity represents a greater impact within the
discipline and, conversely, whether a lower quantity implies a lesser impact in the area. How do we explain a country that has a large quantity but lower citation counts? Therefore, to balance production and impact, our study creates a novel index, the F-index, to examine the problem. The F-index is a combined index for production and impact evaluation and is computed as follows:

$$F\text{-index} = \frac{2 \times \text{production indicator} \times \text{impact indicator}}{\text{production indicator} + \text{impact indicator}}.$$  \hspace{1cm} (6)

The concept of the F-index is extended from the popular index F-measure, which is commonly used to measure accuracy. We take the TAI as the production indicator and the CPP/FCSm as impact indicators. The F-index is a composite index for productivity and article impact. An F-index greater than 1.0 indicates that the influence of the given country is greater than the world average.

RESULTS

Productivity

The number of papers in computer science, as covered by the Web of Science, increased from 16,965 in 2001 to 36,420 in 2006 but dropped to 23,012 in 2010. Figure 3 shows the percentages of papers produced by each country observed in our research from 2001 to 2010. The top five countries with the largest production are China, the USA, Germany, England and France. Figure 4 shows the publication productivity trend in term of paper counts for each country.

Figure 3: Country-wise Publication Productivity in Computer Science Research During 2001–2010
Due to the differences in geographical size and population, we cannot evaluate productivity based on only the number of papers produced by a given country. Our research aims to evaluate countries’ research outputs based on a variety of factors. The growth rate in terms of quantity shows that from 2001 to 2006, paper output increased in each country except for Russia (Figure 5a) and that all countries have experienced a decrease since 2006. The quantity growth rate in Russia was positive from 2002 to 2005 but has decreased since 2006. A comparison of the years 2002 and 2006 shows that China and Korea progressed tremendously in computer science research publication, with growth rates of nearly 400%. Moreover, apart from China and Korea, India (183.14%), Canada (124.70%) and Hong Kong (121.37%) had growth rates over 100%. The comparison of growth rates (Figure 5a) shows that four of the top five most productive countries are located in Asia and that Russia has experienced negative growth since 2005.

We divide the first ten years after the year 2000 into two periods to evaluate the growth of different country in computer science domain (Figure 5(a) and Figure 5(b)). We found Malaysia has less research in computer science domain before 2006 compared to the other countries (this is why the data for Malaysia’s publication productivity is not transparent in Figure 5(a)). However, from 2006 to 2010, Malaysia has incredible growth rate in computer science domain than the other countries. It is observed that while most developed countries have been putting efforts computer science research since 2000, Malaysia has been picking up in this domain after 2006 and this finding is consistent with Abrizah and
Wee's (2011) study who found that the overall output of computer science research productivity in Malaysia has grown steadily since 2006.

Figure 5a: Growth Rate of Publication Productivity by Country (2001-2006)

Figure 5b: Growth Rate Publication Productivity by Country (2006-2010)
A TAI indicator value of 1.0 represents the world average. Most countries have TAI indicator values of between 0.8 and 1.2, which means that they achieve the global average. Malaysia’s TAI value dramatically increased from 0.4 to 2.2, indicating that the country has experienced high growth in computer science research. The TAI value for China and Korea increased from 0.6 in 2001 to 1.3 in 2006 but has decreased since 2006. The TAI value for Russia decreased from 1.6 to 0.86, and that of the USA also decreased from 1.65 to 0.84. Therefore, compared with other countries, Russia and the USA experienced slower growth in computer science research productivity. On average, Asian countries experienced fair or high growth in computer science, and Taiwan, Korea, China and India are the most productive countries. The growth rates of the G8 countries remained constant or decreased slightly.

The PPI indicator is an index of the percentage of authors in the national population. Our research finds that Singapore, Hong Kong, Canada and Taiwan have higher PPI values, especially Singapore. This finding means that these countries are less populous but have a higher percentage of authors compared with the average for all countries observed in our research. India, China and Russia had lower PPI values because their large populations dilute the percentage of authors in their country.
The PPI allows us to observe the proportion of authors to the national population, and it can detect whether a country’s proportion of authors has increased. For example, the TAI for Korea obviously increased during 2001–2006, as did its PPI. Thus, it is clear that Korea put great effort into this research area. By contrast, China’s TAI value is rising rapidly; however, the growth rate of China’s population is greater than the growth rate of the number of authors in China, resulting in China’s PPI being lower than that of other countries. Therefore, our research suggests that the TAI should be combined with the PPI as a reference for the effect of population on publication productivity in a given country.

Figure 8 illustrates each country’s NPI. The NPI is an index that calculates the ratio of the number of papers per author in a given country to the world average. The NPI value of 1.0 represents the world average, and if a country’s NPI is greater than 1.0, then author productivity of that country is above the world average. In computer science, Taiwan, Korea, and India have the top three highest NPI values. With regard to the number of authors in each country, these three countries have the lowest production. Thus, the NPI can detect countries with fewer papers or a lower population but higher productivity rates compared with the world average.
Impact Analysis

Three indices are used in the impact analysis: the AIF, CPP/FCSm and F-index. The AIF is an index used to calculate the citation counts in a country compared with the number of papers that the country produced. Russia and Korea have the lowest citation rates per year. Except for the years 2006 and 2007, the AIF in all countries generally decreased due to decreasing publication productivity. Figure 9 illustrates the trend.

The average AIF for the ten-year period is 3.15. Surprisingly, Malaysia ranked at the top for the AIF index, with a value of 5.3, giving an indication that Malaysia is influential in computer science research even with low paper production. England (3.85), the USA (3.57), Germany (3.39), France (3.36), and Canada (3.3) had high AIF values, and all of them belong to the G8. Based on the principle that “the higher percentage of citations, the more powerful a country is in the discipline,” we find that the G8 countries are powerful in the field of computer science. Among the other Asian countries, Hong Kong and Singapore have higher AIF values, while Taiwan, with an AIF of 1.92, ranks ninth out of the 15 countries observed.
While the AIF uses the number of papers and citations for a country, the CPP/FCSm compares a given country with the global average. If the CPP/FCSm is greater than 1.0, then the country is more powerful than the world average. The observations are shown in Figure 10. CPP/FCSm values in the range of 0.8 to 1.2 represent the world average; values smaller than 0.8 means that the country’s research performance is below the world average, values greater than 1.2 represents better performance, and values greater than 2.0 indicates excellence in the research field. For example, Taiwan’s CPP/FCSm values are all above 0.8, meaning that its research performance meets the standard of the world average. Malaysia is ranked first, with a high average value of 2.8; this value indicates that Malaysian computer science researchers often cite their papers. Among other prominent countries, England, France, and Germany increased their values above the world standard. For England, the CPP/FCSm value reached 1.5 in 2005 and rose to 1.66 in 2006. Russia was below the world average, except in 2006, when its value jumped to 1.18, indicating that the country improved its performance that year. Japan was also below the average, except in 2006, when it climbed into the average range. The other members of the G8, namely the USA, Canada and Italy, were in the world average range every year. Among the Asian countries, Singapore has the highest CPP/FCSm value, while Korea has the lowest.
The F-index is a novel index developed to combine production and research quality. We find that most of the countries observed had an F-index in the range of 0.8 to 1.1, meaning that in terms of both quantity and quality, most countries meet the world standard in the field of computer science. Over the past ten years, Malaysia (1.25), England (1.12) and France (1.06) have been in the top three average F-index values. Taiwan (0.95) was placed tenth, and Japan (0.84), Russia (0.74) and Korea (0.72) had the lowest F-index values. Figure 11 illustrates the findings.

The F-index of Taiwan is close to the average value for the past ten years, meaning that
Taiwan’s research performance in computer science is at the average level. Malaysia had the best research performance of all of the countries observed; moreover, its F-index for 2010 (2.53) was incredibly high, further confirming the country’s research excellence in computer science. The USA achieved the world average, but its F-index value decreased slightly in recent years. Singapore’s ten-year average F-index value is 1.02, placing it in the top five, and it was also ranked in the top two in 2006. Although China has a decreased CPP/FCSm value, its F-index value increased because of the rapid growth of production in the country. Russia and Korea had lower F-index values. The F-index value for Russia increased slightly over the ten-year period, and that of Korea also increased slightly and fluctuated around 0.75. The F-index for Japan (0.86) is slightly below the world average. Because Japan is a prominent country with the second largest GDP in the world, we postulate that its lower F-index is the result of the country making greater effort in other research disciplines.

Our research concludes that most of the G8 countries produce more papers and accumulate more citations in the field of computer science and therefore have larger CPP/FCSm and F-index values, indicating that the G8 countries are more prolific in computer science research than the Asian countries sampled. For example, England is a typical prominent country in our observations. The Asian countries that had a higher impact usually collaborated with multiple authors, while G8 countries published more single-author papers. All of the countries prefer national collaboration, which suggests that national collaborations have a higher chance of garnering citation.

CONCLUSIONS

To examine countries’ research performance within a specific discipline, this paper constructed an analytical system consisting of three modules: data retrieval, index calculations, and comparison and analysis. The first module, data retrieval, extracted literature from public databases, filtered it by region, and then stored the information in a local data warehouse. The second module, the index calculations, enabled us to examine each country’s performance in each factor. Finally, through comparison and analysis, we gathered regional observations and offered an interface for users to understand the differences between our country, comparable neighbors and prominent countries.

The contribution of our research is that this system gathers multiple indicators about a country’s scientific output, categorizes the output into different dimensions and creates novel indices for completeness. This research separates the indices into two outcomes:
publication productivity and impact analysis. For productivity, we calculate the number of papers published each year for every country, the growth rate, journal types and the TAI, PPI and NPI indicators. Among those indicators, the PPI and NPI are new indices that mitigate the effect of population on a country’s production. They avoid the bias that large populations give to countries publishing more papers and identify countries with small populations but abundant production. Finally, for impact analysis, our research collects and filters the suitable indices, the AIF and CPP/FCSm, and combines them with the novel F-index to complete the assessment.

Our study focused on countries’ research performance to help scholars understand the strengths and weaknesses of individual country’s scholarly communication. Currently, we observed data from the period 2001 to 2010. Some observations would be easier to be explained if the period of study is extended. For example, Russia has decreased publication productivity but an increased impact analysis in terms of CPP/FCSm. A more extensive study might reveal the causes of this phenomenon.

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