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Limitations of citation analysis on the measurement of research impact: A summary

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ABSTRACT

Although citation analysis is broadly used to design and develop bibliometric indicators or methods measuring the research impact, some limitations of citation analysis regarding citing motivation and behavior, database coverage and bias, as well as the analytical methods may threaten the validity and reliability of the measurement. This paper reviews the literature on the limitations of citation analysis in the measurement of research impact, which is not addressed by many bibliometric studies introducing new indicators or methods for research evaluation, to remind researchers of the possible inappropriate use of citation-based indicators or methods on research evaluation.

KEYWORDS

Citation analysis; Nature of citation; Limitation; Measurement of research impact

Introduction

Citation analysis is the core of bibliometrics in which citations are used to measure the impact of research (Garfield, 1972, 1979; Melkers, 1993). Each citation is regarded as an acknowledgement to the distinctive contribution of the previous work (Kaplan, 1965; Merton, 1973), thus citations received could represent the intellectual influence of the research (Baldi, 1998). As a result, the number of citations received is used to measure the research quality or impact, and many citation-based indicators (e.g., total number of citations, average number of citations, number of highly cited publications, proportion of highly cited publications, h-index, etc.) are designed and developed for the purpose of research evaluation. However, some limitations regarding citing motivation and behavior, database coverage and bias, as well as the analytical methods may detract from the validity and reliability of the measurement when using citation-based indicators. Unfortunately, these limitations were not well addressed by bibliometric studies introducing new method of measurement or indicators. The purpose of this paper is to review the literature regarding the limitation of citation analysis, which should be aware when measuring the research impact using citation analysis.

Citation Analysis

The term bibliometrics was created by Alan Pritchard in 1969 as "the application of mathematics and statistical methods to books and other media of communication" (Pritchard, 1969, p. 349). Bibliometrics originates from library activities such as counting books, articles,

publications, citations and their attributes (Bawden & Robinson, 2013) to analyze academic literature and measure the output of scientific research (De Bellis, 2009; Melkers, 1993). As a key subfield of bibliometrics, citation analysis is defined as the examination of the patterns and frequencies of citations in articles, books and other publications (Garfield, 1979; Moed, 2005). Citation analysis focuses on the analysis of bibliographic references, "which form part of the apparatus of scholarly communication" (Nicolaisen, 2007, p. 609).

A brief History

Although there is no agreement on when citations originated, most of historians of science believe that scientific authors started to cite and refer to earlier works (theories, methods, concepts, etc.) that related to their own works in the end of the sixteenth century (Nicolaisen, 2007). It has become a scientific tradition giving credit to other researchers and acknowledging their contributions to your work in the form of reference citations (Garfield, 1977).

In 1927, Gross and Gross (1927) conducted the earliest citation analysis and found the skewed citation distribution from 3,633 bibliographic references in the Journal of the American Chemical Society. It is regarded as the beginning of citation analysis. With the development of computers and databases, citation analysis entered the modern era by the appearance of Science Citation Index (SCI) database, created by Eugene Garfield and his Institute for Scientific Information (ISI) in 1963. Citation indexes allow for the efficient citation tracking and journal impact evaluation based on the number of citations (Garfield, 1972, 1979), and the exploration of research networks by co-citation analysis (Small, 1973). Price (1963) used quantitative methods to describe the growth of science, which established the field of bibliometrics as "the science of science" (Price, 1965).

Citation analysis is broadly used in many research fields to explore the advancement of knowledge and the impact of research in their fields (Melkers, 1993). As Zunde (1971) and Nicolaisen (2007) describe, citation analysis has four main applications as (1) qualitative and quantitative evaluation of scientists, publications, and scientific institutions; (2) modeling of the historical development of science and technology; (3) information search and retrieval; and (4) knowledge organization.

Measurement of Research Impact

According to Merton (1973), citations are regarded as social rewards to scientists by granting them recognition for their distinctive contributions, which provides the fundamental basis for using citation analysis to measure research impact. Since the reason to cite is to acknowledge others'intellectual influence (Baldi, 1998), the citation is regarded as an indicator of research impact or quality (Cole & Cole, 1967); and the purpose of citation analysis is to obtain indications of research quality from the citations in scholarly publications (Moed, 2005). Based on the normative theory, Smith (1981) creates the following assumptions for describing citation analysis:

- Citation of a document implies use of that document by the citing author.
- Citation of a document (author, journal, etc.) reflects the merit (quality, significance, impact) of that document (author, journal, etc.).
- Citations are made to the best possible works.
- A cited document is related in content to the citing document.
- All citations are equal. (Smith, 1981, pp. 87-89)

Following these assumptions, the citation analysis is usually equated with citation counts provided by citation databases; and these simple citation counts become one of the most measurable indicators of research impact (Ding et al., 2014; Zhang, Ding, & Milojevic, 2013). On the basis of citation counts, some other indicators (e.g. impact factor, h-index, etc.) have been developed to measure the research impact of a certain article, journal, individual, institution, or country (Brown & Gardner, 1985).

Limitation

However, citation counts are often criticized because they offer no information concerning quality. It is argued that citation analysis evaluates quality through purely quantitative means (Melkers, 1993) under the assumption that more must be better; there is no justification for the claim that "quality as measured by citation analysis is what quality is" (Moed, 2005, p. 26). Moreover, comparisons between scholarly disciplines are difficult because citation frequencies vary significantly across disciplines (Okubo, 1997) as some disciplines systematically cite more works than others. It also shows that the reliability of citation analysis may be affected by misprints and spelling errors, incorrect author attributions, and author name ambiguity (André s, 2009; De Bellis, 2009). Indeed, both the validity and the reliability of citation analysis have being challenged by scholars (Bloor, 1976; Cozzens, 1989; Edge, 1977; Knorr-Cetina, 1981; Latour & Woolgar, 1979; MacRoberts & MacRoberts, 1984, 1989; Moravcsik & Murugesan, 1975; Murugesan & Moravcsik, 1978; Simkin & Roychowdhury, 2003; Swales, 1986; Voos & Dagaev, 1976; Zhu, Turney, Lemire, & Vellino, 2015)

In addition, some scholars even argue that the purpose of citation is not to acknowledge others'contribution but to convince audience of the authoritative of research findings (Gilbert, 1977), which subverts the conceptual framework of the citation analysis. Some scholars appeal to using the content citation analysis instead of the simple citation counts (Ding et al., 2014; Hou, Li, & Niu, 2011; Moravcsik & Murugesan, 1975; Simkin & Roychowdhury, 2003; Zhang et al., 2013; Zhu et al., 2015), which is used by almost all research measurement using citation analysis.

In summary, the limitations of citation analysis on measuring research impact could be grouped into three categories: (1) argument on the nature of citation; (2) threats to research validity; and (3) threats to the research reliability.

Argument on the Nature of Citations

The theoretical framework of citation analysis is based on the normative theory contributed by Merton (1957), suggesting that scientists give credits to peers whose works have the intellectual influence on their current works. Thus citations could be counted as the research impact of authors whose works are recognized. On the other side, based on the constructive theory, Gilbert (1977) proposes a totally different notion that the citing is only an aid to persuasion. It means that citations have nothing to do with credits or research impact.

Normative Theory vs. Constructive Theory

According to the normative theory (Merton, 1957), science could be regarded as a social institution with values, norms and organization. The institution of science can reward its members (scientists) because of their performance. Members also would like to present their achievements in order to get the rewards. Merton (1973) also points out that the scientific achievement can be rewarded only if others admit it. As a result, scientists are eager to pub-

lish their works; peers read the publications and recognize their achievements by citing them in their own works.

In addition, in this social institution, scientists must be aware of the norms of science and abide by these norms (Storer, 1966). Kaplan (1965) points out that citing should be regarded as a normative behavior. Specifically, the norm requires scientists to give credit where credit is due whenever they use others' works. The normative theory of citation forms the theoretical foundation of using citation analysis to measure the research impact.

On the other hand, constructivism is a theory of knowledge about how people construct their own understanding and knowledge of the world. Piaget (1971) points out that humans learn through the construction of one logical structure after another by experiencing things and reflecting on those experiences. Some social constructivists apply the theory of constructivism into the research on the structure of science, and form a theory called "social construction of science" (Latour & Woolgar, 1979).

Social constructivists challenge the normative theory regarding science as an institution governed by a set of internally norms. They have totally different interpretations on scientific authors' citing behavior. They believe that scientists have more complex citing motivations including social, political and financial issues than acknowledging the intellectual influence (May, 1967). Specifically, scientists need to "convince others that what they do is important, that what they say is true, and that their proposals are worth funding" (Latour & Woolgar, 1979, pp. 69-70).

In the social construction theory of citation, science is an art of persuasion (Latour & Woolgar, 1979), and the citation is the tool of persuasion (Gilbert, 1977). Indeed, in order to support their persuasion, scientists would like to cite papers that they consider their audience would consider as valid and important (Gilbert, 1977).

Empirical Studies

In order to validate either normative or constructivist theory and investigate if one theory works for their own research, a lot of empirical studies regarding the nature of citations have been conducted (See Table 1) by what either authors or texts say. Unfortunately, we still don't know enough about why the authors cite or not cite.

Table 1 List of major empirical studies investigating the nature of citations

	Favor Normative Theory	Neutral	Favor Constructive Theory
What People Say	Shadish, Tolliver, Gray, and Gupta (1995) ; Case and Higgins (2000) ; R. Tang and Safer (2008) ; Hellqvist (2010)	Vinkler (1987) ; White and Wang (1997)	Prabha (1983) ; Brooks (1985) ; Mansourizadeh and Ahmad (2011)
What Texts Say	Baldi (1998)	Lipetz (1965) ; Hodges (1972) ; Spiegel–Rosing (1977) ; Frost (1979) ; Peritz (1983) ; Oppenheim and Renn (1978) ; Ahmed, Johnson, Oppenheim, and Peck (2004)	Moravcsik and Murugesan (1975) ; Chubin and Moitra (1975) ; Cano (1989) ; Krampen, Becker, Wahner, and Montada (2007)

Although the normative theory of citation was confirmed by some studies, the constructive

theory of citation was also proved. One of the most notable studies was reported by Moravcsik and Murugesan (1975), indicating about one-third of citations are redundant and two-fifth of citations are perfunctory. MacRoberts and MacRoberts (1984) even declare that persuasion, instead of the norm giving credit where credit is due, is the major citing motivation. Brooks (1985, 1986) also indicate that persuasiveness is ranked first in terms of the citing motivation after interviewing authors at University of Iowa.

In addition, Kochen (1974) states that most authors arbitrarily select references for their bibliographies. Both Edge (1977) and Kaplan (1965) report that authors' citing decision may be influenced by their colleagues or peers, even by the gatekeepers including editors and editorial boards (Camacho-Minano & Nunez-Nickel, 2009; Cronin, 1982; Franck, 1999).

Previous studies reveal that the reasons to cite are complex rather than a single one. Acknowledging the intellectual influence is a major citing motivation, but persuasion also motivates scientists to cite in some cases. Thus the notion that citations represent the intellectual contribution may not be absolutely right, as the normative theory would have us believe. As a result, we should be aware that citations are not simple events and simple citation counts missed the complexity of the underlying events when measuring research impact using the citation analysis.

Threats to Research Validity

Using citation analysis to measure the research impact is based on the assumptions that scientific authors need to recognize others'contributions or impacts by citing them in their own works; and cite the best possible works. So citations can reflect the merit (quality, significance, impact) of the cited works (Smith, 1981). When scientific authors fail to cite all others' contributions accurately, correctly, and unbiasedly, the validity of citation analysis will be questioned.

Missing Citations

Garfield (1977) claims that "the vast majority of citations are accurate and the vast majority of papers do properly cite the earlier literature" (p. 217). According to the normative theory, failure to give credit where credit is due is rare (Cole & Cole, 1967). However, some researches (Edge, 1977; Knorr-Cetina, 1981; MacRoberts & MacRoberts, 1984, 1989; Moravcsik & Murugesan, 1975; Murugesan & Moravcsik, 1978; Swales, 1986) indicate that it is not always the case.

As early as 1967, May (1967) warned that authors might select references for their bibliographies instead of acknowledging every intellectual influence. Kochen (1974) also stated that "many documents which should have been cited are missed; and many documents which the author does cite are only slightly relevant" (p. 74).

Unfortunately, their worries were confirmed by MacRoberts and MacRoberts (1989)' s research. After carefully reviewing 15 papers in the history of genetics, MacRoberts and MacRoberts (1989) identified 719 references that need to be cited because of their intellectual influence on the citing papers, but only 216 references were cited by the citing authors. They also examined papers in other disciplines and got the similar results: these scientific authors failed to give credit to around 70% of the intellectual contribution although credit is due. White and Wang (1997) also revealed that authors might decide not to cite a document because it is too old, too specific, or too difficult to obtain, regardless of their merits. The discrepancy between the assumptions and research results detract from the validity of citation analysis.

Biased Citations

The normative theory admits that scientific authors with good reputation and successful achievement may get a higher chance of being cited or recognized again, regardless of the actual merits of their contributions. Merton (1968, 1988, 1995) calls this phenomenon of biased citing as " Matthew Effect" . It breaks the norm of universalism that all scientists have morally equal opportunity to claim their discovery and receive the recognition of their contributions (Merton, 1973; Mitroff, 1974).

The biased citing not only exists in citations to individuals but also applies to citations to institutions, countries or languages. Bookstein and Yitzhaki (1999) indicate that scholars prefer to cite articles in their native language. Seglen (1997) complains that American scientists seem particularly prone to citing each other. L. Tang, Shapira, and Youtie (2015) reveal that a high rate of internal citations exists among Chinese researchers.?

In addition, scientific authors may prefer to give the credit to themselves by means of self-citation (Lawani, 1982). Journal editor as well as reviewers may encourage self-citations to their journals and influence authors' citing decision. (Camacho-Minano & Nunez-Nickel, 2009; Cronin, 1982; Franck, 1999). All such biased citations will put the validity of citation analysis in question.

Incorrect Citations

Generally, scientific authors should read the literature, assess their values before citing them. However, previous studies indicate that a lot of authors have not consulted what they cite and given incorrect citations (Broadus, 1983; MacRoberts & MacRoberts, 1989; Prabha, 1983; Simkin & Roychowdhury, 2003).

When Broadus (1983) had accidentally found that two articles were cited incorrectly by a book, he investigated 148 papers that had cited both the book and two articles. Surprisedly, he found that 34 out of 149 papers had the same mistake in their bibliographies. Broadus suspected that authors might lift their bibliographic reference from other publications without consulting the original sources.

After surveying 19 faculty members from the Department of Business Administration at University of Illinois, Prabha (1983) found the same problem that authors had not consulted what they cited in their papers. She indicated that more than one third of the total citations were not consulted by authors.

MacRoberts and MacRoberts (1989), based on their research, also found that only 37% of references were correctly cited, and only 38% of the references were consulted from the original sources. Simkin and Roychowdhury (2003) estimated that only 20% of authors read the original sources before citing them. It also breaks the assumption that published articles are read and assessed by the community of peers before receiving the recognition (De Bellis, 2009).

Threats to Research Reliability

As a subfield of bibliometrics, citation analysis is indeed a research method investigating the patterns and frequencies of citations in articles, books and other publications (Garfield, 1979; Moed, 2005). Any methodological bias will reduce the reliability of the measurement of research impact.

Data Bias

The citation analysis is based on the data provided by the citation indexing databases such as Web of Science (WoS), Scopus, Google Scholar, and so forth. These databases have different coverage and data collections. Any data bias will affect the reliability of the citation analysis.

When Eugune Garfield created the world's first citation indexing database, Science Citation Index (SCI), only the core journals were included in the database. "The SCI is not trying to cover all the world's science but rather the significant, recognized, influential, mainstream science… obvious bias in coverage of the major scientific countries would be a serious defect" (Carpenter & Narin, 1981, p. 431). Although it is believed that Scopus and Google Scholar provide more adequate coverage than WoS including SCI, SSCI and AHCI, no citation database covers all of the literature but be representative (Okubo, 1997). The impact of a research activity strongly depends upon whether it is published in a journal indexed by the citation database (Van Leeuwen, 2001). It also means that some research activities may be excluded from the citation analysis and lose their deserved rewards.

Another significant problem is language bias against articles published in language using non-Latin alphabet (Zhou & Leydesdorff, 2007). Although the major citation indexing databases cover non-English journals, papers published in non-English journals have a considerably lower impact than those published in English (Van Leeuwen, Moed, Tijssen, Visser, & Van Raan, 2001). Both Hamel (2007) and Montgomery (2013) point out that excellent scientific findings may not be acknowledged by peers if they are published in other language than English. For example, it has been examined that Chines language articles are biased in citation (Shu & Lariviè re, 2015). The language bias in the database of social sciences and humanities is more serious than that of nature sciences (Ammon, 2006; Hicks, 1999). The language bias of coverage may lead to faulty analytical results for international comparison and evaluation of national research performance (Hennemann, Wang, & Liefner, 2011; Van Leeuwen et al., 2001).

Since the citation data come from different sources, the citation databases inevitably contain mistakes or incomplete entries (André s, 2009; De Bellis, 2009). Among these random errors, authors name ambiguity may result in a big problem in any citation analyses based on author names (Moed, 2002). This problem is getting worse when more and more Chinese and Korean names appear in the citation databases (Strotmann & Zhao, 2012). For example, the name, Wang, Y., is recorded that she or he has published 14,178 articles in international journals and gotten 80,845 citations over 46 disciplines when it is retrieved from the China Science Indicator Database (CSI) by last name and first initial.

A Chinese name consists of a surname in one or two characters and a given name in one or two characters. More than 1.1 billion people, 82.1% of China' s population, share the top 100 surnames; there are 114 surnames shared by 2 million and more people (Wu & Yang, 2014). The most popular Chinese name, Wei Zhang (张伟), shared by 290,607 people (Lang et al., 2009). When publishing in English journals, Chinese scholars translate their names into English through the Pinyin Romanization system using the Latin alphabet to represent Chinese pronunciation (Qiu, 2008). Compare to 45,000 Chinese characters, Chinese only has around 410 base syllables; it means that many characters have to end up with the same Romanized representation (Arsenault, 2001). Wei Zhang can represent two totally different Chinese name, 张伟 and 章威, because they are represented by the same syllable. Traditional au-

thor identification with surname and given name initial cannot distinguish Chinese authors with the same translated English name (Qiu, 2008; Strotmann & Zhao, 2012).

Citation Counts

The citation analysis is based on the number of times articles are cited by the citing articles indexed by the citation databases. The reliability of citation analysis strongly depends on the accuracy with which research impact are represented (Moed, 2005). Traditionally, based on Smith (1981)'s assumption, all citations are equal so that they are given the equal weight when counting the citations. It means that each reference in the bibliography will be counted as "1", regardless of how many times it appears in the citing paper.

This simply citation counts is always argued and challenged by scholars. Herlach (1978) conducts a statistical test and finds a close relationship between a given cited paper and the citing papers in which that reference is mentioned more than once in the same citing paper. Hou et al. (2011) also points out that references contributing more to a paper are cited more frequently in the text. They believe that counting citations in the text reflects the scientific research impact more accurately than simply counting citation from the bibliography. R. Tang and Safer (2008) find that citation frequency is an effective indicator of citation importance. They suggest giving more weight to references that are cited multiple times in the citing document.

In addition, the simply citation counts is criticized for treating all citation including the negative citation, redundant citation and so on with equal weight (Ding et al., 2014; Voos & Dagaev, 1976; Zhang et al., 2013; Zhu et al., 2015). Voos and Dagaev (1976) suggest that citations in different locations may have different values. It is reported that methods, results, and discussion sections contain more meaningful citations than the introduction sections (Maricic, Spaventi, Pavicic, & Pifat-Mrzljak, 1998; Suppe, 1998). R. Tang and Safer (2008) suggest giving more weight to references cited in the Methods and Results section of the citing document and less weight to references cited only in the Introduction section of the article.

With the increasing number of co-authored papers, how to count the participation of co-authorship is one of the ambiguities of the citation analysis (Okubo, 1997). "Full credit" or "divided credit" or "first author only" is reasonable and applied to the citation analysis. Until now, bibliometricians have not reached a consensus on how to allocate credit to the co-authored papers. As a result, citation analysis based on different methods of credit allocation will produce different results (MacRoberts & MacRoberts, 1989).

Variation by Discipline

Since scholars in different disciplines have different traditions and habits of publication and citation, the publication and citation activities significantly vary by discipline (Glanzel, 2003; Lariviè re, Archambault, Gingras, & Vignola-Gagné , 2006; Okubo, 1997). Since the major citation databases (i.e. WoS and Scopus) only index journal articles, some citations in books or book chapters may be excluded from the citation analysis. According to Lariviè re et al. (2006), about 93% of the citations in medicine come from journal articles while journals only produce half of citations in the social sciences and humanities.

The citation rate (i.e. number of average citations received per article) also varies among different disciplines. It is pretty low in social science and humanities but high in nature science. In nature science, medicine is on the top of ranking while mathematics and engineering are in the bottom (Lariviè re, Archambault, Gingras, & Wallace, 2008; Narin, 1976).

Due to the variation, it is impossible to compare the research impact among different disciplines through simply citation counts. We have to use some normalized indicators in the citation analysis to compare research impact among different disciplines.

Conclusion

Although the citation analysis is broadly used to measure the impact of scientific research, some limitations may have negative effects on the validity and reliability of the measurement. Unfortunately, these limitations have not been well addressed by bibliometric studies measuring the research impact using citation-based indicators or methods.

Indeed, a unified theory of citations has been called for a long time, but it is still lacking (Cronin, 1981; Leydesdorff, 1998; Small, 2004). Either normative theory or constructive theory is supported or challenged by different research findings, it is difficult to say that one theory is better than another (Small, 1998). Acknowledging the intellectual influence is a major citing motivation, but persuasion also motivates scientists to cite in some cases. Although the former establishes the theoretical foundation of using citations to measure research impact, we should be aware that the measurement may be biased or deficient when the latter is considered.

In addition, on the basis of the normative theory, Merton (1973) presents a rewards system of science in which scientists' achievements are represented as their publications (quantity) and citations received (quality), but does not offer details regarding the measurement of achievement. Simply counting citations is frequently used to design and develop bibliometric indicators or methods measuring research impact, although its validity and reliability has been argued by bibliometricians (Ding et al., 2014; Voos & Dagaev, 1976; Waltman & Traag, 2017; Zhang et al., 2013; Zhu et al., 2015).

In summary, in this paper, we briefly review the literature on the limitations of citation analysis in the measurement of research impact, to remind researchers of the possible abusive use of citation-based indicators on research evaluation due to these limitations. Since the comprehensive indicators or methods that could overcome the limitation of citation analysis have not been formulated, we have to keep using current citation-based indicators or methods to measure the research impact, but with extreme caution.

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