PCSI: A Standardization Method for Single-Paper Citation Frequency Postprint

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Abstract

[Purpose/Significance] The citation count of an article has always been an important indicator for quantitatively evaluating its academic impact. However, papers published in different disciplines and years exhibit significant variations due to factors such as the number of research papers in the field and citation lag. Therefore, when comparing two papers, it is difficult to judge their relative impact simply based on the absolute value of citation counts. To address this, this paper designs a new computable mathematical model that enables each paper to have a standardized index, allowing for direct comparison of academic impact across papers published in different disciplines and years. [Method/Process] By analyzing the distribution patterns of citation counts across disciplines for papers in Chinese scientific and technological journals in 2006 and 2017, and adopting the prior assumption that the distribution of citation counts for papers within the same discipline most closely approximates a log-normal distribution, this paper proposes a citation count standardization index—the Paper Citation Standardized Index (abbreviated as PCSI, Chinese name "论文引证标准化指数"). Finally, using the selection results of excellent papers from Chinese scientific and technological journals by the China Association for Science and Technology as a case study, an empirical comparative analysis is conducted between these papers and all papers in their respective disciplines. [Results/Conclusion] The results demonstrate that PCSI standardizes the citation counts of papers from different years and disciplines, reflects the linear differences in citation counts, and serves as a relatively ideal tool for comparing and evaluating the academic impact of individual papers.

Full Text

PCSI: A Method for Standardizing Single-Paper Citation Frequency

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Abstract: [Purpose/Significance] Citation count has long served as a crucial metric for quantitatively evaluating a paper's academic influence. However, papers published in different disciplines and years exhibit substantial variations due to factors such as field size and citation lag, making it difficult to compare papers based solely on absolute citation numbers. This study proposes a new calculable mathematical model that provides a standardized index for each paper, enabling direct comparison of academic influence across disciplines and publication years. [Method/Process] By analyzing citation distribution patterns across Chinese scientific journals in 2006 and 2017, and assuming that within-discipline citation distributions most closely approximate log-normal distributions, we propose a standardized citation index called Paper Citation Standardized Index (PCSI). Using selected outstanding papers from the China Association for Science and Technology as a case study, we conduct an empirical comparison with all papers in their respective disciplines. [Results/Conclusions] Results demonstrate that PCSI effectively standardizes citation frequencies across different years and disciplines while preserving linear differences in citation counts, making it an ideal tool for comparative evaluation of single-paper academic influence.

Keywords: citation count; single-paper evaluation; Paper Citation Standardized Index; academic influence; PCSI **Classification Number:** G301 **DOI:** 10.13266/j.issn.0252-3116.2020.23.003

On February 17, 2020, China's Ministry of Science and Technology released the "Several Measures for Breaking the 'Paper-Only' Orientation in Science and Technology Evaluation (Trial)," which proposed "strengthening peer review of representative works and implementing a combination of quantitative and qualitative evaluation." This policy shift moves away from previous evaluation paradigms that emphasized paper quantity and "journal prestige," instead highlighting the value of representative research. Many universities have already adopted representative work evaluation systems, though scholars continue to investigate how to avoid personal biases and effectively combine quantitative with qualitative assessment methods [1-8].

Discipline standardization methods are mathematical approaches designed to eliminate disciplinary differences in citation metrics. In the early 1980s, physicist A. Raan and his team at the Centre for Science and Technology Studies

(CWTS) at Leiden University established that citation counts must be standardized for international comparisons within each field, comparing research performance against international benchmarks. This metric was formerly known as the Crown Indicator [9-13]. Zhang Zhihui systematically discussed the principles and evaluation criteria of discipline standardization, comparing two common linear standardization methods—mean ratio and z-score—as well as a non-linear method: percentile rank [14]. The core of representative work evaluation lies in assessing individual papers. To conduct such evaluations scientifically, external metrics, particularly citation counts, must be considered. Citation metrics reflect objective recognition from professional readers and should not be abandoned but rather used rationally. In practice, cross-disciplinary and cross-year comparisons of individual papers are frequently needed, but variations across fields and publication years prevent direct comparison using absolute citation values. While various standardization methods have been proposed in the literature, they are often overly complex, rely on numerous parameters (such as reference counts with unclear evaluative significance), or introduce subjective classification criteria, without fundamentally improving upon the mean ratio method in practice.

Major international databases Web of Science and Scopus both provide discipline-normalized citation impact metrics using the mean ratio method. In Elsevier's Scopus, this is named Field-Weighted Citation Impact (FWCI) [20], while in Clarivate's InCites it is called Category Normalized Citation Impact (CNCI) [21]. Since both employ the same standardization approach, we refer to this class of algorithms uniformly as CNCI in our discussion.

However, because citation distributions are objectively asymmetric, existing standardization methods fail to adequately address the standardization problem. Dividing citation counts by discipline means reflects only the relationship to the average, which, according to Bradford's Law, does not represent the majority of citation frequencies. More importantly, a highly cited paper is not equivalent to the sum of several low-cited papers—higher citation frequencies are increasingly difficult to achieve and more scarce, much like a 10-carat diamond cannot equal the value of one hundred 0.1-carat diamonds. This scarcity property is ignored by mean ratio methods including CNCI and FWCI. Therefore, further research into citation distribution patterns is needed to develop standardization methods that better reveal paper value.

1. Distribution of Citation Frequencies

The choice of standardization method must be based on scientific understanding of citation distribution patterns. Previous research on citation distributions includes: Eom and Fortunato's analysis of *Physical Review D* found log-normal distribution superior to power law, though with poor right-tail fit [22]; Chatterjee et al. found that citation counts divided by discipline-year averages follow log-normal distribution while maximum citations follow power law [23]; Vieira et al. proposed a mixed Poisson-exponential distribution [24]; Redner found log-normal-like distributions for *Physical Review* articles [25]; Brzezinski's goodness-of-fit tests on Scopus data showed log-normal, Yule, and shifted power law distributions outperforming simple power law in most disciplines, though differences were modest [26]. Domestic research remains limited but includes Deng Huiying et al.'s study on rice virus papers [27] and Wang Yuechun et al.'s analysis of library and information science papers [28]. These studies provide valuable reference but lack systematic investigation of Chinese scientific papers' citation distributions.

This study employs data from Chinese scientific journals published in 2006 and 2017, grouped by year and discipline, to analyze citation distribution patterns across 86 science, engineering, agriculture, and medical fields based on CNKI's classification system derived from the Chinese Library Classification. The 2006 papers, published 15 years ago , have stable citation counts beyond their citation half-life, representing "older papers," while 2017 papers, published only 3 years ago , are in their active citation peak period, representing "younger papers." Comparing both states provides comprehensive understanding of citation distribution patterns.

Using statistical software (e.g., R), we analyzed distribution types through Gullen-Frey plots (showing skewness and kurtosis) and Q-Q plots, comparing within-discipline, within-year citation distributions against normal, log-normal, exponential, logistic, beta, and gamma distributions, excluding zero-citation papers. Results show: for 2006 data, 71 disciplines approximate log-normal, 13 approximate gamma, and 2 approximate beta distributions; for 2017 data, 78 approximate log-normal, 7 approximate gamma, and 1 approximates beta. The proportion of disciplines fitting log-normal distribution reaches 73.70% in 2006 and 89.06% in 2017.

To visualize these patterns, we randomly selected four discipline groups for illustration. Gullen-Frey plots (Figure 1 [Figure 1: see original paper]) reveal citation distributions cluster closest to log-normal distribution. For instance, 2006 physics citations fall between log-normal and gamma distribution curves, while 2006 light industry/handicraft citations align with the log-normal curve. Q-Q plots (Figure 2 [Figure 2: see original paper]) show that log-transformed citation counts closely follow normal distribution trends, though deviations exist. Low-citation data consistently fall below fitted curves, medium-citation data fit well, and high-citation data show random variation.

Kolmogorov-Smirnov and chi-square tests fail to confirm perfect fit with either exponential or log-normal distributions. For exponential distributions, Q-Q plots show substantial deviation in middle and tail sections; for log-normal distributions, poor fit occurs near zero due to citation counts being non-negative integers. However, Q-Q plots indicate older data (2006) fit log-normal better than recent data (2017) (Figure 3 [Figure 3: see original paper]).

Since log-normal distribution cannot correctly estimate zero-citation articles, and exponential distribution provides better fit at low citation levels, we conclude both distributions offer reasonable bases for standardization. Excluding zero-citation cases, log-normal distribution is generally more applicable. When zero citations must be considered, exponential-based standardization may be used for low-citation segments.

2. Definition and Calculation of PCSI

Based on these findings, we propose the Paper Citation Standardized Index (PCSI) to enable comparison of single-paper citation frequencies across different years and disciplines.

PCSI is defined as follows: Remove zero-citation data. Let x be the citation count of a paper from the same discipline and year (a positive integer). Let y = ln(x) be the natural logarithm, with $\bar{y}$ as the mean and S as the standard deviation. Then:

$$PCSI = e^z \quad \text{where} \quad z = \frac{y - \bar{y}}{S} \quad \text{for} \quad x > 0$$

PCSI qualifies as a standardized index because when x follows a log-normal distribution, y follows a normal distribution, and the standardized variable z follows a standard normal distribution.

For example, Paper A was published in 2017 in the crop science discipline with 27 citations. The natural log is 3.30, while the national average for 2017 crop science papers is 0.91 (corresponding to 2.48 citations, with an actual mean of 3.75 citations) and the standard deviation is 0.85. Paper A's PCSI is calculated as $e^{(3.30-0.91)/0.85} = 16.58$.

After standardization, non-zero citation papers from different disciplines and years approximately follow a standard log-normal distribution (=0, σ^2=1). Since the mathematical expectation of log-normal distribution is $e^{\mu+\sigma^2/2}$, the theoretical mean PCSI for non-zero citation papers is 1.65 ($e^{1/2}$).

Due to the asymmetry of citation distributions, equal citation differences correspond to different log values at different citation levels. For instance, increasing from 10 to 20 citations yields ln(20)-ln(10) = 0.693, while increasing from 20 to 30 yields ln(30)-ln(20) = 0.405. Higher citation frequencies require disproportionately larger absolute increases to achieve the same log-scale improvement, reflecting the genuine difficulty and scarcity of high-impact research. This property aligns with the value attributes of individual papers and contemporary emphasis on quality over quantity—unlike CNCI and FWCI, which treat all citation increments equally.

Table 1 compares PCSI and CNCI for three papers with 10, 20, and 30 citations. While each 10-citation increment produces identical 0.5 CNCI increases, PCSI differences grow from 0.847 (10$→20)*to*1.277(20→$30), accurately reflecting the increasing difficulty of citation gains at higher levels.

3. Comparison with CNCI Algorithm

This section compares PCSI with CNCI using outstanding papers selected by the China Association for Science and Technology (CAST) across four selection cycles (2012-2019), totaling 319 papers matched in CNKI, spanning 85 disciplines (396 papers when counting multi-disciplinary papers separately).

3.1 Temporal Comparison

Citation frequencies naturally increase with publication age due to citation lag. For example, 2012 papers average 6.69 citations versus 2.61 for 2018 papers—a 2.56-fold difference that renders direct comparison meaningless. PCSI, however, enables cross-year comparison: from 2012 to 2018, mean PCSI standard deviation is only 0.04, with annual means around 1.80 (close to the theoretical 1.65). Older papers show PCSI values converging toward 1.65, confirming better log-normal fit for mature citation data.

Outstanding papers demonstrate 13.50×, 13.36×, and 12.27× higher citation counts, PCSI, and CNCI respectively compared to control groups, showing both metrics preserve citation differences linearly.

3.2 Disciplinary Comparison

Citation frequencies vary dramatically across disciplines. "Shipbuilding" averages 2.38 citations while "Environmental Science & Resource Utilization" averages 7.49 (3.15× difference). After PCSI standardization, the range narrows substantially: the lowest mean PCSI is 1.69 (Traditional Chinese Medicine) and highest is 2.05 (Automation Technology)—only 20.09% variation.

Table 3 presents data for 20 selected disciplines across science, engineering, agriculture, and medicine, representing various publication volumes. Outstanding papers in each discipline show citation counts, PCSI, and CNCI values far exceeding discipline averages. The mean PCSI for outstanding papers is 28.07 versus 1.84 for all papers (15.28× ratio), comparable to the 17.81× citation count ratio (94.28 vs. 5.29), demonstrating PCSI's ability to preserve citation differences. The CNCI ratio is only 11.72× (11.72 vs. 1.00), failing to reflect actual citation gaps.

4. Empirical Research

Our analysis yields five key conclusions:

1. **Citation frequency as an external impact metric**: Post-publication citations reflect objective professional recognition and serve as important reference indicators for evaluating research quality and performance, both in statistical assessments and expert peer review of representative works.
2. **Need for standardization**: Citation frequencies vary significantly by publication year and discipline, creating a practical demand for cross-

disciplinary and cross-temporal comparability. Existing Web of Science and Scopus "field-weighted citation impact" metrics (CNCI/FWCI) overlook citation distribution characteristics and require improvement.

3. **Distribution characteristics**: Through literature review and empirical analysis of 86 disciplines from CNKI's 2006 and 2017 datasets, we find citation distributions cannot perfectly fit any single distribution but show greatest similarity to log-normal distribution across most disciplines, though social science distributions require further investigation.
4. **PCSI formulation**: We propose PCSI based on the log-normal distribution model. After removing zero-citation papers, take the natural logarithm y of citation count x, standardize using normal distribution parameters ($z = \frac{y-\bar{y}}{S}$), then exponentiate ($PCSI = e^z$) to restore compressed citation differences. This approach yields a theoretical mean of 1.65 for non-zero citation papers.
5. **Validation**: Empirical comparison using CAST outstanding papers (2012-2019) demonstrates PCSI effectively eliminates absolute citation differences while preserving quality distinctions. Statistical analysis shows high consistency with peer review outcomes, establishing PCSI as a viable quantitative method for evaluating single-paper academic influence.

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Author Contributions: Wu Junhong: Primary author and originator of the index, responsible for research and data analysis sections; Xiao Hong: Lead researcher on calculation methodology, proposed methodological revisions and finalized the manuscript; Ren Meiya: Lead researcher on calculation methodology, investigated citation distribution patterns, conducted all data process-

ing, participated in literature review, and manuscript review; Feng Shiyong: Principal reviewer of calculation methodology, verified mathematical theoretical foundations; Ding Zhe: Conducted data analysis and visualization, validated citation distribution patterns.

PCSI: A New Index to Quantitatively Evaluate Scientific Articles Based on Citation

Abstract: [Purpose/significance] The citation count of an article has always been an important factor to quantitatively evaluate its academic influence. However, articles published in different disciplines and years will show great differences due to factors such as the number of research articles in this field and the lag of citation. Therefore, when comparing two papers, it is difficult to judge the influence of papers simply according to the absolute citation counts. Therefore, we design a new calculable mathematical model, so that each paper can have a standardized citation index, so as to directly compare the academic influence of papers published in different disciplines and years. [Method/process] In this paper, by analyzing the citation distribution law of papers in various disciplines of science and technology in Chinese academic journals in 2006 and 2017, and adopting the precondition that the citation distribution of papers of the same subject is closest to the lognormal distribution, an index for standardizing the citation—Paper Citation Standardized Index (PCSI) is proposed. Finally, taking the selection results of The Outstanding Papers from Sci-tech Journals of China Association for Science and Technology as an example, an empirical comparative study is made between them and all the papers in the same subject. [Method/process] The results show that PCSI standardizes the citation counts of papers in different years and different disciplines, which reflects the linear difference of citation, thus PCSI is an ideal tool for comparative evaluation of academic influence of single paper.

Keywords: citation counts; single paper evaluation; Paper Citation Standardized Index; paper academic influence; PCSI

Note: Figure translations are in progress. See original paper for figures.