

The Synergy Effect: How Funding and Open Access Amplify Research Citations in Emerging Universities

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ABSTRACT

Background: We examined the interaction between Open Access (OA), research funding and citation impact from seven universities in Northeast India by studying 8616 articles between 2015 and 2024. **Methodology:** The findings indicate that OA articles receive substantially more citations than closed access publications, with a 68% citation advantage and statistically significant differences ($p < 0.001$). **Results:** Funding for research makes a publication more likely to be in OA by 1.67-3.9 times, with internationally funded agencies contributing significantly more to OA (60.9-100%) than Indian national funding agencies (16.9-71.2%). We found a significant synergy between funded OA publishing and citation impact; OA articles supported by funding received 171-274% more citations than unfunded papers that were closed access. **Conclusion:** The advantages of international collaboration were similarly strong; internationally collaborating papers received 21.9-73.1% more citations than their domestic collaboration.

Keywords: Central universities, Citation impact, Northeast India, Open access, Research funding.

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INTRODUCTION

Open Access (OA) publishing has reshaped global scholarly communication by expanding the visibility, accessibility, and reach of research outputs. A growing body of empirical evidence has demonstrated that articles that are freely available through open access publishing receive significantly more citations compared to articles that charge readers for access. However, this increased citation impact is not equal across all research disciplines or research methodologies.

A large-scale empirical study by Piwowar *et al.*, (2018), analysing more than 100,000 scholarly articles, found that OA publications receive approximately 18% more citations on average after accounting for discipline and publication year. The study clearly indicates that there is a measurable and ongoing citation advantage associated with open dissemination by way of OA publishing. Archambault *et al.*, (2016) provided additional evidence supporting the aforementioned trend by analysing millions of published research articles (between 2007-2009) over various fields of science and determining that Open Access (OA) publications have approximately 50% more research impact when compared to Closed Access (OA) publications. Archambault *et*

al., study revealed substantial differences in the publication's impact based on the OA effects; and these differences were attributable to the differences among disciplines with regard to OA adoption rates, level of prestige associated with the journals in each discipline, and shared communication processes in each discipline.

Although there is strong empirical evidence for the OA citation advantage, there remains considerable ongoing theorising about how the OA citation advantage occurs. Some theorists suggest that self-selection and/or early viewing effects may be partly responsible for the OA citation advantage, as researchers may disproportionately upload high-quality or earlier 'first access' articles to OA formats than to traditional publishing channels (Davis, 2011). However, (Gargouri *et al.*, 2010) disagree with this interpretation, showing that mandatory self-archiving, which removes self-selection from the equation, generates the same citation advantage as voluntary OA practices. Thus, it appears that enhanced access is likely to be a major contributor to increased citation rates.

The conclusion drawn from current systematic evidence supports this finding. Langham-(Putrow *et al.*, 2021) reviewed 134 studies on OA and citation impacts to examine OA citation advantage across disciplines and types of open access. Although the results varied according to the discipline and the type of open access models, a large percentage of studies showed that in some disciplines, an OA citation advantage exists. Therefore, it is vital to consider open access within the framework of diverse scholarly communities. In particular, developing nations are creating a greater degree of research output than ever before;



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thus, evaluating the effect of open access, in conjunction with research funding, will enable a better understanding of how open access can contribute to the development and impact of scientific knowledge in these countries.

Open access is increasingly becoming one of the compliance requirements stipulated by international funding bodies, with compliance rates quoted at various levels, ranging from 23% to 91%, depending on their enforcement and monitoring mechanisms (Larivière and Sugimoto, 2018; Robinson-Garcia *et al.*, 2020). The development of open access research ecosystems in developing countries located in the Global South, such as those in Northeast India, face unique challenges when implementing open access strategies for research outputs, as there are multiple central universities located in each of the eight northeastern states that are attempting to develop scientific research output while still having very little international prestige and recognition (Pal and Bhattacharjee, 2022). The majority of the universities in the eight states operate in a resource-poor environment with little access to competitive funding offers from national agencies in an area that serves as an excellent case study for examining the relationship between open access publishing and the funding relationship dynamic between researchers. (Banshal *et al.*, 2019).

This research investigates three questions. The first is what is related to the magnitude and statistically significant of OA Citation Advantage in Northeast Indian central universities? Second, how do different sources of funding influence OA publishing/citation differences? Thirdly, do the way OA articles are published and the funding sources used to fund research impact the visibility of research?

This research extends the evidence base of an area less studied, with 8616 research articles from seven different institutions supporting the hypotheses that currently exist regarding OA. It also explores whether or not existing OA theories and concepts can apply to developing research contexts.

Objectives of our study

To address these research questions systematically, this study pursues the following specific objectives:

- To quantify the Open Access citation advantage at central universities in Northeast India and examine the statistical significance of citation differences between Open Access and closed access publications.
- To investigate the relationship between research funding from international and Indian national agencies and Open Access publishing rates, and to analyse the synergistic effects of different funding sources and Open Access on citation impact.

LITERATURE REVIEW

The Open Access Citation Advantage

One of the most studied aspects of scholarly communication is the Open Access Citation Advantage (OACA). The OACA has been analysed in-depth by (Piwowar *et al.*, 2018), who found that Open Access Articles (OA) have, on average, an 18% higher rate of citation than Closed-Access Articles. Furthermore, (Piwowar *et al.*, 2018) confirmed that Green OA (self-archived manuscripts) and Hybrid OA (Individually OA article within subscription journals) are major contributors to the OACA, thereby showing the significance of both repository-based and publisher-mediated access.

To further substantiate the empirical foundation of OACA, (Archambault *et al.*, 2016) show that Open Access (OA) articles bring about a research impact that is roughly 50% higher across various natural and social sciences. Their big data set reveals a sizable variation of different academic disciplines, which indicates that the advantages of OA are determined by the publishing norms, collaboration structures and information access practices of each specific.

The mechanisms behind Open Access Citation Advantage (OACA) are still disputed. (Davis, 2011) argues for OA based on studies using random control trials, that although readership does rise, citation does not increase consistently. Conversely, (Gargouri *et al.*, 2010) observe that the advantage of citing OA papers is achieved even when the author self-archives under a mandate to do so; thus, they argue the phenomenon cannot be fully attributed to self-selection. Langham-Putrow *et al.*, (2021) (through synthesizing findings from over 100 different studies), state that while OA does not produce a uniform citation advantage, there is a sizeable group of studies which demonstrate clearly that OA results in increased citations.

Research Funding and Open Access

Open access publishing practices depend heavily on the availability of funding. An example of a large international funding agency that has implemented OA mandates is the National Institutes of Health (NIH), as well as the Wellcome Trust. According to Larivière and Sugimoto (2018), NIH and Wellcome Trust have high OA compliance rates (almost 90%) among the biomedical funders they support. However, this is much lower than social science funding agencies such as the Social Sciences and Humanities Research Council of Canada (SSHRC) which have compliance rates as low as 23%. Different levels of compliance are due to differences in how funders mandate compliance as well as the level of infrastructure available to institutional support.

OA mandates of funding agencies have been instrumental in supporting the growth of OA by providing funding for Author Processing Charges (APCs) for OA, requiring the deposit of articles in repositories, and implementing OA into their grant monitoring

process. The result is that funded research is consistently more openly accessible to the public and, therefore, is more likely to be visible. Bibliometric studies show that articles that are funded are often cited more than articles that are unfunded, but this is based on many factors, including collaboration patterns, the quality of the research, and which journals they choose to publish in.

Open Access Models and Differential Impact

Open access models including Gold, Green, Hybrid, Bronze, and Diamond are different in terms of accessibility, sustainability, and cost structures. According to (Piwowar *et al.*, 2018), Green and Hybrid OA generally show a better citation performance compared to closed-access articles. However, their study does not provide exact relative citation ratios for each subtype. On the other hand, Bronze OA is a less secure type of access: for example, publishers may decide to remove free access without giving any notice, thus reducing the potential for long-term discoverability and citation growth (Schiermeier, 2018). These trends can be seen as examples of how OA routes affect not only the access but also the time and the visibility of academic communication.

Geographic and Institutional Contexts

Most of the Open Access (OA) research has concentrated on Europe and North America, and there has been a relatively small amount of research done on the developing research ecosystems. Indian universities are affected by problems such as limitations of the repository infrastructure, constraints of the affordability of Article Processing Charges (APC), and uneven adoption of Open Access policies. Studies have indicated that the Open Access uptake in India is still lower than the global averages, although there has been a steady growth in recent years. So, understanding how Open Access interacts with research funding, collaboration networks, and institutional environments is vital for measuring scholarly impact in emerging research contexts.

While the OA citation advantage has been documented in the developed contexts, there are still substantial gaps in understanding how these dynamics work in the developing research ecosystems that have limited resources and infrastructure. Northeast India, with its mixture of emerging universities, limited funding, and increasing research output, is an ideal setting to study these relationships. This research fills these gaps by examining the effects of open access and different funding sources on the number of citations at the seven central universities in Northeast India.

METHODOLOGY

We analysed scholarly publications of seven different universities of Northeast India that include Assam University, Manipur University, Nagaland University, Rajiv Gandhi University, Sikkim University, Tripura University, and North-Eastern Hill University. The research articles were from the year 2015 to 2025 and were

taken from the Scopus Database. The total number of research papers for the seven universities was 8616.

We chose Scopus as the prime source for our research because it had a very large selection of quality peer-reviewed research. The Scopus Database was able to provide quite a few uniform metadata for each reference like funding sources, the number of citations, etc. Besides, it had well-defined fields that describe each reference's open access status. The Scopus Database is capable of having all the information in it that we needed for a very fast large-scale systematic. We determined open access status using the Scopus OA classification field, which categorizes publications into five types based on international standards (Piwowar *et al.*, 2018):

1. **Gold Open Access:** Articles published in fully open access journals where all content is freely available immediately upon publication.
2. **Green Open Access:** Self-archived article versions available via institutional or subject repositories.
3. **Bronze Open Access:** Articles accessible for free on publisher websites without open licensing or permanent guarantees.
4. **Hybrid Open Access:** Individual OA articles in subscription-based journals.
5. **Diamond Open Access:** OA publishing without author fees, typically supported by institutions or societies.

Publications that did not have an OA label were considered as Closed Access by us. Such a binary classification makes possible primary comparisons while subtype analysis looks for differential effects among OA models (Archambault *et al.*, 2016).

We got the funding information by looking at the "Funding Text" field in the Scopus records which have the full funding acknowledgment statements. We used text-mining methods to locate funding organizations through keyword matching and pattern recognition and then divided the funding sources into three categories.

FUNDING SOURCE CLASSIFICATION

- **National Funding:** Support from Indian government agencies including DST, SERB, UGC, DBT, and CSIR.
- **International Funding:** Support from foreign agencies and multinational organizations.
- **Mixed Funding:** Publications acknowledging both national and international sources.

This classification scheme aligns with bibliometric research methods that use funding source as a variable for examining research outcome effects.

Citation Metrics

Our extraction of citation data from Scopus reflects the time of data collection (November 2024). Citation accrual will depend largely on how long ago the work was published; therefore, papers that are less than one year old will likely have fewer citations than papers published more than one year ago (potential temporal effect). This restriction applies equally to all other comparison groups. To perform our citation analysis, we utilised a variety of citation measurements:

- **Mean Citation Count:** Average number of citations for each individual publication, very dependent on a few highly cited papers (outliers).
- **Median Citation Count:** Provides a central tendency measure not affected by extreme citation counts (e.g., a few very highly cited papers); provides a different perspective than the mean citation count.
- **Total Citation Count:** Total number of citations received by the whole author's body of works for a given time period.
- **High Impact Rate:** Percentage of papers that have received at least the discipline-specific high-impact citation threshold (i.e., 20+ citations).

Statistical Analysis

We used statistical techniques that are suitable for bibliometric data, which are known to have non-normal distributions and are highly positively skewed (Waltman, 2016):

1. **Descriptive Statistics:** We derived mean, median, standard deviation, and other distributional descriptive statistics for all variables across institutions and comparison groups.
2. **Comparative Tests:** We compared citation distributions between OA and closed access groups using Mann-Whitney U tests, which are non-parametric alternatives appropriate for skewed data (Langham-Putrow *et al.*, 2021). To test the differences across OA subtypes, we employed one-way ANOVA and used *post-hoc* Welch tests for pairwise comparisons.
3. **Effect Size:** In order to identify the standardized differences, we made use of Cohen's *d* which 0.2, 0.5, and 0.8 indicate small, medium, and large effects correspondingly. We used Cramér's *V* for the strength of association between the categorical variables.
4. **Regression Models:** To find out the combined effects of OA status, funding presence, and funding source on citation outcomes, we performed multiple regression analysis. Along with a publication year as a control variable, we employed interaction terms to test the combined effects of funding and OA status.
5. **Correlation Analysis:** To determine the degree of relationship between continuous variables, we utilized both

Pearson and Spearman correlation methods, and Spearman correlation was used for non-linear associations.

We implemented all statistical tests with $\alpha=0.05$ significance levels and, when necessary, Bonferroni corrections for multiple comparisons. We also calculated 95% confidence intervals for mean differences and effect sizes.

RESULTS AND FINDINGS

In our study of 8616 journal articles released by 7 universities located in Northeast India, we concluded that 29.7% (2560 articles) are published in an Open Access (OA) format. On average (based on comparison with other studies of OA adoption in India) this percentage is similar to the National OA Adoption Average, which has been previously reported as ranging from 24% to 34%. Along with an increase in OA rates globally, the proportion of articles available as OA has increased to about 45% (about 1 in 2 articles) in 2015 in countries all around the world, with similar increases in OA availability in other regions; however, India's percentage of available articles published OA remains significantly lower than that of other regions.

In our sample, Gold OA represented the largest segment of OA publications (77% to 82% of all OA articles), while Green OA made up only 4.6% to 24.4% of OA articles, indicating relatively low use of Institutional Repository (IR) support for OA publishing. In contrast to Green OA, the percentage of Bronze OA (2.0% to 3.1%) and Hybrid OA (0.4% to 9.2%) were found to be relatively low. While Diamond OA can be found at some universities and research institutions within the country and regionally, you will find no instance of it in any of the institutions listed in our sample. This indicates a very low number of CO-funded OA journals within these study types.

Open Access Citation Advantage

Open access publications demonstrated consistent and statistically significant citation advantages across the entire dataset. OA articles received an average of 11.84 citations compared to 7.04 citations for closed access articles, representing a 68% citation advantage. This effect substantially exceeds the global average of 18% reported by (Piwowar *et al.*, 2018).

Mann-Whitney U tests confirmed statistical significance across all institutional comparisons ($p<0.001$). Effect sizes ranged from Cohen's $d=0.21$ (small-medium) to $d=0.42$ (medium), indicating both statistical significance and practical importance (Cohen, 1988). Citation advantages varied from 53% to 141% across institutions, reflecting differences in disciplinary focus, research quality, and collaboration patterns.

OA model Performance

Different OA subtypes produced substantially different citation outcomes. Green OA demonstrated strong performance, with

average citations ranging from 13.48 to 22.96, often outperforming Gold OA.

One-way ANOVA showed significant differences between OA types ($F=3.80, p=0.023$). Pairwise Welch tests identified substantial differences between Green and Bronze OA ($t=-2.68, p=0.009$). Hybrid OA showed citation advantages ranging from 24.3% to 50.6% above closed access baselines. Bronze OA consistently underperformed, showing effects ranging from -11.7% to minimal positive impact compared to closed access articles.

Relationship Between Funding and Open Access Publishing

Research funding strongly influenced Open Access publishing across studied institutions. Funded papers achieved OA publication rates 1.67-3.9 times higher than unfunded papers. Approximately 35-42% of funded research achieved Open Access compared to 10-20% of unfunded research. Chi-square tests confirmed highly significant associations between funding status and OA publishing ($\chi^2=45.2, p<0.001, \text{Cramér's } V=0.23$).

International Funding and Open Access

International funding agencies demonstrated significantly higher Open Access (OA) compliance rates than national agencies. Research funded by international sources achieved OA compliance rates as high as 60.9% to 100% across the seven universities. Several institutions have been showing their international funding OA compliance close to or at 100% during the last years (2022-2024).

The very high compliance level of international funding is consistent with the literature on the international funder mandates. Among others, the European Commission and Wellcome Trust are agencies that put in place active monitoring systems and

enforce compliance with specific mechanisms (Larivière and Sugimoto, 2018; Schöpfel and Herb, 2018). These enforcement mechanisms seem to work effectively in the university context of Northeast India.

Indian National Funding and Open Access

Compared to European and US agencies, Indian national funding agencies showed lower Open Access compliance rates. Research funded by national sources (including DST, SERB, UGC, DBT, and CSIR) reached OA compliance rates varying from 16.9% to 71.2% across the universities. Such a large difference signals that OA policy implementation is uneven in various Indian funding agencies.

OA compliance of national funding has been getting better during the period of the study, going up from about 30-50% in 2015-2018 to 52-71% in 2022-2024. Although this trend signifies advancement, the compliance rates are still lower than those for international funding. The data suggest that Indian national agencies presently have different policy frameworks or approaches to enforcement than international agencies (see Figure 1).

Funding Source Effects on Citations

Research funding substantially enhanced citation performance regardless of source. Funded research papers achieved 85.7-106% higher average citations compared to unfunded papers across the dataset.

International Funding Citation Impact

Research supported by foreign funding agencies has been shown to have quite high citation rates varying from 14.74 to 26.90 mean citations per paper. The international funding was behind the citation advantages ranging approximately from 5.2 to 36.5% over national funding, and the differences were going from institutions. The scientists, when combining international funding with

Comparison of Standardized Effects in International vs National Funding Models

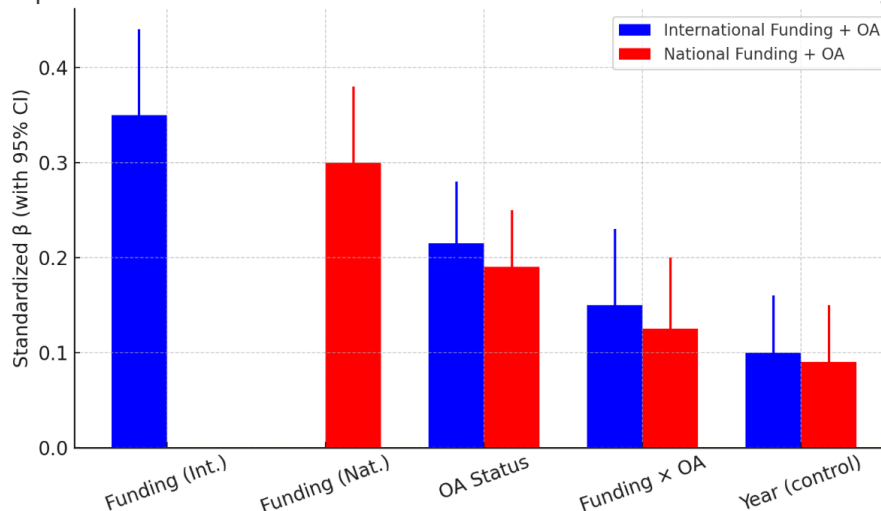


Figure 1: International vs national funding models.

national funding (mixed funding), citation performance was in most cases higher than either source alone, thus suggesting the benefits of collaboration.

The international collaborations, in which international funding was used, have been a major factor leading to citation advantages. Studies, which had cross-border partnerships, gained 21.9-73.1% more citations as compared to those which were conducted only within a single country. Such collaborations help to extend the author networks, to increase the publication visibility in international journals, and to raise the global research reach (Wagner *et al.*, 2019; Waltman *et al.*, 2011).

Indian National Funding Citation Impact

Citations for research supported by national (Indian) funding agencies ranged from an average of 8.45-14.8 citations per publication, which is a lower citation rate than that of international funding agencies; however, the average citation rates of research conducted with national funding sources were still much higher than those without funding sources. Nationally funded research had citation rates that were approximately 86-106% higher than research that was not funded.

The ability of national research funding to generate citations indicates that domestic funding agencies fund high quality research that is recognized through citation. The lower citation rates for nationally-funded research compared to research supported by foreign funders are likely due to differences in how researchers choose to collaborate, which journals they prefer and what topics they research, and not because national funders are funding lower quality research.

Synergistic Effects: Funding × Open Access

The synergistic influence of funding with Open Access (OA) publishing showed that citation rates increased exponentially, rather than just being added together. Papers that were funded through OA had citation rates that ranged from 171-274% higher than closed-access papers without funding, which was far above the individual funding effect of (86-106%) and OA effect of (53-141%).

Table 1: International and national funding impact.

Model	R ²	Adjusted R ²	F-statistic	p-value
International Funding + OA Model	0.26 - 0.32	0.25 - 0.31	24.8 - 32.5	<0.001
National Funding + OA Model	0.24 - 0.28	0.23 - 0.27	21.3 - 28.7	<0.001

International Funding × Open Access

Papers published with the combination of both international funding and Open Access publishing achieved the maximum number of citations. Papers that were published through the path of Open Access with international funding had 220%-274% more citations compared to their corresponding unfunded closed-access baseline papers. This mixture creates more extreme outcomes over numerous different paths: the international funding creates an international signal of quality of the research itself; there will be no restrictions to access because of the availability of research via Open Access; the international funding would provide the means for third-party funding agencies to require compliance with Open Access rules; and finally, there is an increase in visibility for cross-border research partnerships.

The results of the regression analyses show there are significant interactions between international funding and OA status ($p < 0.01$), which indicates that international funding and OA status were acting together to produce the positive results rather than independently. The models account for 26% - 32% of the variance in citations ($R^2 = 0.26 - 0.32$), and reveal the significant impact of the International Funding ($\beta = 0.32 - 0.38$), OA Status ($\beta = 0.19, 0.24$), and the interaction of the two ($\beta = 0.13 - 0.17$) on the number of citations (see Table 1).

Indian National Funding × Open Access

Research that combines Indian national funding with Open Access publishing has achieved citation rates that are 171-195% higher than those of unfunded closed access baselines. Although the citation rates for internationally funded combination are higher, the nationally-funded OA research still exhibits strong synergistic effects. The hybrid effect of national funding and OA was beyond the sum of individual effects (national funding alone: +86-106%; OA alone: +53-141%).

Regression analysis also showed significant interaction effects for national funding and OA status ($p < 0.05$) suggesting that these are genuine multiplicative relationships. The models accounted for 24-28% of the variation in citations ($R^2 = 0.24 - 0.28$), with standardized coefficients indicating contributions from national funding ($\beta = 0.28 - 0.32$), OA status ($\beta = 0.17 - 0.21$), and their interaction ($\beta = 0.11 - 0.14$) (see Table 1).

Citation Hierarchy by Funding Source and Access Type

The data reveal a consistent citation hierarchy across institutions. From highest to lowest citation performance:

- International funding + Open Access:** +220-274% above unfunded closed baseline.
- Mixed funding + Open Access:** +180-220% above baseline.

3. **National funding + Open Access:** +171-195% above baseline.
4. **International funding + Closed Access:** +100-145% above baseline.
5. **National funding + Closed Access:** +86-106% above baseline.
6. **Unfunded + Open Access:** +53-92% above baseline.
7. **Unfunded + Closed Access:** Baseline (reference category).

This structure shows that both funding acquisition and OA publishing are the main contributors to citation impact, and the best results are achieved by their combination.

Open Access adoption rates went up significantly throughout the study period (2015-2024). In general, rates more than tripled at several institutions, going from 4.5-15% during 2015-2018 to 14.3-35% during 2022-2024. Such a trajectory is an indication of increasing institutional and funder commitment to the OA principles. International funding OA compliance showed a very strong temporal improvement; thus, it was close to 100% during the last years (75% in 2015-2018, 88.9% in 2019-2021, almost 100% in 2022-2024). The trend reflects that the enforcement of international mandates has been strengthened. National funding OA compliance also got better going from 30-52% during 2015-2018 to 52-71% during 2022-2024, however, the rates are still lower than those of international funding compliance.

DISCUSSION

The Open Access Model provides greater benefits to article citation rates than do traditional (non-open access) models. Overall, the number of citations received by articles published in the Open Access Model was 68 per cent greater than the citation rate for articles published in a traditional format and was significantly greater than the average citation rates for Open Access Articles published globally (18-50%) (Gupta and Bala, 2011; Prathap, 2018).

The statistical robustness of the findings from the seven participating universities supports the validity of the observed trends. All of the institutions for which data were available showed a significant relationship ($p < 0.05$ to $p < 0.001$) between the citation rates of published articles in the Open Access Model, and therefore support the reliability of the findings from each institution. Effect sizes for each institution were averaged from a small/medium effect (i.e., Cohen's $d = 0.21-0.42$); thus, the findings were statistically significant and had practical implications.

The cross-sectional research design limits the ability to draw causal inferences. Although legitimate accessibility effects for OA articles have been documented through randomized controlled trials (Gargouri *et al.*, 2010) and longitudinal matched-sample

studies (Langham-Putrow *et al.*, 2021), it is necessary to recognize that there are other possible explanations such as author self-selection, early view advantages, and signalling quality through OA options. Therefore, future studies with quasi-experimental or instrumental variable methodologies may help assert more powerful causal claims for OA article advantages in these situations.

The notable success of Green OA across multiple institutions provides an intriguing contrast to existing research on the higher impact of Hybrid and Gold OA that have been documented in developed environments (Archambault *et al.*, 2016; Piwowar *et al.*, 2018). Some possible explanations for the difference in average Green OA performance compared to other models may include the fact that many of the institutional repositories operated by such universities receive active promotion through both university communication channels, and/or that researchers choose strategically which manuscripts they wish to deposit into a repository (many times based on performance metrics). Additionally, the number of publishers that demonstrate questionable practices within certain Gold OA journals (Banshal *et al.*, 2019) may also affect average Gold OA performance.

In contrast, Bronze OA was consistently found to have below-average performance across all other models, with negative effects noted in some cases (-11.7% in some circumstances). These results are consistent with previous studies that indicate that access to many instances of Bronze OA is often unstable and likely to disappear over time, therefore leading to diminished long-term discoverability and citation accumulation (Piwowar *et al.*, 2018). Consequently, institutions should prioritize the establishment of sustainable Green and Gold OA pathways to replace temporary access arrangements associated with Bronze OA.

The influence of research funding on OA publishing has been well established, with funded papers being 1.67-3.9 times more likely to be published in an OA format. The relationship between funding and OA publishing works through several means: (i) funders requiring funded papers to be published OA, (ii) provision of APC funds which enables gold OA, and (iii) the association between funding and acceptance of funded research at OA-accessible journals (Tennant *et al.*, 2016; Zhao *et al.*, 2018).

International funding organisations show much higher levels of OA compliance (60.9-100%) based on the data collected for this study. Large international funding organisations have established comprehensive systems of mandates which have a range of components including compliance monitoring and requirements for compliance (Larivière and Sugimoto, 2018; Schöpfel and Herb, 2018). In the context of university research in Northeast India, the systems of tracking compliance appear to be as effective as those in use by European and North American institutions.

The increasing trend toward 100% compliance with international open access requirements through international funding over the past few years indicates that international agencies have begun implementing these mandates effectively. Over time, international agencies have refined their strategies for enforcing open access. This has been accomplished through the inclusion of open access compliance in grant agreements, through the inclusion of open access compliance in progress reporting requirements and as part of the consideration for renewal applications.

Indian national funding agencies have much lower rates of open access compliance (between 16.9 and 71.2%) than do international agencies. This difference is due to differences in policy structure around open access. While many Indian national agencies have developed their own open access supportive policies, there is a stark contrast in implementation frameworks between international funding agencies and Indian funding agencies. The considerable difference between the highest compliance rates (71.2%) and lowest compliance rates (16.9%) across funding agencies illustrates the varied approaches taken by the agencies to implement policy.

Nonetheless, national funding agencies have increased their rates of compliance significantly during the years from 2015 to 2018 (30-52%) and from 2022 to 2024 (52-71%). National funding agencies could take additional steps to strengthen their open access implementation frameworks through a more robust system of monitoring compliance, clearer reporting requirements for compliance and an increase in the systematic support for APCs that would help their open access compliance approach to achieve international standards.

Both national and international funding have been significantly correlated with an increase in citation performance (an increase of 86-106% compared with unfunded research). As a result, funding from either source has been demonstrated to have a positive impact on the citation rate of funded research. Due to several factors (collaboration patterns, selection of publication venue and topic selection), there appears to be a consistently higher level of citations for internationally-funded research (between 5.2%-36.5%) than for nationally funded research. However, it is important to note that these differences do not appear to be related to inherent differences in the quality of research.

International funding often fosters connections between authors who are distributed over several countries. These author networks allow for increased visibility of published research in international publications via citation and lead to the creation of new global research pathways (Wagner *et al.*, 2019; Waltman *et al.*, 2011). In addition to providing authors with opportunities for increased citations, the additional benefits of collaboration networks can enhance the overall performance of grants and contracts.

The most telling conclusion concerns the multiplicative nature of funding combined with OA publication methods. Authors who

received funding for publishing OA articles were cited between 171% and 274% more than authors who published closed access articles without funding. Overall, the authors reported that their findings were consistent with those presented by (Tennant *et al.*, 2016), who indicated that authors using OA publication methods had received higher citation rates 85-125%, on average, compared to those using closed access models.

Overall, the combination of grants and OA publication methods was expected to be greater in magnitude when both variables were present in the same example than when either variable was ignored. Based on the significant differences found in citation performance in each of these two years (Wagner *et al.*, 2019; Wang *et al.*, 2015), the larger effects documented may represent increased synergy between OA access and grant support in cases where OA publications were substantially more available than traditional sources.

The results of regression analysis indicated statistically significant interaction or multiplicative effects ($p < 0.05$ to $p < 0.01$) after accounting for main effects, indicating that the two funding/two publishing options should be pursued to increase the likelihood of high levels of research impact rather than being pursued as separate/individual approaches.

There was a strong citation premium for research created through international collaborations (21.9%-73.1% higher than research created solely nationally). The findings are consistent with a substantial amount of existing literature that indicates the advantages of collaboration include larger co-author networks, greater ability to publish in internationally recognized higher impact journals, and higher levels of visibility of research globally (Wagner *et al.*, 2019; Waltman *et al.*, 2011).

Different levels of collaboration effect were noted across the various institutions studied (22%-73%), suggesting varying levels of success in establishing partnerships internationally for productive research. As institutions establish exchange programs, joint research centres, and hire international faculty members, the frequency of collaboration and the resulting citation impact will increase. This indicates that strategic institutional investments in internationalisation will generate a very real, measurable return on research impact (Banshal *et al.*, 2019).

However, the proportion of internationally collaborative papers produced by these institutions is much lower than the global average (1.1%-5.2% for the institutions in this study) compared to other universities, where internationally collaborative research is estimated to be 15%-25% of university-generated research (Waltman *et al.*, 2011).

International collaborations may be impacted by numerous factors that act as barriers to participation; these factors include lack of funding to travel, the infancy of building institutional collaborations, and the low level of participation in international

research networks. If institutions were to improve their capacity to overcome the barriers to international collaboration by implementing targeted programmes to increase the level of collaboration, that would greatly enhance the capacity of those institutions to produce highly impactful research.

Indian funding agencies have the potential to develop a more comprehensive and structured approach to OA for the research they support. A large number of Indian funding agencies show low to moderate current compliance rates (16.9%-71.2% across funding agencies) with existing OA policies which may indicate an opportunity to enhance OA policies. Funding agencies should also consider the following: setting deadlines for OA publishing, including a line in the budget for APC funding, designating institutional repositories as OA compliance options, and incorporating OA compliance into the OARs of grant agreements. If implemented, these actions have the potential to create greater alignment between Indian science policy and international open science frameworks as well as provide better access to research.

Universities can develop institutional OA policies to support research while providing the necessary infrastructure and support to do so. Current institutional OA adoption rates (23.4%-34.6%) indicate significant opportunity for institutional OA programs to grow. Institutions may want to implement the following: develop policies for deposit in institutional repositories, establish membership in consortium models to negotiate OA agreements with publishers, set aside a portion of institutional budgets to establish support funds for APCs, and include OA metrics in evaluating faculty.

Evidence suggests that a combined strategy of successfully acquiring funding and OA publishing will yield greater overall impact for a research project. The hierarchy of citation statistics also provides direction for developing an effective plan for future research. Researchers may want to consider: pursuing collaborative funding opportunities where appropriate, ensuring funds are included for publication costs in the grant project, using institutional repositories whether or not APC funding has been obtained from the source of funding, and using sustainable OA models rather than temporary access.

LIMITATIONS

The present study findings have limitations that must be considered. First, due to the nature of the cross-sectional study design, it is not possible to determine causal relationships between the results found and the statistical correlations observed. However, by using regression controls, some of these issues were addressed. To better understand the causal relationships in more detail, a longitudinal design that followed each individual article over time would provide stronger evidence for the causal relationship between the two variables studied.

Secondly, funding information collected was based on information supplied by the authors in the acknowledgment section of the article, which may have incomplete or inconsistently produced information. Smaller grant amounts or institutional support were likely not reported consistently, which may have impacted the estimates of the effects of funding on the publication. Additional and more consistent funding information can be obtained through agency databases, which would allow for a more accurate assessment of funding effects.

Thirdly, the process of classifying OA articles is primarily conducted through an automated process in Scopus and may misclassify certain OA articles, particularly repository-based Green OA, which can have diverse access patterns. As a way to validate the results of this study in terms of the classification accuracy, a manual verification of a representative sample would have been beneficial, but due to the limits of resources in this study, it was not completed.

Fourthly, the use of citations as the primary metric of impact on research products limits the ability to assess only one dimension of influence on research, and additional measures could include the number of downloads, Altmetric scores, policy citations, and media references, to assess the accessibility of OA articles in the academic citation networks (Piwowar *et al.*, 2018).

Finally, findings from Northeast Indian universities may not generalize directly to other institutional contexts with different resource levels, disciplinary profiles, or infrastructure conditions. Replication studies in diverse geographic and institutional settings would strengthen understanding of how these patterns vary across contexts.

CONCLUSION

The findings of this bibliometric analysis of 8616 papers produced by seven institutions in Northeast India support previous research findings about the benefits of Open Access (OA) publishing and OA/citation advantage as a function of funding received. OA publications receive significantly more citations than their Closed Access (CA) counterparts. On an institutional level, OA has a statistically significant effect on the citation performance of publications across all institutions ($p < 0.05$ to $p < 0.001$) and also shows substantial (although not statistically significant) effect sizes.

Thirdly, research funding more than doubles (1.67-3.90) the odds of publishing OA and provides authors with better (86% - 186% increase) than CA paid in full outcomes, meaning there are different levels of OA compliance between international funding vs. Indian National Funding.

Fourthly, while both funding types produce an increase in citations, international funding has an additional benefit through collaborative networks and increased international visibility.

Fifthly, the most interesting finding of this bibliometric analysis is the multiplicative effect that occurs when institutions provide both funding and OA for their publications. OA articles produced with funding are 171-274% more likely to be cited than corresponding CA articles produced without funding, indicating that combining funding and OA produces a larger citation impact than either strategy pursued in isolation.

Research shows that different OA subtypes produce different levels of citation performance. Green OA does particularly well at many institutions, whereas Bronze OA performs poorly suggesting that Researchers and Institutions should focus on using sustainable methods of providing OA. Temporal trends show three-fold increases in OA adoption rates over five years, indicating growing institutional commitment.

Several implications for policy emerged from the data. First, there is much potential for Indian funding agencies to develop/support Open Access policies that are on par with their international counterparts. Second, universities need to establish/openly implement comprehensive “Open Access Policies” whilst having infrastructure and funding support to facilitate these. The third point is that open access publishing, together with the potential for increased funding acquisition will synergistically increase the impact of publishers, and therefore all stakeholders involved.

Future studies should employ a longitudinal design in order to rigorously evaluate causality; examine how Open Access effects vary across disciplines; and examine how different Open Access strategies may be able to provide greater cost savings than others. As the scientific production of developing countries continues to grow; understanding how to maximise the productivity and impact of developing country research via developing Open Access policies and seeking strategic sources of funding will become even more critical for both individuals and institutions, as well as national science policy.

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ABBREVIATIONS

DST: Department of Science and Technology; **SERB:** Science and Engineering Research Board; **UGC:** University Grants Commission; **DBT:** Department of Biotechnology; **CSIR:** Council of Scientific and Industrial Research; **CA:** Closed Access; **OARs:** Open Access Requirements.

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CONFLICT OF INTEREST

There are no competing financial interests or personal relationships could influence the work reported in this paper.

AUTHORS' CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Fullstar Lamin Gayang]. The first draft of the manuscript was written by [Evangelyne Wanniang & Akramul Islam]. All authors read and approved the final manuscript.

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