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Measuring the Impact of Gold and Green Open Access

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ABSTRACT

Using data from Web of Science, this research investigates how physical science researchers funded by the Canadian Institutes of Health Research complied with its open access policy, and compares the citation counts of articles published through gold and green models.

It was found that, for articles published between 2008 and 2015, 9% were available through gold open access routes and 13% were available through green routes; most were not openly accessible. Citation rates were comparable for green open access and non-open access articles, but citation rates for gold open access articles were lower. After controlling for publication year, citation rates of gold, green, and non-open access articles were comparable. Among gold open access articles, citation rates were highest for open access journals with article processing charges, but after controlling for publication year, articles published in hybrid journals, followed by those in open access journals with article processing charges, achieved the highest citation rates. Articles published in free open access journals had the lowest citation rates. The results suggest that green open access is the most economical approach to comply with open access policies, and that it provides researchers with at least as much research impact as gold open access.

Introduction

Over the past decade, funding agencies around the world have adopted open access policies. At the time of writing this article, 71 funding agencies[1] require that journal articles resulting from agency-funded research be made openly accessible within a set amount of time (ROARMAP: Registry of Open Access Mandates and Policies, 2017). Among these agencies, health sciences funding agencies were early implementers of such policies; both the U.S. National Institutes of Health (NIH) and the Canadian Institutes of Health Research (CIHR) instituted open access policies in 2008, and were among only 23 funding agencies that had done so at that time.

There are, however, two ways to achieve open access: gold open access and green open access. "Gold open access" is achieved through publishing in one of three groups of journals. One group charges its authors no article processing fees, generally because the costs of publishing are borne by a sponsoring society or association. Thus, authors can publish in these journals for free. We call them "free open access journals" in this study. A second group of journals collects article processing charges (APC) from authors to publish their articles. We call this group "open access journals with APC." The third group is composed of traditional subscription-based journals that offer authors the opportunity to make their individual article openly accessible upon payment of article processing charges. We call this group "hybrid journals." All gold open access articles are freely available to readers immediately upon publication.

Under the "green open access" model, authors publish their articles in traditional subscription-only journals. Then, after a publisher-specified embargo period has elapsed, they "self-archive" their works by depositing them in institutional or subject-specific repositories. Green open access is permitted by most publishers; at the time of writing this article, SHERPA RoMEO, which provides information on publisher copyright and archiving policies, states that 74% of the publishers listed on their site allow self-archiving of "post prints" (articles that have completed the peer review process) (SHERPA/RoMEO, 2016).

The possible "citation advantage" of open access publishing, that is, the possibility that articles made freely available to readers are cited more often than those behind a paywall, has been studied for more than a decade (Harnad & Brody, 2004). Many studies have been done, and results have varied. However, in 2015, the various studies on this topic were summarized, and it was found that of the 70 studies conducted till that point, 46 showed a citation advantage, while 17 found no

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[1] The 71 funding agencies include both funders and research organizations that are also funders (e.g. NIH, CIHR).

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advantage, and 7 were "inconclusive, found non-significant data, or measured other things than citation advantage for articles" (SPARC Europe). Interestingly, even though nearly a quarter of studies (17/70) found no citation advantage for open access articles, the conclusion reached by SPARC Europe was that it was no longer necessary to update the site, since "the citation advantage evidence" had "become far more common knowledge."

Of the many studies on citation advantage of open access, one stream has focused on that of green open access, and again the results have been mixed. For example, two early studies showed that making a subscription-only article available in a repository increased the citation rate by 36–200%, and that the amount of increase varied by discipline, with physics articles being the greatest beneficiaries of green open access (Hajjem, Harnad, & Gingras, 2005; Harnad & Brody, 2004).

However, some have argued that much of the citation advantage experienced by green open access articles might be the result of other factors. Kurtz et al. (2005) concluded from their study of astronomy journals that the openly accessible articles were cited more often, but that this was the result of two factors. First, the openly accessible articles were all available through ArXiv, a site that allows authors to post preprints, articles that have not yet undergone peer review. Other researchers therefore had greater opportunity (a longer time period) to cite them than they did to cite articles that became available only at the time of publication in a journal. This first factor is called the "early access" or "early view" effect. Second, Kurtz et al. (2005) concluded that authors chose to make only their best work openly accessible, and that because this was higher quality work, it was cited more often – this is called the "self-selection effect" or "quality bias." Like Kurtz et al. (2005), Moed (2007) found that openly accessible journal articles were cited more often; he also attributed this to the selection bias and the early access effect. Davis and Fromerth (2007), however, found that selection bias alone, and not early access, explained the higher citation rates of the openly accessible articles in their study. On the other hand, when Gargouri et al. (2010) compared the articles deposited in a repository (either through author choice or because of a funder or institutional mandate) with non-open access articles, they found that the citation advantage of open access was "real, independent and causal". However, the citation advantage was not due to authors choosing to make only their best work open access (quality bias), but due instead to what Gargouri et al. (2010) call a "quality advantage." They claim that open access does not improve citation rates of all articles, but that it does increase citation rates of high-quality articles, because they are more easily accessible and thus more easily citable.

Another stream of research on the citation advantage of open access articles has concentrated on gold open access. Using data from the Directory of Open Access Journals, Journal Citation Reports, and Scopus, Björk and Solomon (2012) compared the citation rates of open access and subscription journals from a wide variety of disciplines, including sciences, medicine, social sciences, and humanities. They found that the average citation rate of subscription journals was about 30% higher than that of open access journals. However, when they controlled for discipline, journal age, and publisher location, the difference in citation rates of the two types of journals almost disappeared. They also found that free open access journals had much lower citation rates than did open access journals with APC or subscription journals. Björk and Solomon (2012) concluded that open access journals with APC achieved equal citation impact to subscription journals launched in the same period. In another study, McCabe and Snyder used citation data from 100 journals in ecology and related fields (Mccabe & Snyder, 2014). They found that journals that moved from a subscription-based model to an open access one experienced an 8% increase in citation rate. However, it was for the most part the top-ranked journals that experienced the increase, while the lowest-ranked journals experienced a significant reduction in citation rate. The authors speculate that open access not only enhances readers' ability to find the full-text of articles but also gives them more choices of what to read, i.e., readers might not actually read articles from the lower-ranked journals. Open access, then, might actually intensify the competition for readership, creating both winners and losers.

Over the last few years, more and more traditional subscription-based journals have started to offer authors the option to make their article openly available upon payment of APC. A few studies have therefore focused specifically on the citation advantage of hybrid journals. Studying the open access and non-open access articles in journals published by Springer and Elsevier, Sotudeh and colleagues found that open access articles had a citation advantage ranging from 21% to 49%, depending on the year of publication (Sotudeh, Ghasempour, & Yaghtin, 2015). They also found that the citation advantage varied by discipline, with the advantage for natural sciences journals being the highest (35%) and for social sciences and humanities journals the lowest (3%). It was noted that, in their study, they did not differentiate between open access journals with APC and hybrid journals, though the former accounted for fewer than 10% of the total open access articles. Because Springer and Elsevier are both prestigious publishers, it is unclear whether the publishers' reputations increased the citation advantage of the open access papers. Therefore, the results might not be generalizable to less-known publishers. Mueller-Langer and Watt (2014) examined the open access articles and non-open access articles published in the same hybrid journals in economics. The data used in their study were from a Hybrid Open Access Pilot Agreement, under which articles of authors from the participating institutions were automatically published as open access in the piloting hybrid journals, thus reducing the self-selection/quality bias. They found that hybrid open access increased the citation rate by 22% to 26%. However, after institution quality (based on the ranking of the authors' institution in the Academic Ranking of World Universities) and early view (because some of these articles were made available as preprints through the RePEc preprint server) effects were taken into account, the hybrid open access citation advantage was reduced to an insignificant 0.4%. They concluded that paying to make an article hybrid open access did not represent a worthwhile investment if researchers' motivation for publishing in a hybrid open access journal was to receive more citations.

While many studies have looked at whether open access publishing (either gold or green) leads to greater numbers of citations, relatively few have directly compared the citation counts of gold and green open access. Studying the types of open access papers at the European and world level from 1996 to 2013, Archambault and colleagues found that green open access articles had the greatest citation advantage, being cited 53% more than the average of all papers in the study (Archambault et al., 2014). In contrast, gold open access articles (which in their study included articles published in free open access journals and open access journals with APC, but not hybrid journals) had a citation disadvantage of 35% compared to that of all papers. Gold open access journals had a citation rate even lower than that of non-open access articles. They concluded that green open access articles have a huge citation advantage over other types of open access models, and advocated that green open access be the preferred route for open access. Miguel, Chinchilla-Rodriguez, and de Moya-Anegón (2011) explored the average number of citations per document for articles published in open access journals, subscription journals allowing self-archiving, and subscription journals not allowing self- archiving. Their findings were similar to Archambault's: the subscription journals allowing self-archiving achieved the highest citation rates per document, followed by subscription journals not allowing self- archiving. Open access journals had the lowest citation rate. Once again, hybrid journals were not considered separately.

Research objectives

In the current academic climate, obtaining research funding has become increasingly competitive, and so it is important for researchers to both use their funds to their best advantage and maximize the

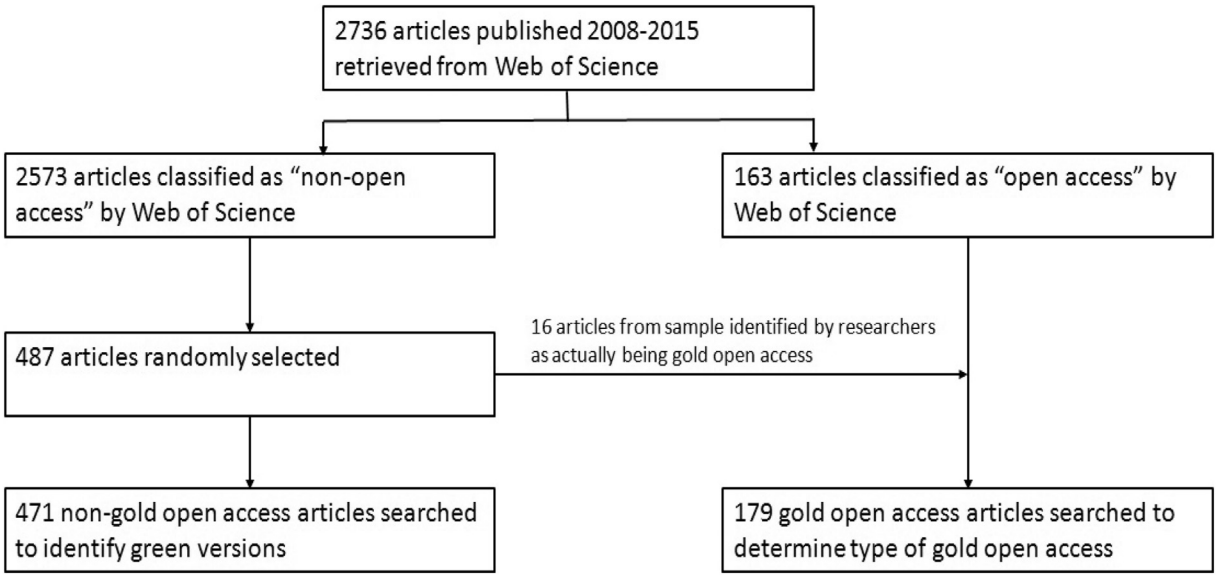

Fig. 1. Workflow and the number of articles searched for open access type.

possibility of achieving high scientific impact for their work. The average article processing charges range from $1000 for open access journals with APC to $3000 for hybrid journals (Björk & Solomon, 2014a). Naturally, researchers will ask themselves if there are compelling reasons to use the gold approach when the green road is free, and, further, if it is worthwhile to pay the higher APC of hybrid journals.

As discussed in the Introduction, few studies have directly compared the citation advantage of green open access with gold open access, and fewer still have looked at the citation rates of each type of gold open access (free open access journals, open access journals with APC, and hybrid journals). This research is intended to complement previous studies by investigating the citation advantages of different types of open access models. It has been nine years since the institution of open access policies by health science funding agencies in 2008; the time is now ripe to assess the scientific impact of green and gold open access. Health science research is becoming increasingly interdisciplinary, and collaboration with those working in fields such as science and technology is common. Using bibliometric analysis, this research studies the articles funded by CIHR in the research fields of physical sciences, hoping to help researchers to decide how to comply with open access policies, to achieve higher scientific impact, and to balance financial costs of APC. The results will be of interest not only to researchers in the health sciences, but also to researchers in the physical sciences, since the U.S. National Science Foundation, and Canada's Natural Sciences and Engineering Research Council, which together fund the majority of science and technology research in these two countries, have recently implemented open access policies.

Specifically, the following research questions are investigated:

- How did researchers comply with CIHR Open Access requirements? Green open access or gold open access?
- Were there differences in the number of citations received by green open access and gold open access articles?
- Among the gold open access articles, what percentage of articles was published in free open access journals, open access journals with APC, and hybrid journals? Were there citation differences among the three groups?

Methods

We searched Web of Science to identify articles funded by the Canadian Institutes of Health Research using the "Funding Agency" search field. During the initial search, it was found that authors used several different variations of CIHR, therefore, we used the following search string to try to capture as many eligible articles as possible:

FO = ("Canadian Institutes of Health Research") OR FO = ("Canadian Institute of Health Research") OR FO = ("Canadian Institutes for Health Research") OR FO = ("Canadian Institute for Health Research") OR FO = (cihr).

Because CIHR has required fund recipients to make their peer-reviewed journal articles openly accessible since 2008, we limited the results to the publication types of "journal article" and "review" and used year limits of 2008–2015. Other publication types such as proceedings paper, editorial material, book chapter, letter, reprint, software review or book review were excluded, as they are not covered by the policy.

Since we were interested in finding out how physical scientists complied with the open access policy, we limited the results to Web of Science's Research Areas of physical science, which includes 17 research areas.

The bibliographic data from Web of Science was downloaded in January 2016 for further analysis.

Web of Science classifies articles as non-open access or open access. Because the number of non-open access articles was large, a random sample was selected. We then searched Google Scholar to determine if the full text of each article in the sample was available in either an institutional repository or a subject repository, thus whether the article was available through a green open access route. We used the "All versions" function within Google Scholar to find the various versions of these articles.

During the research process, we found that the articles classified as "open access" by Web of Science included only those published in free open access journals or in open access journals with APC, but not those published in hybrid journals. Open access articles published in hybrid journals were actually included in the non-open access category. Also, some free open access and open access journals with APC were misclassified by Web of Science as "non-open access." Thus, as we came across open access articles in our non-open access sample, we moved them to the gold open access category for analysis. See Fig. 1 for the workflow. Therefore, our gold open access category consists of the articles classified as "open access" by Web of Science, plus the articles in our "non-open access" sample that were either published as open access articles in hybrid journals, or were published in open access journals, but were misclassified by Web of Science.

For each gold open access article, we searched the journal's website

to determine whether it was a free open access journal, an open access journal with APC, or a hybrid journal. The APC of each open access journal with APC and each hybrid journal were recorded based on the information found on their websites. Some journals charged a base APC for a certain number of pages, with additional fees charged for extra pages. In that case, we recorded only the base fee. Some journals also offered discounts to certain groups of authors, e.g., members of certain scientific associations, or authors from developing countries. In those cases, we recorded only the regular charges for these journals. If APC were expressed in a currency other than U.S. dollars, we converted them to U.S. dollars using the exchange rate on the day of research.

We then compared the citation counts of these different types of articles to determine whether there were differences in the scientific impact, as measured by citation counts, of the different open access models.

Results

2754 records funded by CIHR in the research areas of physical sciences were retrieved from Web of Science. We then limited the results to the publication years of 2008–2015, and received 2736 results. Before 2008, only two records reported the funding agency as being CIHR, one from 2005 and one from 2007. In 2008, the number of records that reported that the funding agency was CIHR increased to 101, indicating that it was in this year that researchers began to comply with CIHR's open access policy, part of which is to acknowledge CIHR as the funder. As we stated earlier, 2008 was also the year that the CIHR open access policy came into effect. The numbers of physical science articles funded by CIHR in each year can be found in Table 1.

Table 2 indicates the number of articles in each physical science research area. As can be seen, the top three research areas were chemistry, physics, and mathematics, with 1711, 461, and 244 articles respectively. Note that the total number of articles from these research areas was larger than 2736, the total number of records included in this study, because individual articles can be classified into more than one research area.

Of the 2736 articles, 2573 were classified as “non-open access” by Web of Science and 163 as “open access” (Fig. 1). As we stated above, Web of Science does not classify open access articles published in hybrid journals as “open access.” Therefore the 163 open access articles includes only those published in free open access journals or open access journals with APC. These “open access” articles accounted for only 6% of the total number of articles. The total number of articles, as well as the number of “open access” articles per year is shown in Fig. 2. As can be seen, the number of open access articles published in free open access journals and open access journals with APC has stayed somewhat stable since 2011.

A random sample of 487 articles was selected from the 2573 non-open access articles (confidence level: 95%; confidence interval: 4%).

Table 1
Number of articles by year that reported the funding agency as CIHR.

Year	Number of articles
2005	1
2006	0
2007	1
2008	101
2009	294
2010	329
2011	400
2012	431
2013	382
2014	388
2015	417
2016	10

Table 2
Number of articles in each research area.

Research area	Number of articles
Chemistry	1711
Physics	461
Mathematics	244
Optics	139
Polymer Science	123
Crystallography	98
Water Resources	23
Electrochemistry	21
Geochemistry & Geophysics	21
Geology	17
Meteorology & Atmospheric Sciences	15
Oceanography	8
Mineralogy	7
Physical Geography	5
Thermodynamics	4
Mining & Mineral Processing	1

Of the 487 sample articles, we found that 16 were actually gold open access articles, which included 12 articles published in hybrid journals, 2 in free open access journals, and 2 in open access journals with APC. These 16 articles were moved to the Gold Open Access Category. Therefore, 471 were studied to determine if they were available through a green open access source (institutional or subject repository) (Fig. 1).

Composition of green and gold open access

Of the 471 articles, 67 articles could be accessed through either an institutional or subject repository. Three of the 67 were available in both a subject and an institutional repository. The remaining 404 articles were not openly accessible through a green route.

Of the 163 articles categorized as “open access” by Web of Science, 8 were published in free open access journals, 155 were published in open access journals with APC, but none were published in hybrid journals. Because the open access category of Web of Science did not include those published in hybrid journals, it is difficult to determine exact number of open access articles published in hybrid journals. Based on the proportion of open access articles classified as “non-open access” by Web of Science, we were able to estimate the percentage of green open access, gold open access, and non-open access categories, as shown in Fig. 3. Researchers used green open access (13%) more often than gold open access (9%). However, the vast majority of the articles were not openly accessible. In other words, only 22% of the articles were openly accessible through either gold or green routes.

We also estimated the percentage of each of the gold open access types. As can be seen from Fig. 4, open access journals with APC was the most used type of gold open access; it accounted for 67% of the gold open access articles, followed by hybrid journals with 25%. The least used type was free open access journals, which accounted for only 8% of the gold open access articles.

Citation comparison of green and gold open access

We compared the average number of citations per document for gold open access articles, green open access articles, and non-open access articles. Surprisingly, gold open access articles had the lowest average number of citations per document (8.71), whereas green open access achieved an average of 12.37 citations per article, a level 1.42 times that of the gold articles. Non-open access articles were also cited more often than gold articles; they had an average number of citations of 11.90. Research has shown that there is often a time lag between publication date and citation peak (Glänzel, 2007), and it is best to compare the citations of articles published in the same period. The

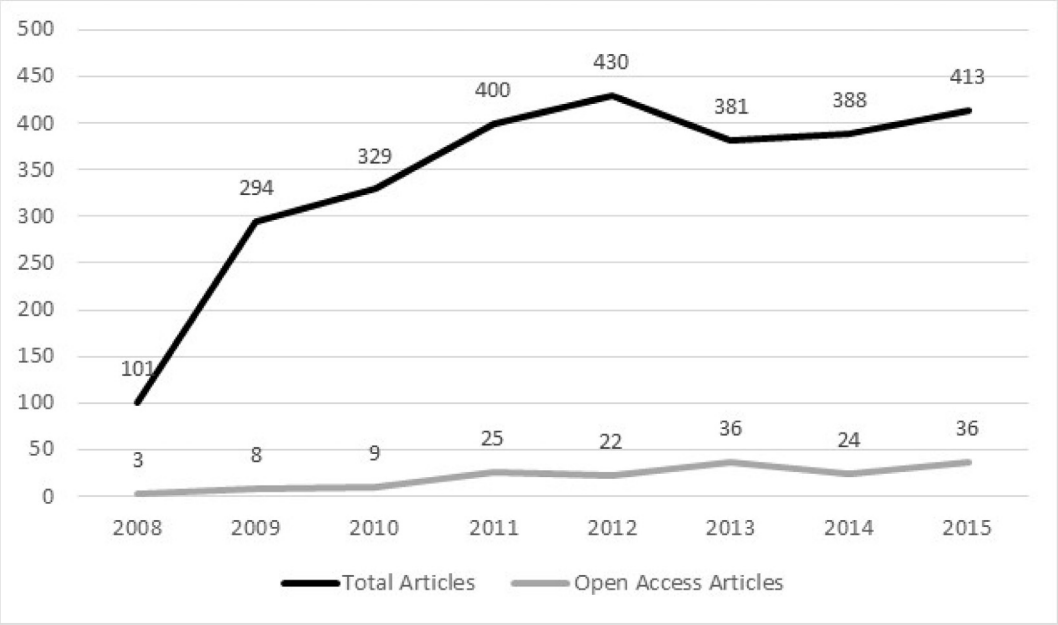

Fig. 2. Number of articles published per year from 2008 to 2015.
Note: The open access articles shown in the figure includes only those published in free open access journals and open access journals with APC, not those published in hybrid journals, or those misclassified by Web of Science.

average publication year of gold open access articles (mid-2012) is significantly more recent that of the green open access articles and that of non-open access articles (both mid-2011) ($p < 0.001$). Therefore, to reduce the effects of the difference in publication dates, we compared the citation rates of the articles published from 2012 to 2014 in the three categories. 2012 was the earliest publication date of articles published in hybrid journals in our sample, therefore the period of 2012–2014 would allow us to have a reasonable representation of each access type, and have at least a one-year citation window. As can be seen in Table 3, when the publication date of 2012–2014 was considered, the three types achieved similar average citations, with the average number of citations of green open access articles and non-open access articles being slightly higher than that of gold open access articles. This difference is not significant, however ($p > 0.05$).

Comparison of three types of gold open access

The average APC for hybrid journals and open access journals with APC was $1589 USD (SD = 43), with a range of $33 USD to $3975 USD. For the 12 articles published in hybrid journals, the average APC was $2459 USD. The average APC for the articles published in open access journals with APC was $1523 USD, substantially lower than that for hybrid journals; a *t*-test showed this difference to be significant ($p < 0.01$).

The 155 articles published in open access journals with APC appeared in 27 journals, only one of which was not listed in Journal Citation Reports. Journals listed in Journal Citation Reports are often considered core research journals in their fields, so there is some indication that these are high-quality journals. Seven journals published more than three of the articles examined in our study. The title, impact factor, and APC of these journals are listed in Table 4.

Table 5 lists the titles and impact factors of the five free open access journals. The titles of the hybrid journals where the 12 articles were published are listed in Table 6. All hybrid and free open access journals were included in Journal Citation Reports. On average, hybrid journals had the highest impact factor (5.212), followed by open access journals with APC (3.156), while the free open access journals had the lowest impact factor (1.327).

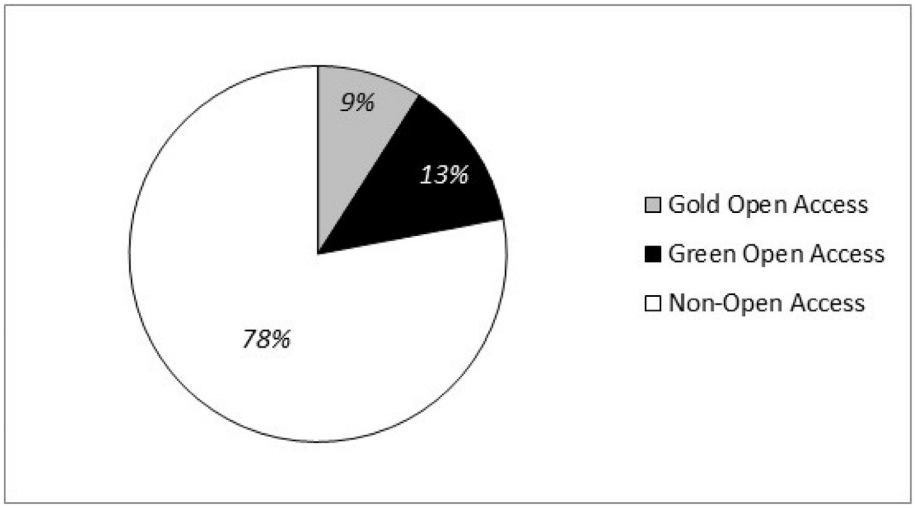

Fig. 3. Estimated percentages of articles accessible through green and gold routes.

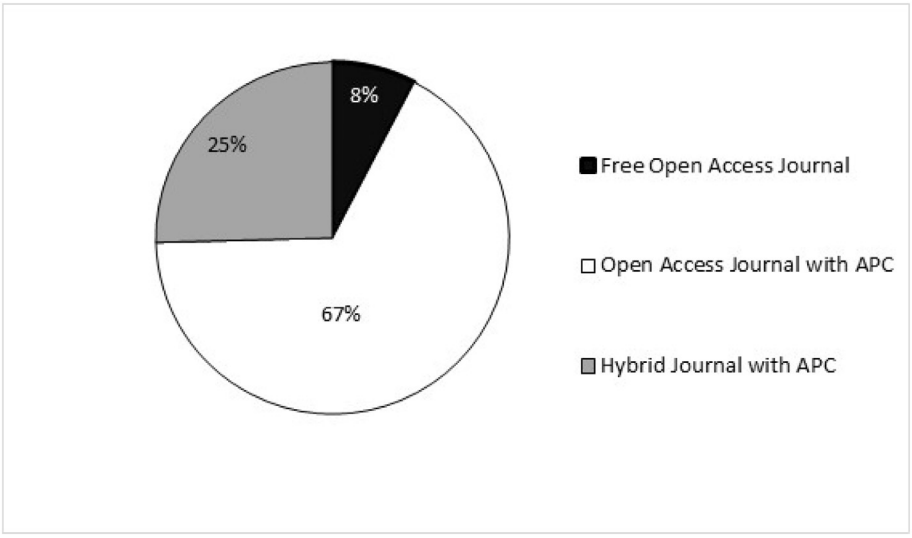

Fig. 4. Estimated percentages of articles of the three types of gold open access.

Table 3
Average citations of gold open access, green open access, and non-open access.

Types of open access	Number of articles	Average citation/ article	Number of articles published 2012–2014	Average citation/ article of articles published 2012–2014
Gold open access	179	8.71	89	7.4
Green open access	67	12.37	30	7.73
Non-open access	404	11.90	101	7.75

Table 4
Impact factor and APC of open access journals with APC that published more than three of the articles examined in this study.

Journal title	Number of articles	Impact factor	APC (USD)
Biomedical Optics Express	44	3.34	1489
International Journal of Molecular Sciences	35	3.26	1718
Optics Express	22	3.15	1904
Molecules	13	2.47	1931
Sensors	7	2.03	1931
New Journal of Physics	4	3.57	2080
Acta Crystallographica Section *E*-Structure Reports Online	3	N/A	165
Average*	N/A	3.156	1523

* The average of impact factor and APC are for all open access journals with APC identified in this study, not just those listed in this table.

Table 5
Impact factor of free open access journals.

Journal title	Number of articles	Impact factor
Acta Physica Polonica A	1	0.525
Arkivoc	2	1.177
Beilstein Journal of Organic Chemistry	3	2.697
Electronic Journal of Statistics	1	0.736
Physical Review Special Topics-Accelerators and Beams	1	1.5
Average	N/A	1.327

Table 6
Impact factor and APC of hybrid journals.

Journal title	Number of articles	Impact factor	APC (USD)
ACS Nano	1	13.334	1000
Acta Pharmacologica Sinica	1	3.166	3300
Analyst	1	4.033	2312
Bioinformatics	2	5.766	3000
Chemical Science	2	9.144	2312
Climatic Change	2	3.344	3000
Journal of Biomedical Optics	2	2.556	960
Plant Foods for Human Nutrition	1	2.276	3000
RSC Advances	1	3.289	2312
Average	N/A	5.212	2459

We also compared the average number of citations per article for the three gold open access types: free open access journals, open access journals with APC, and hybrid journals. Open access journals with APC had the highest average number of citations per article (8.9), whereas the average number of citations per article for hybrid journals and free open access journals were much lower: 5.6 and 5.5, respectively. When we compared the citations of those articles published between 2012 and 2014, the results were quite different. Hybrid journals had the highest average citations of 10.83, double of that of open access journals with APC (5.31). The average number of citations for articles published in free open access journals dropped to 2.8 for 2012–2014. However, numbers of both hybrid and free open access articles were very small for this period, so this sample may not be representative. Details are listed in Table 7.

Discussion

This study explores how physical science researchers receiving funding from CIHR complied with the open access policy. The results show that in the eight years following implementation of CIHR's open access policy, the compliance rate was low; only 22% of the articles funded by CIHR were openly accessible. Our results align with previous literature, which indicated that about 20%–24% of peer-reviewed journal articles were openly available (Björk et al., 2010; Gargouri, Larivière, Gingras, Carr, & Harnad, 2012). However, one should bear in mind that these earlier studies used samples from scientific literature in general, and did not focus on those articles funded by a body with an open access mandate. When open access of research articles is mandatory, it has been predicted that the open access rate would be much higher. In her study of researchers' willingness to make their articles

Table 7
Comparison of citation numbers of the three gold open access models.

Types of gold open access	Number of articles	Average citation/article	Number of articles published 2012–2014	Average citation/article of articles published 2012–2014
Free open access journals	10	5.5	5	2.8
Open access journals with APC	157	8.9	78	5.31
Hybrid journals with APC	12	5.6	6	10.83

openly accessible, for example, Swan (2006) found that 95% of the researchers would do so if required by their institutions or funding agencies. A few funding agencies with open access mandates have reported their compliance rates. For example, the NIH reported a compliance rate of 83% as of 2015 (National Institutes of Health, 2015), while the Wellcome Trust reported a rate of 69% in 2014 (Van Noorden, 2014). In the latter case however, the Wellcome Trust, which requires that researchers make their articles openly accessible within 6 months, pays the APCs incurred by researchers; these charges are not paid out of author grants (Wellcome Trust, n.d.). A lower compliance rate was found among articles resulting from scientific research funded by the Spanish government; though by law they must be made openly accessible within one year of publication, Borrego (2016) found that only 58.4% of articles complied. Gargouri et al. (2010) found an average uptake rate of 60% when open access was required by researchers' institutions . The compliance rate of 22% identified in our study for articles funded by CIHR is therefore much lower than those reported when open access is mandatory.

It has been argued that if there is no open access enforcement in place, the compliance rate is likely to be low (Van Noorden, 2014). The NIH and the Wellcome Trust began stricter enforcement in 2012, and so far, are the only two funders worldwide that have withheld grants for open-access violations. As a result of the enforcement policy, the compliance rate of the two funding agencies has increased noticeably since 2012 (Van Noorden, 2014). This suggests that CIHR and other agencies might want to consider implementing similar policies to increase compliance with their open access policy.

Funding agencies are experimenting with other approaches to increase the open access compliance rate. One such method is to consider only openly accessible articles when assessing a grant applicant's research. For example, four higher-education funding bodies in the U.K. recently announced that only final peer-reviewed manuscripts deposited in an institutional or subject repository will be eligible for the Research Excellence Framework, a system for assessing the quality of research in U.K. higher education institutions (Higher Education Funding Council for England, 2015). Research institutions can also help to increase open access compliance rates using bottom-up policy enforcement. For instance, the University of Liège, in Belgium, recently announced that only articles placed in a local repository will be counted toward internal evaluations such as those for the award of merit pay or promotion (Rentier, 2015). Whether or not funding agencies or research institutions themselves adopt strategies to enforce open access mandates, librarians can play an important role in improving compliance rates by educating users about methods for compliance. Migheli and Ramello (2014) found that a researcher's decision whether or not to make research results openly accessible can be affected by the “popularity” of open access within the researcher's department. By proactively reaching out to researchers to promote and to increase their knowledge of open access, librarians can help to establish a culture of open access.

As Rizor and Holley (2014) noted, one of the greatest problems with green open access is its discoverability, because the full text of articles deposited in various repositories might not be as easily discovered as articles published in gold open access journals. This may in turn translate into lower readership and citation rates for green open access articles. However, our study found that the citation count per green open access article was 42% higher than that of gold open access articles. Even when we controlled for publication date, green open access articles still achieved citation counts that were similar, if not higher, to gold open access articles. These results are in line with previous research (Archambault et al., 2014; Miguel et al., 2011).

In recent years, the infrastructure of institutional and subject repositories has improved, and advances in Internet search engines (e.g. Google Scholar, arguably the most used academic search engine) have made it easier to retrieve different versions of the full text of an publication (Harnad, 2015). In addition, many academic libraries have implemented link resolvers to help users to retrieve the full text of an article. Link resolvers often provide direct links to Internet full text available through Google and/or Google Scholar, thus making it relatively straightforward to find the full text of articles deposited in institutional or subject repositories. As green open access poses no financial cost to researchers, our results suggest that green open access is the more economical approach, therefore making it the best choice for funding recipients to comply with open access requirements. The fact that in our study, green open access was used 44% more frequently than gold open access, indicates that researchers are likely aware of the advantages of green open access, and that is their preferred approach to comply with the CIHR open access mandate. Our results also support the recommendations of the U.K. House of Commons' committee on open access, which put more emphasis on green open access because currently, the cost of adopting gold open access is much higher than that of green open access (House of Commons, Business, Innovation, and Skills Committee, 2013).

Of the three gold open access types, free open access journals were the least used type (8%), while hybrid journals were used more often (25%) and open access journals with APC were the most popular choice (67%). The average impact factor of free open access journals is the lowest, and the average citation counts per document, when publication date is considered, is also the lowest for this group. This finding is consistent with previous literature. Comparing the impact of different models of open access journals in sciences, Björk and Solomon (2012) found that free open access journals launched from 2002 to 2011 had a much lower average impact factor (1.25) than either open access journals with APC or subscription journals launched during the same time period, each of which had an average impact factor over 3.0. Since a journal's reputation and prestige are among the most important factors that a researcher considers when deciding where to publish their research findings, the low uptake rate of 0.7% of all articles (or 8% of all gold open access articles) for free open access journals identified in our study may reflect researchers' awareness of the prestige and reputation of this group as a whole.

We found that both the average APC and impact factor of hybrid journals were significantly higher than those of open access journals with APC, which echoes previous findings that there is a positive correlation between APC and journal impact factors (Björk & Solomon, 2014b). By publishing in hybrid journals, researchers expect to benefit from the reputation and readership of these journals, and to receive more recognition as a result of the higher APC they pay (Attema, Brouwer, & Van Exel, 2014). Indeed, after controlling for publication year, we found that the articles published in hybrid journals received the highest average citation count. However, the uptake rate of hybrid journals was very low (2.7% of all articles) even though many

subscription-based journals have offered a hybrid option for a few years. The low uptake rate may indicate that researchers are sensitive not only to journal reputation, but also to the APC price level (Sotudeh et al., 2015), and that the high APC of hybrid journals is hindering the uptake of hybrid open access. Further, it has been argued that the hybrid open access model is "dysfunctional" (Björk & Solomon, 2014b). One problem is "double dipping": publishers may charge twice for the same article, once through the subscription fee and once through APC. Paying journal subscription costs as well as their researchers' APC may be unsustainable for libraries/research institutions. Björk and Solomon (2014b) outline a number of different models through which funding agencies could help to create a "transparent, competitive and reasonably priced APC system"; options include establishing maximum APC beyond which the funder will either not pay, or will pay only a percentage of the cost, and pressuring publishers of hybrid journals to refund APC to subscribing institutions.

It should be noted that, when publication date is controlled, the citation advantage of hybrid journals over other types of open access models, as exhibited in this study, may be subject to self-selection/quality bias. Because the APC of hybrid journals are much higher than open access journals with APC and, of course, than green open access sources, authors may select only their highest quality research for publication in hybrid open access journals. Therefore, the higher citation rates of papers published in hybrid journals might be a reflection of the quality of those papers, instead of the effect of hybrid open access. As pointed out by Mueller-Langer and Watt (2014), if researchers' main reason to pay APC for publishing in hybrid journal is to receive more citations, they might not get what they expect. Furthermore, the sample of open access articles published in hybrid journals in this study is small; therefore, it is unclear whether the findings presented here are applicable on a larger scale. Further research is needed to have a more comprehensive understanding of the impact of hybrid open access journals.

This study has several limitations. First, we used Web of Science as the data source, thus the articles included are limited to those indexed in Web of Science, which is known to be selective in choosing journals for indexing. Therefore, our results might not be applicable to those not indexed in the Web of Science. However, the journals indexed in Web of Science are generally considered to be the core journals in scientific literature, thus we believe our results are able to provide a snapshot of the current status of open access for articles funded by CIHR. Second, we used Google Scholar as the tool to determine whether the full text of a publication was freely accessible on the web through green open access in either an institutional or a subject repository. It is possible that the full text of some articles was deposited in institutional repositories or subject repositories, but that these openly accessible versions were not identified by Google Scholar, and thus that the actual percentage of green open access articles could be higher than the percentage reported in this study. To test whether this was the case, we later selected a random sample of 20 articles categorized as "non-open access" in our study, and searched the Internet using a variety of search strategies to try to find the full text of these articles. However, none of these was found in an institutional or subject repository. Therefore, the results are believed to be accurate. Third, it is possible that some of the articles in our study resulted from research funded by CIHR grants received before the implementation of the open access policy (i.e., before 2008), and thus the grantees were under no obligation to comply with this policy, and thus the compliance rate is higher than our calculations show. Finally, we searched for the green open access versions of the articles in our sample in early 2016. The articles in our study were published from 2008 to 2015. To comply with the policy, researchers have 12 months to make their articles open accessible, meaning that if they had published their work in late 2015, they would not have to make their work openly accessible until late 2016. It is therefore possible that we have missed some of the articles available through the green open access route, and that again, the compliance rate is somewhat higher than what we calculated.

Conclusions

In this study, we found that most articles did not comply with CIHR's open access policy. It is our hope that the low open access compliance rate identified in this study might serve as an impetus for CIHR and, potentially, other funding agencies, to take action to increase, or at least monitor, compliance.

The green, rather than the gold, open access route was a more common choice for those researchers who complied with the policy. We found that articles available through the green route were more likely to be cited than gold open access articles, but that after controlling for publication date, there was no significant difference in citation rates between green and gold. Of gold open access journals, open access journals with APC were chosen for the majority of articles, while hybrid journals were the second choice, and free open access journals were much less popular. After controlling for publication date, hybrid journals had a higher citation rate than did open access journals with APC; free open access journals had a much lower citation rate than the other two categories.

In this time of scarce research funds, maximizing the impact of one's work and using one's research funds wisely makes sense. Our study shows that green open access is the most economical method for researchers to comply with funder open access policies, and that it provides researchers with at least as much research impact as does gold open access. The results identified in this study also have implications for librarians. When providing educational sessions on open access, librarians should ensure that they provide information on selecting and using institutional and/or subject repositories, and identifying and negotiating publisher copyright and self-archiving policies.

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