



Should open access lead to closed research? The trends towards paying to perform research

Lin Zhang^{1,2,3} · Yahui Wei^{1,2} · Ying Huang^{1,2,3} · Gunnar Sivertsen⁴

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Abstract

Open Access (OA) emerged as an important transition in scholarly publishing worldwide during the past two decades. So far, this transition is increasingly based on article processing charges (APC), which create a new paywall on the researchers' side. Publishing is part of the research process and thereby necessary to perform research. This study analyses the global trends towards paying to perform research by combing observed trends in publishing from 2015 to 2020 with an APC price list. APC expenses have sharply increased among six countries with different OA policies: the USA, China, the UK, France, the Netherlands, and Norway. The estimated global revenues from APC among major publishers now exceed 2 billion US dollars annually. Mergers and takeovers show that the industry is moving towards APC-based OA as the more profitable business model. Research publishing will be closed to those who cannot make an institution or project money payment. Our results lead to a discussion of whether APC is the best way to promote OA.

Keywords Open access · Article processing charges · Scientific publishers · Gold journals · Hybrid journals

Introduction

Open Access (OA) is a movement for change in the international infrastructure of scientific publishing to make publications freely available on the public internet (Budapest Open Access Initiative, 2002). Over the past decade, many countries, funding agencies, and institutions have formulated policies to promote the development of OA. On March 21, 2016, Max-Planck-Gesellschaft of Germany and other institutions launched the global

✉ Lin Zhang
zhanglin_1117@126.com

¹ Center for Science, Technology & Education Assessment (CSTEa), Wuhan University, Wuhan, China

² Center for Studies of Information Resources, School of Information Management, Wuhan University, Wuhan, China

³ Centre for R&D Monitoring (ECOoM) and Department MSI, KU Leuven, Louvain, Belgium

⁴ Nordic Institute for Studies in Innovation, Research and Education (NIFU), Oslo, Norway

OA 2020 initiative, inviting universities, research institutions, funders, libraries, and publishers to work together to transform most traditional subscription journals to OA models. To date, more than 150 organizations have responded to this initiative (Max Planck Digital Library, 2021). On May 9, 2016, the “UNESCO/COAR Open Access Joint Statement” signed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Confederation on Open Access Repositories (COAR) stated that “*Open Access has become a global trend*” (EURO CRIS, 2016). On September 4, 2018, a coalition of European and national research funders (cOAlitionS) announced Plan S: “With effect from 2021, all scholarly publications on the results from research funded by public or private grants provided by national, regional and international research councils and funding bodies, must be published in Open Access Journals, on Open Access Platforms, or made immediately available through Open Access Repositories without embargo.” Under this framework, researchers funded by these bodies and councils would be obliged to make all their research immediately OA (European Science Foundation, 2018). A total of 113 research institutions from 37 countries on five continents signed a statement announcing their support for Plan S (Max Planck Digital Library, 2018).

While OA publishing models first emerged as experimental models, it took only a few years for them to become mainstream approaches to delivering scientific knowledge with Article Processing Charges (APC) as a driving force (Demeter & Istrate, 2020; Demeter et al., 2021). The business model based on APC gradually replaces the subscription-based model with gold OA journals, where all articles are immediately available, and hybrid OA journals, which publish both OA and subscription-only content (Piwowar et al., 2018; Smith et al., 2021). In a study of the journals in the Directory of Open Access Journals (DOAJ), Crawford (2021) found that the total APC fees collected by DOAJ journals probably exceeded 1.27 billion USD in 2020. Our study arrives at a slightly lower estimate (1.19 billion) but we can add 0.54 billion USD as the estimated total revenues from APC in 2020 in hybrid journals. Since then, the year 2021 saw rapid increases in the volumes of articles in APC-based gold journals. In a situation where the APC-based model now probably represents a turnover of 2 billion USD annually, which, for comparison, is three times the budget of UNESCO (unesco.org/en/budget-strategy), our study aims to demonstrate empirically the trends towards paying to perform research and discuss their implications.

APC is practiced in gold and hybrid OA publishing. Before introducing our research questions, we will shortly review earlier literature on gold and hybrid publishing with a focus on the economics of APC. We are aware of other types of OA, such as green OA, bronze OA,¹ delayed OA, grey OA, and black OA (Björk, 2017; Fuchs & Sandoval, 2013; Laakso & Björk, 2013; Piwowar et al., 2018; Suber, 2008; Zhang & Watson, 2018). However, these types seldom apply APC and will only be used for contextualization in our country analysis.²

The economics of APC in gold journals are that the articles are immediately made open against APC. Hybrid journals are more complicated. These journals place their articles behind a paywall for access with an option to make them accessible to everyone for free

¹ Many OA advocates and research funders would not regard Bronze as truly OA because the publisher can stop the publications being freely available at any time (i.e., it relies upon the good will of the publisher), whereas genuinely OA publications have a specific license that means the publication is irrevocably OA and the terms of use and reuse are clearly stated. Retrieved from <https://brookesoa.blog/open-access/the-different-models-of-open-access/>.

² We consciously do not use capital letters for the OA types. They are practices, not ideals.

against an APC paid by the article's author, the author's institution or funder, or the journal's publisher (Mering, 2020). Traditional subscription-based journals may also lift an embargo and allow OA after a certain time from the date of publication (i.e., delayed OA). Publishers are slowly transforming their business models from subscription fees while more swiftly shifting to author payments (Budzinski et al., 2020; Zhang & Watson, 2018). A large number of publishers operate a hybrid subscription/OA model offering the option to pay an APC in order to make a particular article open within an otherwise subscription-based journal (Pavan & Barbosa, 2018; Pinfield et al., 2016). Our study finds that in the year of 2020, among the 12,289 journals covered by InCites (Clarivate), only 2577 journals remain only subscription-based while 9712 journals are gold or hybrid.

APC is clearly more applied by commercial publishers than by non-commercial publishers (Bruns et al. 2020). According to Crawford (2021), the number of articles published in the journals included in the DOAJ has doubled between 2016 and 2020 while the total revenues from APC have tripled, indicating a market of researchers and institutions willing to pay higher prices to get published. The nine largest publishers within DOAJ represented a potential total revenue from APC of more than one billion US dollars in 2020, according to Crawford (2021). Our data show that seven of these largest publishers in gold OA publishing also dominate in hybrid or subscription-based publishing: Elsevier, IEEE, Oxford University Press, Springer Nature, Sage, Taylor & Francis, and Wiley. Recent takeovers demonstrate investments in gold OA based on APC: BMC, Springer Nature and Frontiers now have the same owner, Holtzbrink Publishing Group. Wiley has acquired the gold OA publisher Hindawi, Taylor & Francis has acquired the gold OA publisher Dove, and Elsevier has acquired the gold OA publisher KeAi. Another sign that the two business models are merging, are the so-called "Read and publish agreements" signed between major publishers and specific countries or institutions. They are meant to be transformative agreements leading to complete OA but so far represent hybrid OA with APC directly paid by the country or institution as part of their subscription package.

Björk and Solomon (2014) found that hybrid journals were consistently charging higher APC than gold journals. We find the same in our study. Pinfield et al. (2016) suggested that the commercial publishers of mostly hybrid journals have occupied a large proportion of the APC market while at the same time dominating the subscription market. We find the same. APC prices continue to rise, indicating a market of demand. For example, Universities UK (2017) reported that the mean APC rose by 16 percent from 2013 to 2016, higher than the consumer price index. Morrison (2019) indicated that the mean APC for 739 APC funded journals increased by 50% percent from 2010 to 2019. Furthermore, some OA journal publishers will set higher APC for more frequently cited journals with more articles (Asai, 2020). Crawford (2021) estimates that the total APC revenues of the nine largest publishers within DOAJ increased by more than 50 percent only between 2019 and 2020.

Some studies have indicated that APC outperforms subscriptions in terms of revenues per journal. Before any discounts, the average price of subscription to journals covered by Journal Citation Reports (JCR) was estimated to be 2300 USD per subscriber while the average APC per article was estimated to be 2652 USD. A high volume of articles is then more profitable than reaching a high number of subscribers. And, from the perspective of institutions, if one were to subscribe to all 10,535 journals—excluding gold OA journals from the 12,201 journals in the JCR—the sum of the subscription prices is estimated to be about 24 million USD. Nonetheless, the total APC amount required to submit an article to each of the gold and hybrid OA journals is about 30 million USD (Kim & Park, 2020). Hong Kong University spent 1.5 million USD for 942 articles with APC in 2017. Had they paid for all 5000 articles written by its authors during that year to be published OA, the

potential APC bill would have been nearly 12 million USD, which is significantly more than the 4.7 million USD paid for subscriptions to the five publishers who publish most articles (Green, 2019). If the subscription model was profitable before, it seems that the APC model is even more profitable.

Although previous studies have researched the APC of journals (Björk & Solomon, 2014; Cleusa & Barbosa, 2018; Kim & Park, 2020), few studies have analyzed the APC income of gold and hybrid journals in combination and in relation to different OA policies among countries. We also focus on trends in this rapidly changing market for scientific publishing because these trends may raise new demands for independent research and knowledge. So far, the trends have been jointly influenced by the governments and funding organizations on one side, as advised by the OA movement, and the multinational industry of scientific journal publishing on the other side.

The research questions of this paper are: Within the period studied, 2015–2020, what are the trends in:

- (1) the degree and types of OA publishing?
- (2) the total expenses of APC?
- (3) potential APC revenues among major publishers and journals?

Data and methods

Publication data

Publication Data for this study were collected from InCites, an analytical tool based on the Web of Science (WoS). We collected all scientific articles and reviews (both referred to as research articles below) published in 2015 to 2020 that can be attributed to the countries, major publishers and journals selected for the study (see below). The data retrieval was completed on 13th, February 2022.

Types of OA

Research articles are classified by OA type in the WoS platform. This classification is the result of a partnership with *Our Research*³ and their *Unpaywall*⁴ Database. The algorithm collects metadata information from legal gold journals, other free content at publishers' websites and self-archived documents in repositories. There are five OA types of articles:

Gold—Identified as having a Creative Commons (CC) license by *OurResearch Unpaywall* Database. All articles in these journals must have a license in accordance with the Budapest Open Access Initiative to be called gold.

³ OurResearch, formerly known as ImpactStory, is a nonprofit organization which creates and distributes tools and services for libraries, institutions and researchers. The organization follows open practices with their data (to the extent allowed by providers' terms of service), code, and governance. Retrieved from https://en.wikipedia.org/wiki/Our_Research.

⁴ Unpaywall is a project of OurResearch, a nonprofit building tools to help make scholarly research more open, connected, and reusable. Retrieved from <https://unpaywall.org/team>.

Hybrid—Items identified as having a Creative Commons (CC) license by *OurResearch* but that are not in journals where all content is gold. Hybrid journals are based on subscriptions, but individual articles can be read for free if the author pays charges. The payment can also be covered by a “Read and publish agreement” between the publisher and the author’s institution or country.

Free to Read (*aka Bronze*)—The licensing for these articles is either unclear or identified by *OurResearch* as non-CC license articles. These are free-to-read or public access articles located on a publisher’s site.

Green (include *published, accepted, and submitted*)—*Green published* is the final published version of articles hosted in an institutional or subject-based repository (e.g., an article out of its embargo period posted to PubMed Central). *Green accepted* is the accepted manuscripts hosted in a repository without the publisher’s copyediting or typesetting. *Green submitted* is the original manuscripts submitted for publication, but that has not been through a peer review process.

Non-OA—All other research articles are not OA.

When multiple OA versions of an article are available, WoS prioritizes publisher-hosted content (i.e., gold, hybrid), then the most complete version (i.e., for green OA, the order is firstly the published version, then the accepted version, and then the submitted version) (Bosman & Kramer, 2018). Within the new classification system in 2021, WoS only includes the article’s ‘best’ OA status determined by the algorithm, and uniquely assigns the OA type of each article, solving the problem that an article is assigned to multiple OA statuses.⁵

As mentioned in the introduction, it is straightforward to identify OA articles in gold journals. In hybrid journals, these articles need to be identified among other articles, which can be complicated, especially for newly published articles. *Unpaywall* uses oaDOI to find OA content in many ways, including using data from open indexes like Crossref, DOAJ where it exists, and independently monitoring over 50,000 unique online content hosting locations, such as gold OA journals, hybrid journals, institutional repositories, and disciplinary repositories.⁶ According to Piwowar’s (2018) research, the recall of the oaDOI service is 77 percent, meaning that 77 percent of the truly open articles are correctly identified as open by oaDOI. The precision of the oaDOI system is 96.6 percent, meaning that 96.6 percent of the time that oaDOI reports an article is open, it really is open. In general, the classification accuracy of OA types by InCites is about 68.5 percent (van Eck et al. 2018; Wang et al. 2018).

To validate the algorithm used for *Unpaywall* in these cases, we looked at the 11 hybrid journals selected for special attention in our study (see below) and visited the journal web pages directly to find OA articles and compare them to the number found by *Unpaywall* in InCites. This was feasible only for the five journals published by Elsevier (ScienceDirect). For four of the journals, *Journal of Cleaner Production*, *Science of the Total Environment*, *Journal of Alloys and Compounds*, and *Chemical Engineering Journal*, InCites reported 73 percent, 79 percent, 86 percent, and 87 percent of the actual OA articles respectively. It means InCites reported relatively fewer OA publications in general. However, there are exceptions, InCites reported 256 percent of the articles in *International Journal of Biological Macromolecules* as OA. After checking the specific data, we found that the total

⁵ Retrieved from <https://webofscience.help.clarivate.com/en-us/Content/open-access.html>.

⁶ Unpaywall. Data sources, Retrieved from <https://unpaywall.org/sources>.

number of articles counted by the two sources is consistent, but the number of OA articles is inconsistent. *Unpaywall* may mistakenly identify the OA status of articles, such as identifying the self-archived article version of the author as the officially published version and reporting the incorrect OA status. To conclude the validation in our sample, we found that InCites indicates fewer OA articles for the majority of hybrid journals, which implies that we may underestimate the APC expenses due to the data limitation.

Representative countries

A group of six countries with different OA performances and policies are selected for our study. China and the USA are chosen as the largest contributors of articles to WoS and because they differ by the degree and types of OA. UK, France, Netherlands, and Norway are countries of different size that all have joined Coalition S and thereby stimulated both hybrid and gold OA. We will return to a closer look at how the OA policies and practices of the six countries affect the trends in the discussion after we have presented the OA publishing and publishing fees trends.

Articles are attributed to the countries by the authors' addresses. The articles may thereby be overlapping between two or more of the countries. After de-duplication of articles, the six countries represent 52.7 percent of the world's scientific output in WoS during 2015–2020. Their proportion of the world's gold OA articles is 47.9 percent while their proportion of hybrid OA articles is 65.0 percent.⁷

Research articles will be analyzed by country both within the total of research articles in WoS and within the selected sets of major publishers and journals that are introduced below.

Major publishers and journals

To estimate the expenses to support the development of OA in different countries, APC price information is required per journal. The APC data for many gold OA journals can be obtained from the DOAJ website, while the APC data for hybrid journals are difficult to obtain in batch. However, the major international scientific journal publishers provide price lists for their journals on their webpages or inform authors about APC on the webpages of their individual journals. We made it feasible to create an APC price list for both gold and hybrid journals by concentrating on twelve major publishers and forty major journals. They were selected according to their dominance in the market. We looked for the maximum number of articles in WoS that we could cover by using two criteria: 1) the total number of research articles published in 2020, independently of OA, and 2) the number of gold or hybrid OA research articles published in 2020. We first ranked the ten most dominating publishers and the thirty most dominating journals by each criterion and found a high degree of overlap between them. After including publishers and journals that only corresponded to one of the criteria, we arrived at twelve major publishers and forty major journals⁸ for our study as listed in Tables 1 and 2.

⁷ Data was retrieved from the Web of Science Core Collection on 17th, February, 2022.

⁸ The journal *Cureus* could have been included based on the number of its OA publications in WoS, however, this journal could not be retrieved in the Incites database.

Table 1 Twelve major publishers selected by the number of research articles, or the total number of OA research articles, published in 2020

No	Publishers	Avg.-APC for gold journals (USD)	Avg.-APC for hybrid journals (USD)
1	Elsevier	2607/3001	3240
2	Springer Nature	2446/2687	3502
3	Wiley	2975/2997	3869
4	Taylor & Francis	2065/2091	2983
5	MDPI	2205/2205	1199
6	Sage	1913/1947	2900
7	IEEE	1720 /1743	2040
8	Amer Chemical Soc	1214/1214	5000
9	Frontiers Media Sa	2891/2891	2505
10	Oxford Univ Press	2930/2997	3796
11	Public Library Science	1942/1924	–
12	Hindawi	2228/2228	–

Among the twelve publishers, Public Library of Science (PLOS) and Hindawi only publish gold journals while the other ten publish both gold journals, hybrid journals, and traditional subscription-based journals without the hybrid model. Table 1 shows the average APC of gold and hybrid journals for the major twelve publishers. The first value of “Avg.-APC for gold journals” is the average APC of all gold OA journals in the sample data, and the second value is the average APC of journals in the sample data excluding the journals with an APC of 0 (namely, the diamond OA journals). It can be seen that the average APC for hybrid journals is generally higher than for gold journals.

Among the forty journals, 29 are gold OA journals and 11 are hybrid OA journals. There are no traditional subscription-based journals without the hybrid model included. The twelve major publishers are behind most of these journals (80 percent). The eight journals with the largest number of research articles are all gold OA journals based on APC, and some of them are quite new, indicating that “the future of scholarly publishing” is already here.

As seen from Table 3, the twelve major publishers cover around 70 percent of all scientific output from each of the countries in WoS. Around one third of the gold OA articles from each country are published in the forty largest journals. The lower share for hybrid journals is due to the smaller average size of these journals and the fact that many articles in these journals are published without OA.

Attribution of articles and APC expenses to countries

The appearance of countries in the authors’ addresses is the widely used criterium for attributing research articles to countries. In cases where more than one country appears in the addresses of an article, the usual methods are full counting (each country is credited one article) and fractional counting (each country is credited the fraction or a modification thereof according to the total number of countries) (Sivertsen et al., 2019). We use the first alternative, full counting, in this study because we focus on APC. We did not fractionalize the APC expenses, as the expenses are generally borne by the institution of the authors

Table 2 Forty major journals selected by the total number of research articles, or the total number of OA research articles, published in 2020

No	Journals title	OA type	APC (USD)	Publisher
1	Scientific Reports	Gold	1990	Nature Portfolio
2	IEEE Access	Gold	1750	IEEE
3	PLOS One	Gold	1749	Public Library Science
4	Sustainability	Gold	2071	MDPI
5	International Journal of Molecular Sciences	Gold	2180	MDPI
6	International Journal of Environmental Research and Public Health	Gold	2507	MDPI
7	Applied Sciences-Basel	Gold	2180	MDPI
8	Sensors	Gold	2398	MDPI
9	Science of the Total Environment	Hybrid	3400	Elsevier
10	Energies	Gold	2180	MDPI
11	Nature Communications	Gold	5560	Nature Portfolio
12	Molecules	Gold	2180	MDPI
13	ACS Applied Materials & Interfaces	Hybrid	5000	Amer Chemical Soc
14	Materials	Gold	2180	MDPI
15	Medicine	Gold	1950	Lippincott Williams & Wilkins
16	Environmental Science and Pollution Research	Hybrid	3280	Springer Nature
17	Physical Review B	Hybrid	250	Amer Physical Soc
18	Journal of Cleaner Production	Hybrid	3850	Elsevier
19	RSC Advances	Gold	1005	Royal Soc Chemistry
20	Journal of Alloys and Compounds	Hybrid	3410	Elsevier
21	Remote Sensing	Gold	2725	MDPI
22	Journal of Clinical Medicine	Gold	2616	MDPI
23	Monthly Notices of The Royal Astronomical Society	Hybrid	3344	Oxford Univ Press
24	Angewandte Chemie-International Edition	Hybrid	5100	Wiley
25	Physical Review D	Hybrid	2625	Amer Physical Soc
26	Nutrients	Gold	2834	MDPI
27	Cancers	Gold	2616	MDPI
28	Chemical Engineering Journal	Hybrid	3910	Elsevier
29	International Journal of Biological Macromolecules	Hybrid	3500	Elsevier
30	BMJ Open	Gold	2680	BMJ Publishing Group
31	Frontiers in Psychology	Gold	2950	Frontiers Media Sa
32	ACS Omega	Gold	1250	Amer Chemical Soc
33	Water	Gold	2398	MDPI
34	Frontiers in Microbiology	Gold	2950	Frontiers Media Sa
35	Frontiers in Immunology	Gold	2950	Frontiers Media Sa
36	Optics Express	Gold	2020	Optical Soc Amer
37	Polymers	Gold	2616	MDPI
38	Frontiers in Oncology	Gold	2950	Frontiers Media Sa
39	Heliyon	Gold	1950	Elsevier
40	Cells	Gold	2398	MDPI

Table 3 Research articles published by the major publishers and journals as a percentage of all research articles in WoS from the same country

Country	Twelve major publishers			Forty major journals		
	Total (%)	Gold (%)	Hybrid (%)	Total (%)	Gold (%)	Hybrid (%)
UK	70.08	62.79	74.22	9.27	35.41	2.81
France	68.71	62.48	57.87	8.90	34.63	5.32
Netherlands	72.30	67.68	84.10	9.52	35.72	2.60
Norway	74.19	69.07	80.10	9.06	32.30	2.63
China	68.20	60.63	52.61	11.88	34.61	5.15
USA	66.21	62.05	58.29	7.08	32.08	7.62

submitting the paper. Our problem is still: Which country is paying in cases with authors from more than one country?

It is a complicated question of which author is the principal author and who (or whose institution) may pay the APC. It can depend on the fields, countries, research teams and even individual authors. Larivière et al. (2016) found that the first and last authors typically contribute to more tasks than the middle authors and are more likely to pay for the APC of the article, while Rahman et al. (2021) considered that the most suitable person for the principal author remains to be the corresponding author, since the fact that the first author is often a post-doctoral student, graduate student, or even an undergraduate student or a junior colleague who reports to the principal author. Taubert et al. (2021) also considered that the corresponding authors (or their institutions) are the main authors who pay for publications with the APC. Bruns et al. (2020) developed five possible models of attributing costs based on author roles, numbers of authors, and author-address-combinations. The results revealed that the average share of first authors is the highest (68.3 percent).

In general, the first author or corresponding author can be regarded as the leader of an article because they have completed most of the work of the article (Dotson et al., 2011; Rahman et al., 2021). Therefore, it is reasonable to assume that the corresponding author or first author have the highest possibilities to pay for the APC of their OA publications. In this study, we attributed the APC payment to the country of the first author or corresponding author in a publication. For example, if the corresponding author or first author of a publication is affiliated in China, we assume that the APC is paid by China. This is done for both domestic and internationally co-authored articles. The method can only provide rough estimates, which is sufficient for our study where we mainly look at trends in country profiles and try to provide a realistic impression of changes in the scientific publishing business.

APC calculation

The real expenses of APC by country and the real revenues from APC by publisher or journal are not available as public information. Expenses and revenues still need to be reasonably *estimated* for an enlightened discussion of the APC model in the public domain. Rough estimates are also needed for discussion with publishers about how OA is best supported. We provide rough estimates using these methods to calculate APC per published OA article.

The APC prices of journals were retrieved from a combination of sources including the DOAJ database, the publishers' websites and the journals' websites. Since the APC for each year under study is not available, we estimated the total payment of APC based on the latest price.⁹ This way, the APC of all articles in gold journals could be obtained, and about 97 percent of the articles in hybrid journals could be matched with their APC prices in our data sample. In addition, among the 1655 OA journals from twelve major publishers, only 86 journals are APC-free. And among the 636,185 gold OA articles of these major publishers, only 3 percent of the articles have been published in diamond OA journals. Therefore, we confirm that the diamond OA journals and the APC-free OA publications from major publishers are quite marginal.

We needed the following solutions for specific cases:

- (1) Some publishers do not list the APC of each journal but provide a standard rate. As examples: The APC of American Chemical Society's hybrid journals is 5000 USD; The APC of IEEE's hybrid journals is 2045 USD; The APC of Taylor & Francis' hybrid journals is 3000 USD; and the APC of Sage's hybrid journals is 3000 USD. We used standard rates for all journals without specified rates for such publishers.
- (2) The APC prices of articles may differ with different OA licenses, thus it is difficult to determine the specific amount of APC paid for each article. For the convenience of calculation, we select the CC-BY license with the highest price of APC. Furthermore, it is not possible for us to consider possible discounts or waivers for individual articles.
- (3) Whenever prices differ by type of articles, country of the author or discounts for member institutions, the normal high APC was selected.
- (4) Non-USD prices were converted using the foreign exchange rates on the MSN Money website and the average rate of 2021.

Results

We present the results in three parts. Part A analyses the trends among the six countries regarding the degree and type of OA publishing. In part B, we describe the same trends by estimating the expenses of APC. Part C focuses on APC expenses related to the selected publishers and journals. All research articles indexed in WoS 2015–2020 are considered in parts A and B, not only those published by the selected publishers and journals.

Part A: trends in the degree and type of OA publishing among six countries

In Fig. 1, we measure the number of research articles, the articles increased rate compared to 2015, and the degree of OA publishing as a percentage of all research articles in WoS from the six countries. This measurement makes the countries comparable and shows the growth of the output in the same period, which increased by 97 percent for China in the high end and by 19 percent for France in the low end.

Overall, the UK has the highest degree of OA publishing while China has the lowest. In contrast to the three other European countries, the degree for the UK stabilized and

⁹ The data retrieval time is from December 27 to 31, 2021.

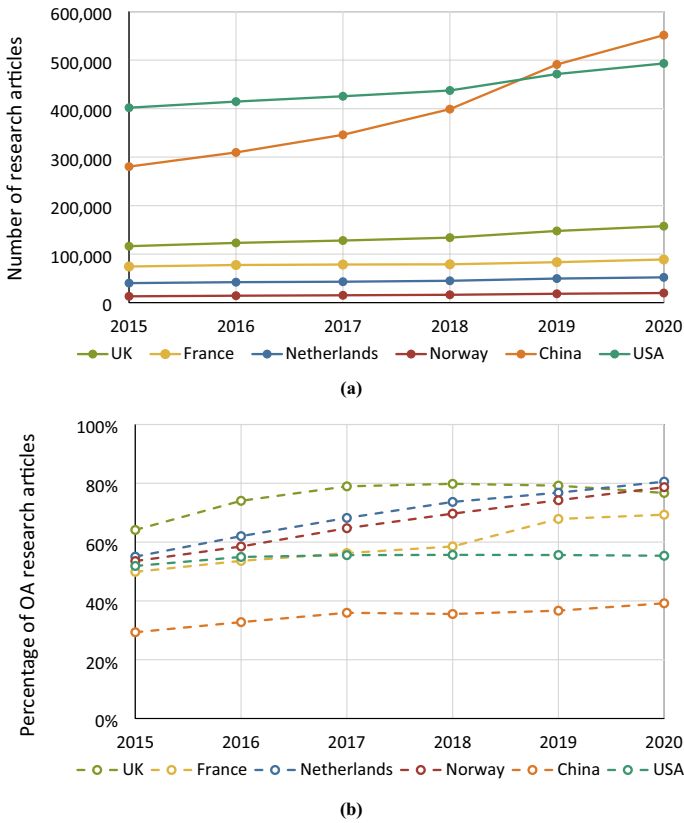


Fig. 1 **a** Number of research articles in WoS 2015–2020 that can be attributed to the six countries and the increased rate compared to 2015. **b** Percentage of OA research articles in WoS 2015–2020 that can be attributed to the six countries

slightly decreased after 2017. USA stands out with only a small increase in the degree of OA publishing. The general picture, however, is that OA publishing has been advancing as a proportion of the total output.

Figure 2 is based on the five types of OA research articles that are used in InCites and based on articles in WoS. Note that the trends of the green type are not easy to interpret. Unlike publisher-hosted OA (gold, hybrid), the date when the green article became open is generally different from the date the article was first published. Authors often self-archive (upload their article to a repository) months or years after the official publication date of the articles, typically because many journals have policies that authors must wait a certain length of time (the “embargo period”) before self-archiving (Piwowar et al., 2019).

We observe that the countries not only differ by the degree of OA publishing, but also by type. Among the European countries, the UK and France have the largest proportion of Green OA research articles, while Netherlands and Norway have more gold and hybrid OA research articles than other types. Still, the proportion of gold and hybrid OA research articles from the four countries has been increasing. The increasing trend towards hybrid research articles in these countries might be explained by the development of Plan S, which

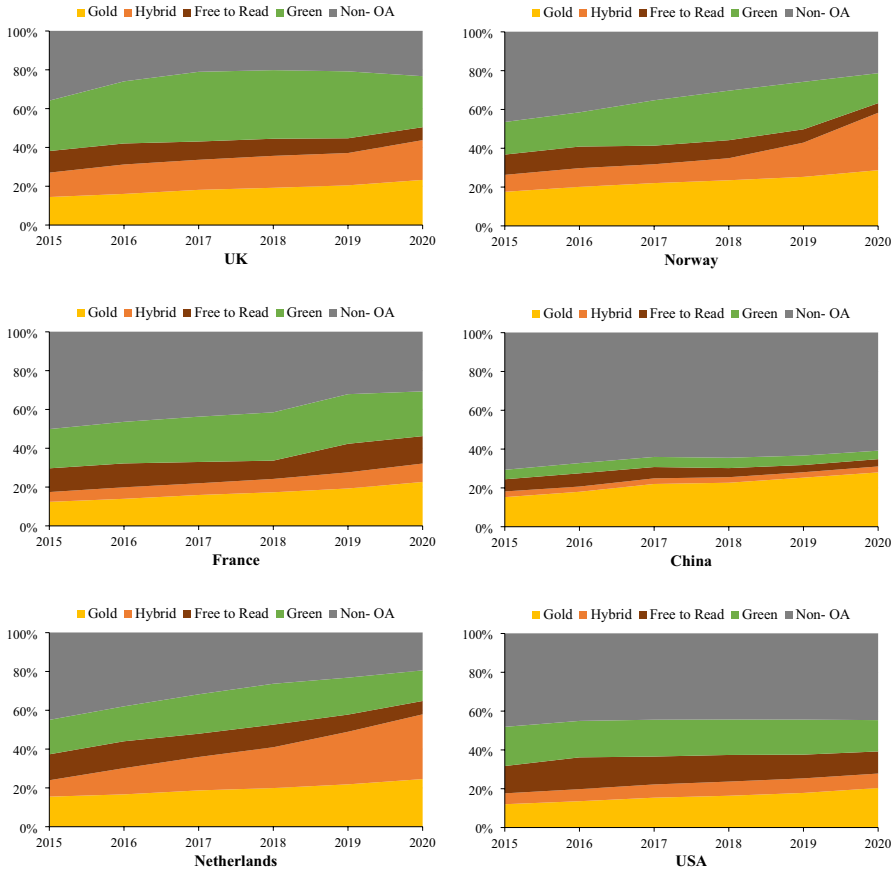


Fig. 2 The relative shares of five types of OA research articles in the six countries (2015–2020)

did not accept hybrid at the start, but then promoted hybrid ‘transition agreements’ with publishers. Norway, for example, started entering national Read & Publish agreements for hybrid journals with most major publishers in 2018.

The percentage of gold OA research articles from China is much higher than that of other OA types. This cannot be solely explained by OA policies. We will return to the topic in the discussion section below. For the USA, the percentage of Green OA research articles is the highest, followed by gold OA, and the share of hybrid OA research articles is the lowest. This is consistent with their OA policies, which we will return to in the discussion as well.

Part B: trends in the total expenses of APC

Based on Table 3 above, Table 4 provides the estimated total expenses of APC paid by the six countries from 2015 to 2020. We calculate the estimates as follows:

Table 4 The estimated APC expenses in million USD per country (2015–2020)

Country	Gold		Hybrid		Total- APC (million USD)
	Avg.-APC (USD)	Total-APC (million USD)	Avg.-APC (USD)	Total-APC (million USD)	
UK	2454/2552	235	3657	374	609
France	2395/2504	127	3579	49	176
Netherlands	2392/2477	84	3554	163	247
Norway	2313/2380	34	3427	35	69
China	2272/2324	1183	3048	172	1355
USA	2425/2503	757	3374	411	1168

$$T_y = \frac{T_p}{C_p}$$

where T_y indicates the total APC payment derived from the country y , T_p indicates the total APC payment of articles to the 12 major publishers in country y , and C_p is the coverage rate of the articles from the 12 major publishers for country y .

The average APC paid by the UK for each article is slightly higher than that of other countries, but the overall differences are not very large. This is as expected since we are comparing six countries that mainly publish in the same international journals. However, the average APC of hybrid OA articles is nearly 1000 USD higher than that of gold OA articles. Except for the UK Netherlands, and Norway, all other countries pay more APCs for gold OA articles than for hybrid OA articles. China pays the most APC in total, followed by the USA. The total estimated APC expenses of both countries exceed 1 billion USD. For comparison, the annual budget of the European Research Council is 2.9 billion USD (European Research Council, 2021).

As explained above, the six countries represent more than half of the total scientific output as indexed by WoS. It is relatively easy to estimate the global expenses of and revenues from APC as well, based on InCites and our price list. Focusing on the year 2020, among a total of 12,289 journals in InCites, 2577 journals are only subscription-based while 9712 journals are gold or hybrid journals. Within the latter group, 7717 journals could successfully be matched to our APC price list. Of these, 1615 are gold journals and 6124 are hybrid journals.¹⁰ By matching OA articles in 2020 in these journals to the price list, we find that the estimated total expenses on APC in these journals were:

- 1067 million US dollars in the gold journals
- 421 million US dollars in the hybrid journals

As a next step, we calculated the proportion of the articles that we could match to our price list as a percentage of the total number of articles in the category in InCites. The database has 552,182 gold OA articles published in 2020, of which we could match 90 percent. It has 156,986 hybrid OA articles of which we could match 78 percent. Since our data

¹⁰ 22 journals are found with both hybrid OA papers and gold OA papers in InCites. This may be due to the algorithm problem described in the methods section above.

is limited to journals of the standard required by WoS, and the general quality and APC price range could be considered comparable among the WoS journals, therefore we assume the same average prices for journals not covered by our price list. The estimated global total in gold journals then increases to 1.186 billion USD while the global total in hybrid journals increases to 540 million USD, which sums up to 1.726 billion USD in estimated APC expenses /revenues in 2020. Having seen the rapidly increasing volumes of articles in gold OA journals during 2021, we find it reasonable to assume that the global expenses on APC will exceed 2 billion USD in 2022.

Part C: trends in APC payments to major publishers and journals

Our study will now concentrate on the research articles from the six countries that have been published by the selected major publishers and journals. We start by analyzing the twelve major publishers, first jointly and then separately.

Figure 3 shows the number of research articles in WoS that were published in the journals of the twelve publishers, and the percentage shares of these that were gold and hybrid OA between 2015 and 2020. The shares of each of the two OA categories have doubled and thereby represent an important explanation for the almost 70 percent increase in the general volume of published articles. The further implementation of OA policies, e.g., Plan S, may explain the increasing shares. But does APC as a business model also stimulate the general growth in the total scientific output as seen in Fig. 3? Crawford (2021) shows that, within DOAJ, fee-based publishing has grown much faster than no-fee publishing with 120 percent versus 37 percent since 2015. In 2020, 65 percent of all articles in DOAJ were paid for. Although APC is a paywall for performing research, it might pave the way for growth in journals that expand their annual volumes to increase the turnover. We will return to the observations in Fig. 3 in the Discussion section.

For each of the six countries and their total of research articles in WoS in 2015–2020, Table 5 shows the percentage of their gold and hybrid OA research articles that were

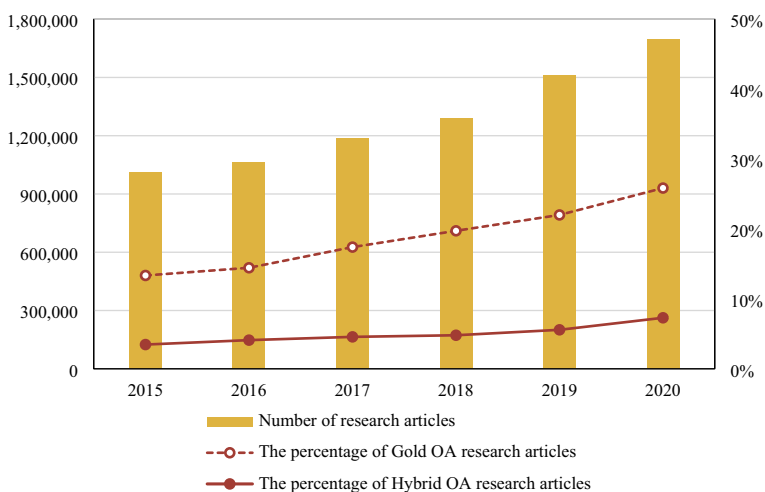


Fig. 3 The number of research articles in WoS and their percentage shares of gold and hybrid OA research articles, published by the twelve major publishers from 2015 to 2020

Table 5 The percentage of gold and hybrid OA research articles published by the 12 major publishers

Publisher	Gold%	Hybrid%	Publisher	Gold%	Hybrid%	Publisher	Gold%	Hybrid%
UK			France			Netherlands		
Springer Nature	17.33	17.81	MDPI	15.24	0.00	Springer Nature	19.40	23.04
MDPI	12.02	0.01	Springer Nature	13.86	12.55	MDPI	13.20	0.01
Public Library Science	10.12	0.00	Frontiers Media Sa	9.84	0.01	Public Library Science	11.53	0.00
Frontiers Media Sa	8.20	0.04	Public Library Science	9.43	0.00	Frontiers Media Sa	10.17	0.08
Elsevier	4.60	23.63	Elsevier	4.92	22.50	Elsevier	4.53	21.41
Wiley	3.60	16.40	Wiley	3.03	11.14	Wiley	3.66	17.23
IEEE	1.79	0.44	Oxford Univ Press	1.92	5.15	Taylor & Francis	1.53	9.43
Oxford Univ Press	1.64	6.01	Hindawi	1.32	0.00	Oxford Univ Press	1.13	4.42
Hindawi	1.14	0.00	Taylor & Francis	1.17	2.07	Hindawi	0.95	0.00
Sage	1.09	3.25	IEEE	0.84	0.67	Sage	0.91	4.20
Taylor & Francis	0.99	3.50	Sage	0.53	0.79	IEEE	0.42	0.15
Amer Chemical Soc	0.27	3.12	Amer Chemical Soc	0.37	2.97	Amer Chemical Soc	0.24	4.14
Other publishers	37.21	25.78	Other publishers	37.52	42.13	Other publishers	32.32	15.90
Norway			China			USA		
Springer Nature	21.33	15.85	MDPI	16.39	0.04	Springer Nature	12.64	9.42
MDPI	13.63	0.00	Springer Nature	10.38	11.79	MDPI	12.14	0.02
Public Library Science	9.46	0.00	Hindawi	7.16	0.00	Public Library Science	10.68	0.00
Frontiers Media Sa	9.10	0.11	Frontiers Media Sa	5.99	0.04	Frontiers Media Sa	8.52	0.02
Wiley	4.35	17.11	IEEE	5.46	3.15	Elsevier	5.13	20.59
Elsevier	3.97	30.68	Public Library Science	3.43	0.00	Wiley	4.72	9.68
Taylor & Francis	2.68	7.24	Elsevier	3.42	22.39	Oxford Univ Press	2.36	6.40
Sage	1.19	2.55	Wiley	3.00	7.70	Sage	1.56	1.10
IEEE	1.10	0.20	Sage	2.30	0.85	Hindawi	1.55	0.00
Hindawi	1.06	0.00	Taylor & Francis	1.98	1.28	IEEE	1.15	5.55

Table 5 (continued)

Publisher	Gold%	Hybrid%	Publisher	Gold%	Hybrid%	Publisher	Gold%	Hybrid%
Oxford Univ Press	0.97	4.66	Oxford Univ Press	0.60	3.24	Taylor & Francis	1.13	2.09
Amer Chemical Soc	0.23	1.70	Amer Chemical Soc	0.51	2.12	Amer Chemical Soc	0.48	3.41
Other publishers	30.93	19.90	Other publishers	39.37	47.39	Other publishers	37.95	41.71

published by each of the twelve major publishers and by other publishers. The ranking is by gold OA for each country. In general, Springer Nature and MDPI have become the major publishers of gold OA articles for all six countries. Note that the owner of Springer Nature now also controls Frontiers while Wiley controls Hindawi. Elsevier, Springer Nature and Wiley remain major publishers of hybrid OA articles across all countries. Particularly MDPI, but Frontiers as well, have come to dominate over PLOS (and BMC), the first movers towards gold only.

Table 5 also shows that more than half of, and up to two thirds of, the total scientific output from the countries is published by only twelve major publishers. China and the USA rely more on other publishers than the European countries do. Particularly in hybrid publishing, the European countries seem to prefer the journals of the major publishers, which might reflect a more widespread use of institutional and national Read & Publish arrangements.

We now turn to rough estimates of the total annual APC payments per publisher for gold and hybrid OA articles derived from the six countries. Because the countries differ by size, Fig. 4 shows the results for China and the USA while Fig. 5 shows the results for the four European countries.

The results for China are influenced by the general rapid growth of the scientific output in WoS. Apart from this, we see differences between the two countries in their OA approaches which we will return to in the discussion. Both countries have increasing expenses. We estimate that in 2020, China paid more than 4.6 times more for gold OA

Fig. 4 The estimated total APC payments (in million USD) derived from China and the USA for gold and hybrid OA research articles in journals from the twelve major publishers

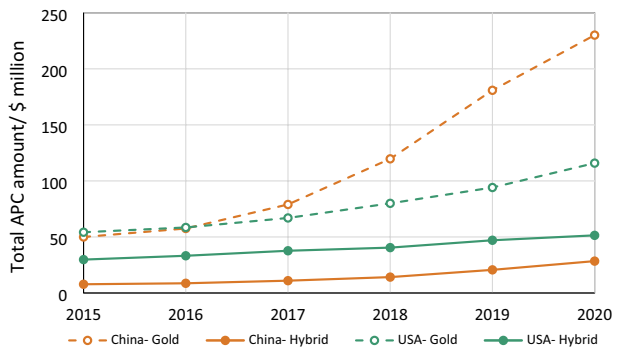
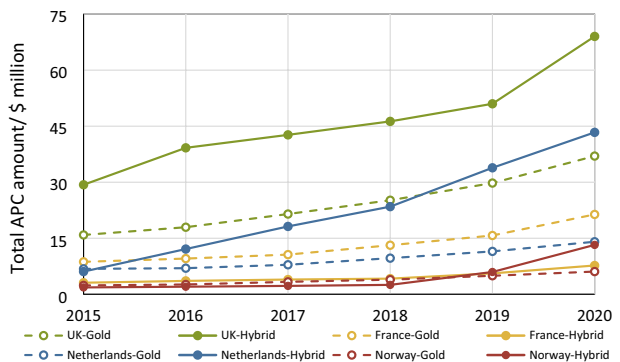


Fig. 5 The estimated total APC payments (in million USD) derived from four European countries for gold and hybrid OA research articles in journals from the twelve major publishers



than in 2015 and 3.5 times more for hybrid OA. The expenditure of gold OA more than doubled for the USA while the expenditure of hybrid increased by 70 percent.

Figure 5 shows rapid increases in expense also for the four European countries. In contrast to China and the USA, these countries have rapid increases also for the hybrid alternative, particularly in the last two years. Hybrid OA tends to dominate among the expense for the Netherlands, Norway, and the UK. In general, estimated APC expense paid to the twelve publishers have tripled between 2015 and 2020. The combined expense reached more than 200 million US dollars in 2020.

We now turn to the forty selected journals which only partly represent the twelve publishers. They were selected by their size, the number of research articles published in 2020.

The total APC payments derived from the six countries to pay for publishing in 29 gold journals and the relative growth rate of the amount of APC paid per year in six countries compared to 2015 are shown in Fig. 6. The total estimated expenses for the four countries combined in these few journals reach almost 200 million US dollars in 2020, of which

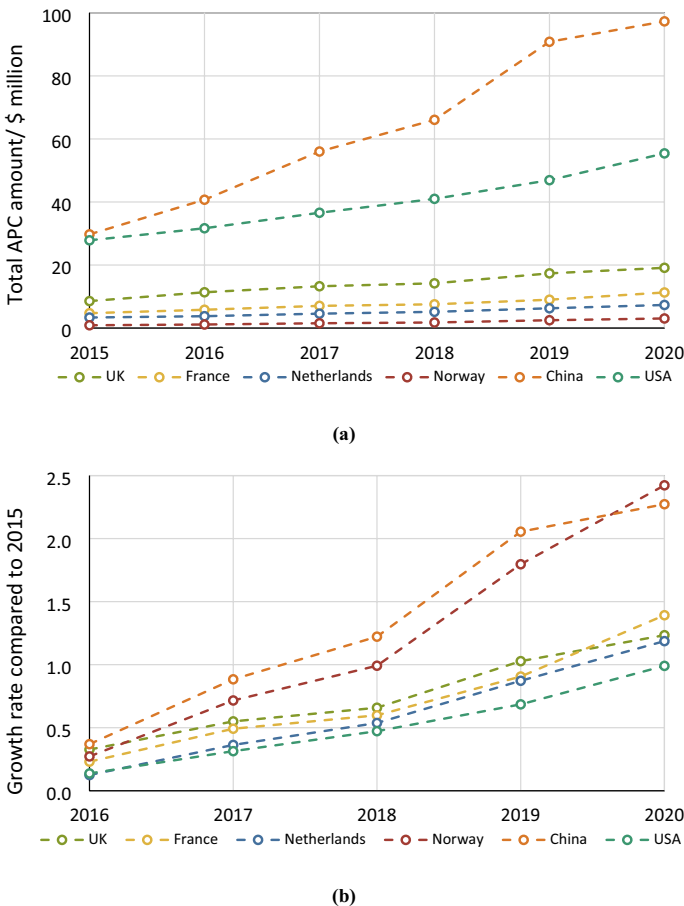


Fig. 6 **a** Total APC payments (in million USD) derived from the six countries for gold journals. **b** The relative growth rate of the amount of APC paid per year in six countries compared to 2015

China paid half. The total amount for all six countries was 1.6 times higher in 2020 than it was in 2015. China and Norway have increases above the factor of 2.

Figure 7 shows the total APC payments derived from the six countries for APC in 11 hybrid journals and the relative growth rate of the amount of APC paid per year in six countries compared to 2015. The total expenses are lower in the hybrid journals since their number and volume of publications is smaller and articles paid for by APC are only a part of the total volume. The USA have the highest expenses, but these are stable. Most of the increase in expenses for China is explained by the rapidly growing output of articles in WoS, as shown in Fig. 1. The increases for the European countries may be more due to the stimulation of OA publishing by relevant policies. The total APC revenues from the six countries to the eleven journals are estimated to reach 7.9 million US dollars in 2020 after an increase by a factor of 1.4 since 2015. The costs of China increased by a factor of 5.9 while the costs of Norway increased by a factor of 74.

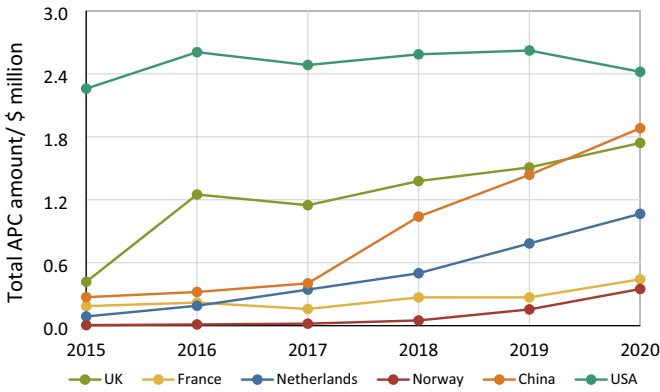
Among the 29 gold OA journals, only the total APC revenue of *PLoS One* shows a downward trend, as shown in Fig. 8. New journals are taking over. *Nature Communications* has had the highest APC revenue while *IEEE Access* has the largest increase in APC revenue. The USA paid the highest amount of APC in *Nature Communications*, reaching 58 million USD from 2015 to 2020, while China paid the highest amount of APC in *IEEE Access*, reaching 46 million USD from 2015 to 2020. Among the six countries, the USA paid the highest total amount of APC in *PLoS One* (47 million USD), followed by China (28 million USD). For the other three journals, China is the country that paid the highest total amount of APC.

Discussion and conclusions

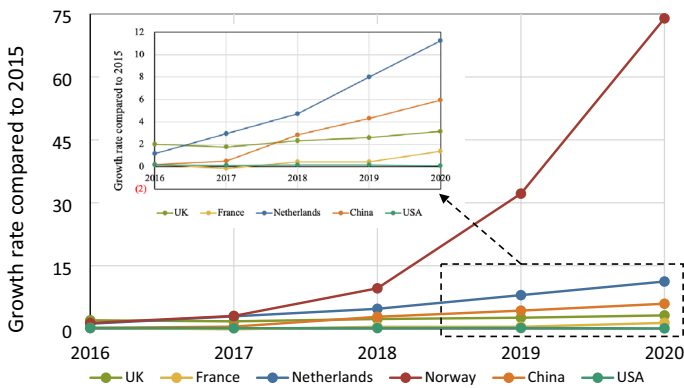
Our study has two main findings. Firstly, by comparing six countries, we find variations in the trends in how they transit to OA publishing. The differences are related to the degree of OA versus traditional publishing, the speed of the change, and the types of OA publishing. The first part of our discussion will focus on explanations for such differences between the countries. Secondly, we have seen rapid increases in the expenditure on APC among all the countries. We regard these increases as representative of global changes in the market of scientific publishing and will discuss the implications in the final part of the discussion.

The influence of Plan S and its principles on the four European countries was already noted above. In the initial phase, Plan S has stimulated all types of OA including the hybrid alternative (cOAlition S, 2018). Our results show that in general, the degree of OA in the European countries is higher than that in China and the USA. The UK has the highest proportion of OA articles among the six countries, but the Netherlands and Norway are closing the gap. This finding is consistent with Mering's view that "*European countries, especially the UK, have played a leading role in promoting OA*" (Mering, 2020). Long before the launch of Plan S in 2018, OA publishing was raised on the European agenda in 2006, and the Lisbon Treaty clearly emphasized the European Union's commitment to OA publishing (European Parliament, 2007).

The UK initially promoted green OA. It was recommended that Higher Education Institutions (HEIs) developed repositories, that the Government financed the institution 'of an interlinked network of institutional repositories', and that the Research Councils should implement mandates for researchers to deposit research findings in repositories (green OA) (Picarra, 2015). In 2012, the UK Government officially adopted a policy favouring gold



(a)



(b)

Fig. 7 a Total APC payments (in million USD) derived from the six countries for hybrid journals. b The relative growth rate of the amount of APC paid per year in six countries compared to 2015

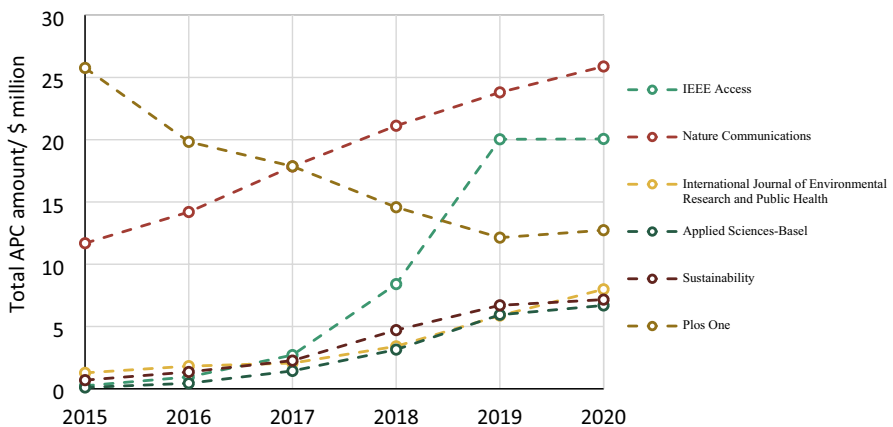


Fig. 8 Total APC amounts (in million USD) paid by the six countries in six gold journals

OA while also promoting publishing OA in hybrid journals. Public funding should in principle be made available to cover APCs (Willetts, 2012).

Similarly, France also initially supported the development of OA through the construction of institutional repositories. After the signature of a national agreement in 2006, aiming to foster OA, some universities established an institutional open archive. As of 2017, 95 of them do have an institutional repository (Dazy, 2017). The *French Plan for Open Science* released in 2018 provides France with a coherent and dynamic policy in the field of OA. The policy supports an OA economic publishing model that does not require the payment of articles or book processing charges (Ouvrir la Science, 2021), implying that France may not support the hybrid OA model. This may explain why France has a lower share of hybrid OA articles than the other three European countries under study here.

The Netherlands has for a long time been strongly engaged in making all publicly funded research available through OA. The ambition to reach 100 percent OA for all publicly funded research was first formulated in 2013 in a Letter to Parliament by State Secretary Sander Dekker, who expressed a clear preference for the gold route over the green (repository) route to OA (Bosman et al., 2021). On February 9th, 2017, the report *National Plan Open Science (NPOS)* was presented in The Hague. The parties involved have set out ambitions for OA in the Netherlands for the period 2017–2020 (NPOS Stuurgroep, 2017). These ambitions are divided into four main topics: (1) *100 percent open access publishing*, (2) *Make research data optimally suited for reuse*, (3) *Recognising and assessing researchers*, and (4) *Encouraging and supporting open science*.

The Norwegian Ministry of Education and Research (2017) first said that any formulation of national goals for OA in Norway must be in line with developments in other countries and the European Union in particular. This modest approach clearly changed in 2018 as the Research Council of Norway not only joined but took a lead in Plan S and said all of their funded projects after 2021 should be published OA. The Norwegian government then set the deadline in 2024 for all their institutions independently of external funding. Since then, the country has engaged in contracts involving APC payment at the national level with most major journal publishers following the gold and hybrid model.

Summing up, the strong trends that we observe in our study towards OA and APC payment among the four European countries, even the slight observed difference for France, can be explained on policy backgrounds. Governments and research funding organizations have motivated the trends towards increased APC expenses while the industry is setting the prices.

China is different. Research policies and evaluation criteria are under general change in this country and OA policies cannot be separated from other policies. During the last two decades, China's research evaluation and funding policies have had a strong focus on quantitative indicators with incentives to publish in journals covered by the WoS (Quan et al., 2017; Zhang & Sivertsen, 2020). More recently, some gold or hybrid OA journals indexed in WoS and publishing with APC have expanded their annual volume of articles and lowered the threshold for publication (Chen, 2019), thus affecting the choices of Chinese researchers to some extent. The rapid increase in gold journals covered by WoS can be explained by these incentives. However, the growth rate of the total APC in 2020 is significantly lower than that in previous years, which may be related to the new evaluation and funding policies issued by China in early 2020. The new policies generally weaken the incentives to publish in journals covered by WoS. One of the policy documents addressed the need to manage the expenditure on APCs more tightly (Ministry of Science & Technology, 2020): "For a single paper whose publication expenditure exceeds RMB 20,000

(around 3128 USD), the academic committee of the corresponding author or first author's institution must review the necessity of publishing the paper".

However, China is not against OA. Zhang Xiaolin, Chairman of the Strategic Planning Committee of the Chinese National Science and Technology Library said that the impression that OA has little influence in China is misleading (International Science Council, 2019). Since 2014, funders and research institutions in China have encouraged and funded scientists to publish their papers in open-access formats and to archive manuscripts openly online (Schiermeier, 2018). In practice, all research funders in China allow the recipient researchers to use part of the grant money for publishing expenses, including APCs for OA journals (Zhang, 2014). This may have led to the observed increase in the number of gold OA articles in China. A support to the Plan S initiative was announced at the 14th world OA conference in Berlin in 2018 (Schiermeier, 2018).

In spite of this support, our results show that the degree of OA publishing in China is the lowest among the six compared countries. The explanation may be that China's OA policies are mostly advisory, not mandatory. Some studies have shown that most Chinese researchers approve of OA in principle (Ren, 2015; Wang, 2013) but, in practice, they are reluctant to submit articles to OA journals or to institutional repositories (Yuan & Zhang, 2016). As stated by Xu et al. (2016), many Chinese researchers are also sceptical and confused about OA publishing. A survey result from the Chinese Academy of Science and Technology for Development (CASTED) (2020) shows that 65 percent of Chinese researchers express a willingness to publish papers in OA journals.

The USA has shown a preference for the green OA publishing model. In 2013, President Barack Obama's administration introduced a policy that required taxpayer-funded research to be made freely available online within 12 months of its publication in a journal (Subbaraman, 2019). The National Institutes of Health in the USA has also imposed a maximum 12-month embargo to support Green OA (National Institutes of Health, 2015). In general, the federal agencies have followed the policy to make peer-reviewed papers from funded projects freely available within 12 months of publication. "We don't anticipate making any changes to our model" said Brian Hitson of the USA Department of Energy in Oak Ridge, Tennessee, who directs that agency's public access policy (Rabesandratana, 2019). Tenopir et al. (2017) investigated researchers' attitudes and behaviors towards gold OA in the USA and found that most respondents hold from neutral to somewhat negative opinions on gold OA, believing that articles published in OA journals are of lower quality than those published in subscription-based journals.

We have so far discussed and explained the background for the observed differences among the six countries regarding the degree and types of OA and the speed of change. A similarity is also observed by our study: All six countries, representing more than half of the world's scientific output, are affected by the same trends towards rapidly increasing expenditure on APC. They are increasing with the transition to OA but also because APC seems to stimulate higher volumes of articles. Our results as shown in Figs. 3 and 8 above were predicted in 2016 by Richard Horton, Editor-in-Chief of *The Lancet* (Horton, 2016):

Publishers are increasingly in thrall to volume. The more they publish, so they believe, the stronger will be their presence in the market of science. The most dangerous embodiment of this trend is the mega-journal. All major publishers now want their own mega-journal, a place where they can publish hundreds, maybe even thousands, of research papers each month. By doing so, they capture market share, and thereby increase their opportunities for the monetisation and control of science.

As the global expenditure on APC are probably exceeding 2 billion US dollars annually, it should be time to discuss whether the original aims of OA are supported by paying to publish as a business model.

One argument for OA has been that the increased availability of research results leads to a faster advancement of science, knowledge, and commerce (Willinsky, 2006). Another argument is that since scientific research is predominantly financed by public funds, the achievements should be considered a public good, which ought to be freely available to the public (Björk et al., 2014). A third argument is that OA will reduce the global expenses of the scientific publishing and dissemination process compared to the subscription model (Houghton et al., 2009).

OA has indeed made the scientific literature more accessible, but it is now reported that OA publishing fees deter researchers in the global south from performing research (Kwon, 2022; Smith et al., 2021). In all parts of the world, APC can be said to restrict research activity to institutionalized and/or funded activities. The admission to perform research in these contexts are sometimes based on questionable selection mechanisms. Even within institutions, APCs have not widely been welcomed by authors, libraries, universities, and their sponsoring institutions (Estakhr et al., 2021), and authors can have problems with paying also in the wealthiest countries (Burchardt, 2014).

China, the country that now pays the most according to our estimates, provides an example of increasing worries about APC. According to a survey, 79.2 percent of Chinese researchers selected “high publishing cost” as the reason for their reluctance to publish articles in OA journals (Chinese Academy of Science & Technology for Development, 2020). China’s Ministry of Science and Technology (2020) issued a policy to manage the costs of APCs more tightly: “Papers published in academic journals on the ‘blacklist’ and early warning list shall not be included in the special funds for national science and technology plan projects”. As an example of such lists, the National Science Library of the Chinese Academy of Sciences (2022) has released an annually revised *Early Warning Journal List* only covering journals indexed by the WoS that were said to be potentially in conflict with academic rigor. The list includes some of journals that selected in our study. Zhang et al. (2022) indicate that not the APC prices in themselves, but the rapid growth of Chinese APC expenditures, and the concentration of these expenditures in particular journals, seems to influence the selection of journals for the Chinese list.

Scientific publications are used to document the experience and qualifications of researchers in contexts where they are assessed for funding, recruitment or promotion. Publications are important for careers. Since APC puts the payment on the same side as the pressure to publish, one might also doubt whether it reduces the global expenses of scientific publishing. We cannot judge whether the increasing expenditure on APC create larger profit margins than the subscription model ever did, or whether the APC model remains a reasonable compensation for departing from the subscription model. We only know that the multinational publishers who used to collect profits from subscriptions have taken over the dominance among DOAJ journals, among which 65 percent of the articles were paid for in 2020 (Crawford, 2021). Our study finds that most subscription-based journals from the same publishers have rapidly turned hybrid. The question whether APC is the best way to promote OA needs to be researched and discussed.

Limitations

Our study still has some limitations. We checked and found that InCites might underestimate the real number of OA articles in hybrid journals. It is difficult to describe OA trends with exact numbers. It is even more difficult to represent the expenses/revenues of APC with exact figures. This information remains with the paying institutions and the invoicing publishers. We can only provide estimates. For these estimates, we could only use the full price of the APC in a journal since possible discounts or waivers in individual cases are unknown to us.

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Declarations

Conflict of interest The first author (Lin Zhang) is the co-editor-in-chief of *Scientometrics*.

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References

- Asai, S. (2020). Market power of publishers in setting article processing charges for open access journals. *Scientometrics*, 123(2), 1037–1049.
- Björk, B. C., Laakso, M., Welling, P., & Paetau, P. (2014). Anatomy of green open access. *Journal of the Association for Information Science and Technology*, 65(2), 237–250.
- Björk, B. C., & Solomon, D. (2014). Developing an effective market for open access article processing charges. *Abgerufen Am*, 22(2), 1–69.
- Björk, B. C. (2017). Gold, green, and black open access. *Learned Publishing*, 30(2), 135–137.
- Bosman, J., & Kramer, B. (2018). Open Access Levels: A quantitative exploration using web of science and Oa. *Peer J*, 2018, e3520v1.
- Bosman, J., de Jonge, H., Kramer, B., & Sondervan, J. (2021). Advancing open access in the Netherlands after 2020: From quantity to quality. *Insights*, 34(1), 1–22.
- Bruns, A., Rimmert, C., & Taubert, N. (2020). Who pays? Comparing cost sharing models for a Gold Open Access publication environment. *Journal of Library Administration*, 60(8), 853–874.
- Budapest Open Access Initiative. (2002). *Read the Budapest Open Access Initiative*. Retrieved from <https://www.budapestopenaccessinitiative.org/read>
- Budzinski, O., Grebel, T., Wolling, J., & Zhang, X. (2020). Drivers of article processing charges in open access. *Scientometrics*, 124(3), 2185–2206.
- Burchardt, J. (2014). Researchers outside APC-financed open access: Implications for scholars without a paying institution. *SAGE Open*, 4(4), 2158244014551714.
- Chen, X. (2019). Beall's list and Cabell's blacklist: A comparison of two lists of predatory OA journals. *Serials Review*, 45(4), 219–226.

- Chinese Academy of Science and Technology for Development. (2020). *Cognition attitude and behavior of Chinese researchers towards open access*. Chinese Academy of Science and Technology for Development.
- Cleusa, P., & Barbosa, M. C. (2018). Article processing charge (APC) for publishing open access articles: The Brazilian scenario. *Scientometrics*, 117(2), 805–823.
- cOAlition S. (2018). *Plan S Principles*. Retrieved from https://www.coalition-s.org/plan_s_principles/
- Crawford, W. (2021). Gold Open Access 2015–2020. Articles in Journals. *Cites & Insights Books*. <https://walcrawford.name/goa6.pdf>
- Dazy, A. (2017). National Open Access Desk. *OpenAIRE*. Retrieved from <https://www.openaire.eu/os-france>
- Demeter, M., & Istratei, R. (2020). Scrutinising what open access journals mean for global inequalities. *Publishing Research Quarterly*, 36(4), 505–522.
- Demeter, M., Jele, A., & Major, Z. B. (2021). The international development of open access publishing: A comparative empirical analysis over seven world regions and nine academic disciplines. *Publishing Research Quarterly*, 37, 364–383.
- Dotson, B., McManus, K. P., Zhao, J. J., & Whittaker, P. (2011). Authorship and characteristics of articles in pharmacy journals: Changes over a 20-year interval. *Annals of Pharmacotherapy*, 45(3), 357–363.
- Estakhr, Z., Sotudeh, H., & Abbaspour, J. (2021). The cost-effectiveness of the article-processing-charge-funded model across countries in different scientific blocks: The case of Elsevier's hybrid, open access journals. *Information Research*, 26(2), 897.
- EURO CRIS. (2016). *UNESCO/COAR joint statement on Open Access*. Retrieved from <https://www.eurocris.org/news/unescocoar-joint-statement-open-access>
- European Parliament. (2007). *The Treaty of Lisbon*. Retrieved from <https://www.europarl.europa.eu/factsheets/en/sheet/5/the-treaty-of-lisbon>
- European Research Council. (2021). *Facts and figures*. Retrieved from <https://erc.europa.eu/about-erc/facts-and-figures>
- European Science Foundation. (2018). *Plan S Principles*. Retrieved from https://www.coalition-s.org/plan_s_principles/
- Fuchs, C., & Sandoval, M. (2013). The diamond model of open access publishing: Why policy makers, scholars, universities, libraries, labour unions and the publishing world need to take non-commercial, non-profit open access serious. *TripleC: Communication, Capitalism & Critique*, 11(2), 428–443.
- Green, T. (2019). Is open access affordable? Why current models do not work and why we need internet-era transformation of scholarly communications. *Learned Publishing*, 32(1), 13–25.
- Horton, R. (2016). The crisis in scientific publishing. *The Lancet*, 388(10042), 322.
- Houghton, J., Rasmussen, B., Sheehan, P., Oppenheim, C., Morris, A., Creaser, C., Greenwood, H., Summers, M., & Gourlay, A. (2009). Economic implications of alternative scholarly publishing models: Exploring the costs and benefits. *A report to the Joint Information Systems Committee (JISC)*. London: JISC
- International Science Council. (2019). *Open Access in China: Interview with Xiaolin Zhang of the National Science Library*. Retrieved from <https://council.science/current/blog/open-access-in-china-interview-with-xiaolin-zhang-of-the-national-science-library/>
- Kim, S. J., & Park, K. S. (2020). Market share of the largest publishers in journal citation reports based on journal price and article processing charge. *Science Editing*, 7(2), 149–155.
- Kwon, D. (2022). Open-access publishing fees deter researchers in the global south. *Nature News*. <https://www.nature.com/articles/d41586-022-00342-w>
- Laakso, M., & Björk, B. C. (2013). Delayed open access: An overlooked high-impact category of openly available scientific literature. *Journal of the American Society for Information Science and Technology*, 64(7), 1323–1329.
- Larivière, V., Desrochers, N., Macaluso, B., Mongeon, P., Paul-Hus, A., & Sugimoto, C. R. (2016). Contributorship and division of labor in knowledge production. *Social Studies of Science*, 46(3), 417–435.
- Max Planck Digital Library. (2018). *Final conference statement: 14th berlin open access conference*. Retrieved from <https://oa2020.org/b14-conference/final-statement/>
- Max Planck Digital Library. (2021). *Expression of interest in the large-scale implementation of open access to scholarly journals*. Retrieved from <https://oa2020.org/mission/#eois>
- Ministry of Science and Technology (2020). *Measures to eliminate the bad orientation of 'Paper Only' in scientific and technological evaluation (trial)*. Retrieved from http://www.most.gov.cn/xxgk/xinxifenlei/fdzdgnr/fgzcgfxfwj/gfxfwj2020/202002/20200223_151781.html
- Mering, M. (2020). Open access mandates and policies: The basics. *Serials Review*, 46(2), 157–159.
- Morrison, H. (2019). *2010–2019 APC update. Sustaining the knowledge commons*. Retrieved from <https://sustainingknowledgecommons.org/2019/11/26/2010-2019-apc-update/>

- National Institutes of Health. (2015). *National Institutes of Health plan for increasing access to scientific publications and digital scientific data from NIH funded scientific research*. Retrieved from <https://grants.nih.gov/grants/NIH-Public-Access-Plan.pdf>
- NPOS Stuurgroep. (2017). *National Programme Open Science*. Retrieved from <https://www.openscience.nl/>
- National Science Library of the Chinese Academy of Sciences. (2022). *Early Warning Journal List*. Retrieved from <https://earlywarning.fenqubiao.com>
- Ouvrir la science. (2021). *Second French Plan for Open Science*. Retrieved from <https://www.ovrirscience.fr/second-national-plan-for-open-science/>
- Pavan, C., & Barbosa, M. C. (2018). Article processing charge (APC) for publishing open access articles: The Brazilian scenario. *Scientometrics*, 117(2), 805–823.
- Picarra, M. (2015). *Open Access in the UK: PASTEUR4OA*. Retrieved from http://www.pasteur4oa.eu/sites/pasteur4oa/files/resource/UK%20Open%20Access%20briefing_FINAL.pdf
- Pinfield, S., Salter, J., & Bath, P. A. (2016). The “total cost of publication” in a hybrid open-access environment: Institutional approaches to funding journal article-processing charges in combination with subscriptions. *Journal of the Association for Information Science and Technology*, 67(7), 1751–1766.
- Piwowar, H., Priem, J., Larivière, V., Alperin, J. P., Matthias, L., Norlander, B., & Haustein, S. (2018). The state of OA: A large-scale analysis of the prevalence and impact of Open Access articles. *PeerJ*, 6, e4375.
- Piwowar, H., Priem, J., & Orr, R. (2019). The Future of OA: A large-scale analysis projecting Open Access publication and readership. *BioRxiv*, 2019, 795310.
- Quan, W., Chen, B. K., & Shu, F. (2017). Publish or impoverish: An investigation of the monetary reward system of science in China (1999–2016). *Aslib Journal of Information Management*, 69(5), 486–502.
- Rabesandratana, T. (2019). Will the world embrace Plan S, the radical proposal to mandate open access to science papers? *Science*, 363(6422), 11.
- Rahman, M. T., Regenstein, J. M., Abu Kassim, N. L., & Karim, M. M. (2021). Contribution based author categorization to calculate author performance index. *Accountability in Research*, 28(8), 492–516.
- Ren, X. (2015). The quandary between communication and certification: Individual academics’ view on Open Access and open scholarship. *Online Information Review*, 39(5), 628–697.
- Schiermeier, Q. (2018). China backs bold plan to tear down journal paywalls. *Nature*, 564(7735), 171–173.
- Sivertsen, G., Rousseau, R., & Zhang, L. (2019). Measuring scientific production with modified fractional counting. *Journal of Informetrics*, 13(2), 679–694.
- Smith, A. C., Merz, L., Borden, J. B., Gulick, C. K., Kshirsagar, A. R., & Bruna, E. M. (2021). Assessing the effect of article processing charges on the geographic diversity of authors using Elsevier’s “Mirror Journal” system. *Quantitative Science Studies*, 2(4), 1123–1143.
- Subbaraman, N. (2019). Rumours fly about changes to US government open-access policy. *Nature*. Retrieved from <https://www.nature.com/articles/d41586-019-03926-1>
- Suber, P. (2008). Gratis and libre open access. *SPARC Open Access Newsletter*. Retrieved from https://dash.harvard.edu/bitstream/handle/1/4322580/suber_oagratiss.html
- Taubert, N., Bruns, A., Lenke, C., & Stone, G. (2021). Waiving article processing charges for least developed countries: A keystone of a large-scale open access transformation. *Insights*, 34(1), 1–13.
- Tenopir, C., Dalton, E. D., Christian, L., Jones, M. K., McCabe, M., Smith, M., & Fish, A. (2017). Imagining a gold open access future: Attitudes, behaviors, and funding scenarios among authors of academic scholarship. *College & Research Libraries*, 78(6), 824–843.
- The Norwegian Ministry of Education and Research. (2017). *National goals and guidelines for open access to research articles*. Retrieved from <https://www.regjeringen.no/en/dokumenter/national-goals-and-guidelines-for-open-access-to-research-articles/id2567591/>
- Universities UK. (2017). *Monitoring the transition to open access*. Retrieved from <https://www.universitiesuk.ac.uk/policy-and-analysis/reports/Pages/monitoring-transition-open-access-2017.aspx>
- Van Eck, N.J., Waltman, L., Larivière, V. & Sugimoto, C. (2018). *Crossref as a new source of citation data: A comparison with Web of Science and Scopus*. Retrieved from <https://www.cwts.nl/blog?article=n-r2s234&title=crossref-as-a-new-source-of-citation-data-a-comparison-with-web-of-science-and-scopus>
- Wang, X., Cui, Y., Xu, S., & Hu, Z. (2018). The state and evolution of Gold open access: A country and discipline level analysis. *ASLIB Journal of Information Management*, 70(5), 573–584.
- Wang, P. (2013). A survey on cognition of web-based academic communication behavior by studying on researchers in social science and humanities in China. *Library and Information*, 19(5), 112–118.
- Willets, D. (2012). *Letter to Dame Janet Finch on the Government Response to the Finch Group Report: “Accessibility, sustainability, excellence: how to expand access to research publications”*. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/32493/12-975-letter-government-response-to-finch-report-research-publications.pdf
- Willinsky, J. (2006). *The access principle: The case for open access to research and scholarship*. MIT Press.

- Xu, J., Nicholas, D., Su, J., & Zeng, Y. X. (2016). Are open access journals trusted by Chinese scholars. *Geomatics and Information Science of Wuhan University*, 41, 131–135.
- Yuan, S. B., & Zhang, H. (2016). Self-storage participation behavior of researchers: Qualitative research based on interviews. *Information and Documentation Services*, 13(3), 80–84.
- Zhang, L., & Sivertsen, G. (2020). The new research assessment reform in China and its implementation. *Scholarly Assessment Reports*, 2(1), 3.
- Zhang, L., Wei, Y. H., Huang, Y., & Sivertsen, G. (2021). The prevalence and impact of different types of open access articles from China and USA. In *Proceedings of the 18th international conference on scientometrics and informetrics* (pp. 1325–1336).
- Zhang, L., Wei, Y., Sivertsen, G., & Huang, Y. (2022). The motivations and criteria behind China's list of questionable journals. *Leaned Publishing*. <https://doi.org/10.1002/leap.1456>
- Zhang, L., & Watson, E. (2018). The prevalence of green and grey open access: Where do physical science researchers archive their publications? *Scientometrics*, 117(3), 2021–2035.
- Zhang, X. (2014). Development of open access in China: Strategies, practices, challenges. *Insights*, 27(1), 45–50.