Transparency to hybrid open access through publisher-provided metadata:
An article-level study of Elsevier

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Abstract

With the growth of open access (OA), the financial flows in scholarly journal publishing have become increasingly complex, but comprehensive data and transparency into these flows are still lacking. The opaqueness is especially concerning for hybrid OA, where subscription-based journals publish individual articles as OA if an optional fee is paid. This study addresses the lack of transparency by leveraging Elsevier article metadata and provides the first publisher-level study of hybrid OA uptake and invoicing. Our results show that Elsevier’s hybrid OA uptake has grown steadily but slowly from 2015-2019, doubling the number of hybrid OA articles published per year and increasing the share of OA articles in Elsevier’s hybrid journals from 2.6% to 3.7% of all articles. Further, we find that most hybrid OA articles were invoiced directly to authors, followed by articles invoiced through agreements with research funders, institutions, or consortia, with only a few funding bodies driving hybrid OA uptake. As such, our findings point to the role of publishing agreements and OA policies in hybrid OA publishing. Our results further demonstrate the value of publisher-provided metadata improve the transparency in scholarly publishing by linking invoicing data to bibliometrics.
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Introduction

The rise of open access (OA) has added complexity to scholarly publishing, particularly concerning transparency of economic dimensions. Financial transparency in journal publishing has long been lacking because Big Deal subscription contracts between academic institutions and large academic publishers usually include confidentiality clauses that prohibit publicly sharing the scope or pricing of such agreements (Bergstrom et al., 2014; Frazier, 2001; Larivière et al., 2015). Further, the distributed payment processes to access and publish scholarly articles add to the opacity of the financial flows of scholarly publishing (Lawson et al., 2016) as they can involve several actors simultaneously, including authors, research institutions, libraries, and funders.

The problem with this lack of transparency becomes more apparent in the case of hybrid OA. In this OA business model, individual articles can be made openly available by paying an article processing charge (APC), while the journal as a whole remains subscription-access. Hence, hybrid OA was originally introduced as a low-risk transitional model that allows journals to gradually convert to full OA and reduce subscription costs as the OA uptake increases (Prosser, 2003). Many large subscription publishers have since incorporated hybrid OA, but there have been concerns that the hybrid model allows for double dipping—receiving two payments for one article, the APC and subscription fees (Prosser, 2015; Shieber, 2009). While publishers assure they adjust their pricing (Mittermaier, 2015), without transparency around the uptake of hybrid OA and both revenue streams, such claims are impossible to evaluate. This is especially concerning because hybrid OA has recently gained popularity after a decade of only slow uptake (Björk, 2012). The main drivers of this development have been research institutions and funders that implemented OA policies, allocated OA funds, and established formal agreements with publishers that allow affiliated authors to publish OA free-of-charge (Laakso & Björk, 2016).

With the recent introduction of transformative agreements, an evolving concept describing contracts that shift library spending from subscriptions to OA (Borrego et al., 2020; Hinchliffe, 2019), the demand for publisher-provided data has increased. More
transparency about hybrid OA uptake and funding could facilitate the assessment and adjustment of publisher contracts (Schimmer et al., 2015), enhance OA mandate compliance monitoring, and avoid double-dipping (Larivière & Sugimoto, 2018). However, previous studies have noted an absence of transparency in hybrid OA publishing and a considerable lack of publicly available and standardized data (Laakso & Björk, 2016; Lawson, 2015; Pinfield et al., 2016).

This paper investigates to what extent publisher-provided data can increase the transparency around hybrid OA by taking Elsevier, the largest scholarly journal publisher (Larivière et al., 2015), as the starting point for an empirical analysis of hybrid OA uptake and invoicing. Our approach is based on openly available data sources and combines scholarly metadata from Crossref, a DOI registration agency, with APC invoicing data from Elsevier. The compiled data enable us to analyze the hybrid OA uptake in Elsevier journals between 2015 and 2019 by license and subject, and to compare it with Elsevier’s full and delayed OA program. Further, we determine whether hybrid APCs were waived or charged to authors or as part of publishing agreements. In the latter case, we examine the invoiced academic consortia and research funders. As such, our findings have implications for research and OA policy and highlight the potential of publisher-provided data for large-scale, instantaneous analysis of hybrid OA uptake and invoicing.

**Background**

**Prevalence and uptake studies**

In the first article-level study on hybrid OA, Laakso & Björk (2016) reported that between 2007 and 2013, the five largest publishers—Elsevier, Sage, Springer, Taylor & Francis, and Wiley—recorded growing numbers of hybrid journals that coincided with a twenty-fold increase in hybrid OA (from 666 to 13,994). As a result, hybrid journals with at least one OA article more than doubled in number (1,082 in 2009, 2,714 in 2013) but fell by 31% relative to the total number of hybrid journals. Laakso and Björk’s (2016) exploratory approach yielded a comprehensive overview tracking the growth of hybrid OA over time and across multiple publishers, but due to the amount of manual data collection and cleaning it is unsuitable for repeated use. Minimizing such manual tasks, Nelson & Eggett (2017) narrowed their focus to one publisher—the American Chemical Society (ACS)—and requested a list of all hybrid OA articles published from
2006-2011 from the ACS. To assess the hybrid OA uptake, the authors aggregated and compared the number of OA (n=814) and subscription articles (n=27,621), finding that over the five years, 2.9% of ACS articles were published as hybrid OA.

Contrary to the previous two studies, Kirkman (2018) took a research funder as a starting point, reporting a 26% share of hybrid OA for articles funded by the Australian National Health and Medical Research Council from 2012-2014 (816 of 3,190). Kirkman collected research articles using the Funding Agency and Funding Text search fields on Web of Science, and classified articles as OA when they were freely available on the publisher website, and further distinguished hybrid OA articles based on journal-level information from the publisher website, such as hybrid OA journal and APC lists. Another approach is presented by Pöönen et al. (2020), who used current research information system (CRIS) data—institutional publication data—to study the extent of OA among Finnish research publications from 2016-2017 (n=34,507 research articles). As part of the analysis, the authors identified hybrid OA articles through a dedicated OA status metadata field that has been mandatory to report in Finland since 2016 and found a 7% share of hybrid OA. However, the drawbacks of Kirkman’s (2018) and Pöönen et al.’s (2020) approaches are that such data sources might not be openly available or, regarding CRIS data, might not be available at all because not all countries maintain comprehensive institutional publication data.

Other studies assessed the share of (hybrid) OA for the entire corpus of research articles. Using DOI-assigned research articles indexed in the Web of Science Core Collection (n=2,610,305) as a benchmark, Martín-Martín et al. (2018) investigated how many research articles from 2009 and 2014 are freely available through Google Scholar. After identifying OA articles through licensing information from Crossref, the authors estimated the share of hybrid OA at around 0.5% in 2009 and 1.5% in 2014. Similarly, in a study assessing the OA level among all scholarly articles and that experienced by Unpaywall users, Piwowar et al. (2018) obtained license information through Crossref and web-scraping. The study found 3.6% of 100,000 random Crossref DOIs were hybrid OA and pointed towards a growing trend in recent years that recorded a hybrid OA share of 9.4% of all articles published in 2015.

Since its launch, Unpaywall has become widely used in bibliometric research and rankings (Huang et al., 2020; Robinson-Garcia et al., 2020). However, the lack of
standardized and comprehensive publisher-provided data has required several updates to Unpaywall to improve hybrid OA identification and differentiation from delayed OA (Piwowar et al., 2019; Unpaywall, n.d.-b; Unpaywall, n.d.-c), illustrating ongoing challenges in tracking and comparing hybrid OA prevalence over time.

**Financial studies**

Pinfield et al.’s (2016) analysis of APC payment records provided by 23 United Kingdom (UK) higher education institutions revealed a sharp increase in central payments from 2007-2013, which was largely attributed to the introduction of block grants by Research Councils UK (RCUK) and non-compliance sanctions by the Wellcome Trust. Moreover, the study showed that OA fees were paid almost exclusively through block grants (92%), and only a small number of APCs were paid through internal funding (7%). In contrast, a recent Springer Nature survey found that authors draw on a range of funding sources to cover OA fees, such as dedicated institutional OA funds, block grants, OA agreements, or research grants (Monaghan et al., 2020). Most hybrid OA authors were supported through dedicated institutional OA funds (43%, excluding block grants) and OA agreements with Springer Nature (34%). The differences between these two studies might be due to different policy and funding arrangements—considering the introduction of OA agreements since Pinfield et al. (2016) and Monaghan et al.’s (2020) more regionally diverse sample.

Regional and policy differences in APC payments also came to light in a study by Jahn & Tullney (2016) that analyzed APC records from 30 German higher education and research institutions, the Austrian Science Fund (FWF), Jisc, and the Wellcome Trust. In particular, the study revealed large differences in the amount of hybrid OA funded from 2014-2015. Whilst hybrid OA accounted for less than 1% of APCs paid by German institutions (23 of 3,846), the three non-German research funders recorded a hybrid share of 75% (11,533 of 15,779). According to Jahn & Tullney (2016), this could point towards differences in science policy, such as hybrid OA being supported by the three non-German research funders but not by Germany’s largest national funder, the German Research Foundation (DFG). Another possibility is that German hybrid OA fees were paid from budgets not reported to the Open APC initiative, a crowd-sourcing effort (Pieper & Broschinski, 2018) from where the authors acquired data. Among these unreported funds are research grants and research unit budgets, which author surveys
identified as APC funding sources (Graaf, 2017; Monaghan et al., 2020). As such, Jahn and Tullney’s (2016) findings could reflect the complexities and potential limitations of institutional OA spending data that Pinfield et al. (2016) and Monaghan et al. (2020) attributed to incomplete or missing records.

In recent years, national consortia in Europe negotiated publishing agreements covering hybrid OA fees for affiliated authors (Borrego et al., 2020). While these improved invoicing workflows, internal assessments of hybrid OA uptake and invoicing remain challenging because transparent and comparative data have largely remained absent (Marques & Stone 2020). Such publicly available information might be scarce because publishers lack or withhold such data, or due to confidentiality clauses (Marques & Stone 2020; Marques et al., 2019; Monaghan et al., 2020).

Research questions and aims

In this paper, we focus on Elsevier, a prominent example in recent hybrid OA uptake and financial studies (Laakso & Björk 2016; Pinfield et al. 2016). Elsevier’s OA portfolio presents the challenges in examining hybrid OA described above. For instance, distinguishing between different OA types. Elsevier supports delayed (Elsevier, n.d.-b), hybrid, and full OA, including so-called mirror journals—full OA counterparts of hybrid journals addressing OA policies opposed to hybrid OA (Harrison, 2019). Further, Elsevier processes APC invoices through various channels, such as agreements with research funders and library consortia or, in the absence thereof, the authors (Elsevier, n.d.-a, n.d.-c). Surprisingly, we found Elsevier article-level metadata embedded in XML full-texts indicating the articles’ OA status and invoicing. Leveraging this publicly available data, we address the lack of transparency around hybrid OA noted in previous studies. In particular, we use this novel approach to answer the following questions:

- What was the uptake of Elsevier’s hybrid OA publishing option between 2015 and 2019?

- Through which channels were hybrid APCs invoiced, and who were the recipients?

Methodology

For this study, we collected data relating to Elsevier’s hybrid OA option by drawing on multiple freely available data sources. We identified Elsevier hybrid journals through Elsevier’s APC list and supplemented our sample with Crossref metadata and
text-mined invoicing data to investigate the invoicing of immediate OA articles provided under a Creative Commons (CC) license in subscription-based journals. Figure 1 visualizes the automated workflow we used to collect data from Elsevier and Crossref.

**Figure 1.** Data Collection Workflow to Obtain Article-Level OA and Invoicing Data.

First, we identified hybrid journals through an Elsevier APC price list from May 2020 provided by Matthias (2020). We excluded journals that transitioned from hybrid to full OA and reverse-flip journals that flipped from full to hybrid OA (Matthias et al., 2019). Overall, we identified 1,970 unique hybrid journals that published between 2015 and 2019.

Next, we used an openly available Crossref database snapshot (Crossref, 2020), which contains all Crossref records registered until March 2020, to calculate the journals’ combined article volume for the five-year period from 2015-2019. We only included articles published in regular issues aside from supplements containing conference contributions like meeting abstracts, indicated by non-numeric pagination. We excluded non-scholarly journal content, such as the table of contents, following Unpaywall’s paratext recognition approach (Unpaywall, n.d.-a), which we expanded to include patterns indicating corrections. Furthermore, we categorized the articles by subject according to the All Science Journal Classification code (ASJC) and added citation indicators from the Scopus Source Title list (version June 2020) based on the journal they were published in.

We identified OA articles through CC licenses in Crossref metadata records (Hendricks et al., 2020) and then downloaded the XML version of all CC-licensed articles published in a hybrid journal. From the XML files, we obtained the articles’ OA status and invoicing information (see Table 1). We determined whether articles were immediate or delayed OA using the XML node `openArchiveArticle` and measured the
uptake of hybrid OA. Moreover, we obtained the invoice channels and recipients of hybrid OA APCs. Using the `openaccessSponsorType` node, we distinguished between four invoice channels, including invoices billed to authors, as part of publishing agreements with funding bodies (cf. Elsevier (n.d.-a)), exempted through fee waivers (e.g., in “cases of genuine need” or due to society or university sponsorships, cf. Elsevier, n.d.-c), and other types not specified by Elsevier. Finally, when hybrid APCs were invoiced as part of agreements, we identified invoice recipients through the `openaccessSponsorName` node.

Table 1

*Metadata in Elsevier XML Full-Texts.*

| XML node                | Description                                                                 |
|-------------------------|-----------------------------------------------------------------------------|
| openaccessArticle       | Was the article open access?                                                |
| openaccessSponsorType   | Invoice channel.                                                            |
| openaccessSponsorName   | Invoice recipient.                                                          |
| openArchiveArticle      | Was open access provided through Elsevier’s Open Archive program?           |

We manually classified invoice recipients based on their institutional sectors, countries, and primary research areas. Following the OECD’s Frascati Manual (OECD, 2015, p. 91), we coded for four sectors: business enterprise, government, higher education, and private non-profit. Due to the low article volume, we combined the business enterprise sector with invoice recipients Elsevier listed as “authors” and “third-party sponsor” into “Others”. Moreover, we categorized invoice recipients according to the countries representing their scope of funding and based on the following primary research areas health sciences, life sciences, physical sciences and mathematics, social sciences and humanities, broad (i.e., multiple research areas), and unknown. Further, we compared Elsevier’s invoicing data with institutional spending data from the Open APC initiative.

Throughout this mostly automated data gathering and analysis process, we used tools from the Tidyverse (Wickham et al., 2019) for the R programming language (R
To allow for efficient data manipulation and retrieval, we imported the Crossref dump to Google BigQuery, applying the rcrossref (Chamberlain et al., 2020) parsers to extract relevant metadata fields. We used crminer (Chamberlain, 2020) to obtain the XML-full texts from Elsevier.

**Results**

This section first presents the results of our analysis of hybrid OA uptake in Elsevier’s journal portfolio with a view to licensing, disciplinary differences, and citation impact. Then, we present a descriptive analysis of Elsevier’s invoicing data, highlighting licensing and disciplinary differences for invoicing channels and invoice recipients.

**Uptake of Hybrid Open Access**

**Overview.** Between 2015 and 2019, 1,755 of 1,970 (89.1%) hybrid journals published at least one OA article. Together these journals published 71,643 OA articles, which represented 3% of their total article volume (n=2,422,087). Table 2 presents findings for each year and the aggregated five-year period, illustrating moderate growth of hybrid OA over time. Each year, the number of hybrid journals with at least one OA article increased, as did the number of immediate OA articles in these journals, which nearly doubled from 10,672 in 2015 to 19,311 in 2019. However, since the journals’ total article output also grew over time, the relative share of OA articles in hybrid journals only increased slightly from 2.6% to 3.7%.
Table 2

*Elsevier Hybrid OA Uptake 2015-2019.*

|                         | 2015  | 2016  | 2017  | 2018  | 2019  | 2015-19 |
|-------------------------|-------|-------|-------|-------|-------|---------|
| **Elsevier Hybrid Journals with ≥ 1 OA article** |       |       |       |       |       |         |
| Total                   | 1,317 | 1,364 | 1,401 | 1,501 | 1,600 | 1,755   |
| **Articles in Elsevier Hybrid Journals with ≥ 1 OA Article** |       |       |       |       |       |         |
| Total                   | 406,701 | 422,423 | 436,418 | 468,952 | 518,062 | 2,422,087 |
| Avg.                    | 308.8 | 309.7 | 311.5 | 312.4 | 323.8 | 1,380.1 |
| SD                      | 401.1 | 419.6 | 427.5 | 445.6 | 479.9 | 1,937.5 |
| **OA Articles in Elsevier Hybrid Journals with ≥ 1 OA Article** |       |       |       |       |       |         |
| Total                   | 10,672 | 12,729 | 13,361 | 15,570 | 19,311 | 71,643  |
| Avg.                    | 8.1   | 9.3   | 9.5   | 10.4  | 12.1  | 40.8    |
| SD                      | 12.9  | 19.7  | 15.6  | 16.2  | 20.1  | 68.9    |
| **OA Uptake in Elsevier Hybrid Journals with ≥ 1 OA Article** |       |       |       |       |       |         |
| Total (%)               | 2.6   | 3.0   | 3.1   | 3.3   | 3.7   | 3.0     |
| Avg.                    | 3.7   | 4.3   | 4.4   | 4.7   | 5.4   | 3.8     |
| SD                      | 4.5   | 5.9   | 5.1   | 4.9   | 5.7   | 4.1     |

Figure 2 presents a box-and-whiskers plot of the OA uptake in Elsevier hybrid journals by year, showing variation among the journals. Notably, the upper quartiles and whiskers stretch farther over the years, which indicates that the range of uptake among journals with an above-average proportion of OA articles increased over the years. Nevertheless, the prevalence of hybrid OA remained relatively low; in 2019, 95% of Elsevier hybrid journals published ≤15.6% of their articles OA.
Figure 2. Open Access Uptake per Elsevier Hybrid Journal (Per Year).

Note: The Y-axis is limited to an OA share of 20%.

During the same period, Elsevier provided OA to 328,601 articles in total (i.e., full, hybrid, and delayed OA combined), representing 12.4% of the total article volume (n=2,643,474). Looking at Figure 3, it is apparent that the OA article volume of hybrid journals (n=71,643; 21.8%) lagged behind delayed OA (n=163,643; 49.8%) and full OA journals (n=93,315; 28.4%), which included 817 articles published in 38 mirror journals.
License Prevalence. As far as we observed, OA articles in Elsevier hybrid journals were published under two possible CC licenses—CC BY or CC BY-NC-ND. CC BY allows others to distribute, remix, adapt, and build upon the licensed work, including for commercial purposes, as long as the original author is credited. In contrast, CC BY-NC-ND is less permissive as it prohibits commercial reuse and derivatives. From 2015-2019, the proportion of hybrid OA articles published under a CC BY-NC-ND license marginally increased and maintained a greater share than CC BY (see Figure 3-B). Interestingly, Figure 3-B also reveals that nevertheless hybrid journals had the highest number and proportion of OA articles licensed under CC BY (n=29,752; 41.5%) compared to full OA journals (n=17,293; 18.5%) and Elsevier’s delayed OA program (n=1,568; 1%). Most delayed OA articles were provided under an Elsevier user license (Els-User), which prohibits reuse for commercial purposes.

Subject Area and Field. Next, we present the hybrid OA uptake of different disciplines. Table 3 presents the high-level findings by ASJC subject area. Between 2015 and 2019, the physical sciences (712 hybrid journals; 29,584 OA articles) and
health sciences (634 hybrid journals; 25,119 OA articles) recorded the most hybrid journals with at least one OA article. However, the life sciences (538 hybrid journals; 31,383 OA articles) published the most hybrid OA articles, while the social sciences published the least (372 hybrid journals; 11,204 articles). It is important to note, though, that there is a large overlap between the journals’ subject areas. Therefore, Table 3 also assigns hybrid journals and OA articles fractionally, where journals assigned more than one ASJC subject were counted once for each. For the remaining results, we only present the full counting.

Table 3
Full and Fractional Counting of Subject Areas (2015-2019).

| Subject area     | Full counting | Fractional counting |
|------------------|---------------|---------------------|
| Health sciences  | 634 25,119    | 506.6 18,415        |
| Life sciences    | 538 31,383    | 368.5 21,753        |
| Physical sciences| 712 29,584    | 584.4 23,915        |
| Social sciences  | 372 11,204    | 283.5 7,462         |

Note: One multidisciplinary journal (61 OA articles) and 11 journals (37 OA articles) that could not be matched to the Scopus Source Title list to obtain ASJC codes are not included.

Figure 4 presents the journals’ five-year OA uptake grouped by subject area and field and in comparison to the overall median (Mdn= 2.5%; excluding one journal coded as multidisciplinary). The box plot reveals some variation between the subject areas. Notably, with the exception of environmental science and earth and planetary sciences, hybrid journals from the physical sciences show a lower median OA proportion, whereas most life sciences and social sciences journals ranked above average. Figure X also shows large variations among the 26 subject fields, with the highest OA rates in immunology and microbiology (Mdn=5.1%), environmental science (Mdn=4.8%), and neuroscience (Mdn=4.3%), whilst chemistry (Mdn=1.4%), materials science (Mdn=1.4%), and dentistry (Mdn=0.6%) recorded the lowest OA rate.
Figure 4. OA Uptake in Elsevier Hybrid Journals by Subject Area and Field (2015-2019).

Note: Y-axis is limited to an OA share of 20%; the red line represents the overall median (2.5), jittered dots represent individual journals. Subject fields are ordered based on the median OA uptake.

Citation Impact. Furthermore, we compared the journals’ field-specific citation impact and their OA uptake. Spearman’s rho correlation coefficient was used to assess the relationship between the 2019 Source Normalized Impact per Paper (SNIP) value calculated by Scopus and the journals’ OA uptake that year. Considering only journals with at least one OA article, we found a weak but positive correlation between journal impact and OA uptake (\( r_s = 0.1679, p < 0.001 \)), suggesting that the relationship is not very strong, based on our data (see Figure 5).
Invoicing for Hybrid Open Access

Invoice Channels. As can be seen from Table 4, hybrid OA APC were most often invoiced to authors (n=41,725; 58.2%) and to a lesser extent as part of agreements (n=24,250; 33.8%). Interestingly, we also found a small number of cases where hybrid APCs were waived (n=4,345; 6.1%).

Table 4
Invoice Channels for Elsevier Hybrid OA Articles (2015-2019).

| Invoicing channel | Hybrid OA articles (n) | Percentage |
|-------------------|-----------------------|------------|
| Author            | 41,725                | 58.2       |
| Agreement         | 24,250                | 33.8       |
| Fee waived        | 4,345                 | 6.1        |
| Other             | 1,323                 | 1.8        |
| Total             | 71,643                | 100.0      |

Figure 6 illustrates that over the years, Elsevier has increasingly invoiced authors directly compared to research funders or academic consortia (“Agreement”). The share of fee-waived articles remained relatively stable, but we found different types of waivers. Around 51.7% of fee waivers were linked to a third party. For instance, the French Académie des Sciences, presumably covering OA publication for 853 OA articles in its society journals for affiliated authors. The remaining 48.3% of waived articles did not
disclose any invoice recipient. Moreover, Figure 6 compares the invoicing channels based on CC license variants. When Elsevier invoiced authors directly, most OA articles in hybrid journals were published under a non-commercial license (n=32,086; 76.9%), whereas most articles billed as part of agreements were licensed under the more permissive CC BY license (n=18,331; 75.6%).

Figure 6. Elsevier Hybrid OA Articles by Invoice Channel and CC License (Per Year).

Note: Grey bars show the total number of hybrid OA articles published in Elsevier journals.

We also observed large differences in OA invoicing among subject fields. Table 5 shows the number of OA articles by subject field and invoice channel. For articles in nursing, decision sciences, and pharmacology, toxicology and pharmaceutics, Elsevier predominantly invoiced authors, whereas most energy and chemical engineering articles were invoiced through agreements. Likewise, the majority of articles in materials science, chemistry and physics and astronomy were not invoiced to authors but facilitated through agreements or waived. The large share of waived APCs in physics and astronomy can be attributed to a single 2015 issue of Nuclear and Particle Physics Proceedings.
Table 5

*Invoice Channels by Subject (2015-2019).*

| Subject                                              | OA articles | Invoice channel (in %) |
|------------------------------------------------------|-------------|------------------------|
|                                                      |             | Author | Agreement | Fee waived | Other |
| Nursing                                              | 1,504       | 82     | 16        | 1          | 1     |
| Decision Sciences                                    | 785         | 72     | 27        | 0          | 1     |
| Pharmacology, Toxicology and Pharmaceutics           | 4,075       | 69     | 27        | 1          | 2     |
| Business, Management and Accounting                  | 1,751       | 68     | 29        | 2          | 1     |
| Dentistry                                            | 288         | 68     | 17        | 10         | 5     |
| Health Professions                                   | 674         | 67     | 24        | 3          | 5     |
| Medicine                                             | 23,623      | 65     | 25        | 6          | 4     |
| Agricultural and Biological Sciences                 | 7,956       | 63     | 31        | 5          | 1     |
| Computer Science                                     | 3,185       | 63     | 36        | 0          | 1     |
| Economics, Econometrics and Finance                  | 2,071       | 62     | 33        | 5          | 0     |
| Veterinary                                            | 2,091       | 61     | 25        | 13         | 1     |
| Social Sciences                                      | 6,306       | 60     | 36        | 3          | 0     |
| Earth and Planetary Sciences                         | 4,532       | 59     | 35        | 5          | 0     |
| Biochemistry, Genetics and Molecular Biology         | 15,903      | 59     | 35        | 4          | 2     |
| Immunology and Microbiology                          | 5,542       | 59     | 34        | 6          | 2     |
| Environmental Science                                | 9,000       | 58     | 38        | 3          | 1     |
| Psychology                                           | 3,087       | 57     | 40        | 2          | 1     |
| Neuroscience                                         | 5,906       | 56     | 40        | 3          | 1     |
| Arts and Humanities                                  | 1,565       | 54     | 44        | 1          | 0     |
| Mathematics                                          | 2,105       | 53     | 38        | 8          | 0     |
| Engineering                                          | 8,405       | 50     | 46        | 3          | 1     |
| Materials Science                                    | 4,838       | 49     | 47        | 4          | 0     |
| Chemistry                                            | 4,033       | 48     | 46        | 5          | 1     |
| Energy                                               | 4,286       | 46     | 52        | 1          | 1     |
| Chemical Engineering                                 | 2,977       | 45     | 47        | 7          | 1     |
| Physics and Astronomy                                | 5,859       | 40     | 38        | 22         | 0     |

**Invoice Recipients.** Elsevier’s data offer more insight into OA invoicing. Overall, we identified 63 academic institutions and funders that received invoices as part of publishing agreements. By a large margin, most invoices were issued to UK-based research funders and institutions (n=14,344; 59.2%), followed by the Netherlands (n=2,835; 11.7%) and the European Union (n=2,164; 8.9%; EU). Figure 7 presents the
geographical distribution by license prevalence, highlighting the dominance of CC BY licensed articles invoiced to institutions in the UK, the United States (US), and, to a much lesser extent, the Netherlands. In contrast, most articles invoiced to institutions from Norway or representing the EU were published under a non-commercial license.

Figure 7. Centrally Invoiced Elsevier Hybrid OA Articles by Country and CC License (2015-2019).

Figure 8 shows the yearly distribution of centrally invoiced articles by year and institutional sector. While UK-based OA invoices were mainly addressed to discipline-specific governmental and non-profit research funders, invoices to the Netherlands and Norway were issued to national academic consortia representing the higher education sector. In 2019, Elsevier also launched similar agreements in countries with lower publication output including Hungary and Poland. Besides, we found that invoice recipients from the UK and the US mainly represented discipline-specific funders, while invoice recipients from other countries focused on a broad variety of disciplines (see Table 6).
Figure 8. Centrally Invoiced Elsevier Hybrid OA Articles by Country and Sector (Per Year).

Table 6
Share of Centrally Invoiced Elsevier Hybrid OA Articles by Country and Subject (2015-2019).

| Country/Subject area | Health science | Life sciences | Physical sciences | SSH | Broad | Total |
|----------------------|----------------|---------------|-------------------|-----|-------|-------|
| United Kingdom       | 25%            | 11%           | 21%               | 5%  | 0%    | 62%   |
| The Netherlands      | 0%             | 0%            | 0%                | 0%  | 12%   | 12%   |
| European Union       | 0%             | 0%            | 0%                | 0%  | 9%    | 9%    |
| United States        | 6%             | 0%            | 0%                | 0%  | 1%    | 7%    |
| Norway               | 0%             | 0%            | 0%                | 0%  | 3%    | 3%    |
| Other                | 1%             | 0%            | 1%                | 0%  | 5%    | 7%    |
| Total                | 32%            | 11%           | 22%               | 5%  | 30%   | 100%  |

Institutional ranking. Table 7 presents the top ten of 63 invoice recipients in our sample. Together, they accounted for around 80% of centrally invoiced APCs. The table also highlights the number of distinct journals and the share of CC BY licensed articles. Notably, UK-based research funders and the US-based Bill and Melinda Gates Foundation mainly received invoices for CC BY licensed articles. In contrast, articles invoiced to VSNU, the European Research Council, and Norway Institutes had a much lower proportion of CC BY.

The table also highlights the proportion of APCs publicly disclosed through the
Table 7
Elsevier Hybrid OA Invoice Recipients (2015-2019).

| Hybrid OA invoice recipients                                | Journals | Articles | %  | CC BY | OAPC |
|-------------------------------------------------------------|----------|----------|----|-------|------|
| Engineering and Physical Sciences Research Council          | 619      | 4663     | 19 | 97    | 55   |
| VSNU                                                        | 357      | 2835     | 12 | 52    | 0    |
| Wellcome Trust                                              | 448      | 2506     | 10 | 98    | 66   |
| European Research Council                                   | 541      | 1986     | 8  | 32    | 9    |
| Medical Research Council                                    | 384      | 1922     | 8  | 95    | 51   |
| Natural Environment Research Council                        | 203      | 1357     | 6  | 97    | 45   |
| Biotechnology and Biological Sciences Research Council       | 309      | 1169     | 5  | 93    | 41   |
| Bill and Melinda Gates Foundation                           | 254      | 1030     | 4  | 100   | 68   |
| Economic and Social Research Council                        | 245      | 922      | 4  | 96    | 48   |
| Norway Institutes                                            | 374      | 694      | 3  | 41    | 0    |
| Other                                                       | 1012     | 5166     | 21 | 54    | 21   |
| All                                                         | 1423     | 24250    | 100| 76    | 36   |

Open APC initiative, showing higher disclosure rates for invoice recipients with a large CC BY share.

**Discussion**

From 2015-2019, Elsevier recorded growth in the uptake of hybrid OA: The number of hybrid OA articles published per year doubled, the number of hybrid journals with at least one OA article grew by 21%, and the share of hybrid OA articles relative to closed-accessed articles in these journals increased from 2.6% to 3.7%. As Laakso & Björk (2016), we found only a weak relationship between the journals’ SNIP and hybrid OA uptake and observed disciplinary differences. In particular, we found the highest count of hybrid OA articles in physical sciences journals (see Table 3). This was followed by the life sciences and health sciences, whereas the social sciences had the lowest count. This order mostly reflects the disciplines’ overall publication output. According to the Open Science Monitor (European Commission, 2019), the physical sciences publish the most articles, followed by the health sciences, life sciences, and social sciences.

Disciplinary differences in hybrid OA prevalence become more meaningful when
considering the relative share of OA articles to closed-access articles. In line with previous research, we found that Elsevier journals from the life sciences and social sciences (Jubb et al., 2017; Kramer & Bosman, 2018; Laakso & Björk, 2016) recorded greater than typical hybrid OA uptake, whereas physical sciences journals generally had a lower than typical uptake (Kramer & Bosman, 2018; Laakso & Björk, 2016; Martín-Martín et al., 2018). In a systematic review of disciplinary OA publishing patterns, Severin et al. (2020) highlighted the importance of socio-cultural and technological factors in shaping publishing cultures and practices. For instance, since many branches of the physical sciences have established self-archiving practices (Severin et al. (2020), Björk et al. (2010), Laakso & Björk (2016)), researchers can provide OA through repositories and might perceive much less of a need for hybrid OA. In contrast, hybrid OA in the life sciences could be enabled through project-based funding structures as they allow for easy integration of publishing costs (Severin et al. (2020). On the other hand, the high hybrid OA uptake that we observed among the social sciences could point to the influential role of OA policies and invoicing agreements (Huang et al., 2020; Larivière & Sugimoto, 2018).

Our invoicing data analysis found that most APCs were invoiced to the author (n=41,725; 58.2%). However, it is important to emphasize although Elsevier’s metadata classifies the sponsor type as “author”, this does not necessarily mean that authors paid for APCs themselves but rather that APCs were not invoiced through publishing agreements. It is possible that these APCs were covered through institutional funds or research grants. This would align with a recent Springer Nature survey that found hybrid OA was predominantly supported through institutional and funder sources (71%), followed by OA agreements (34%), while only 6% were paid from personal funds or savings (Monaghan et al., 2020).

Further, we observed notable differences in licensing. Most hybrid OA articles invoiced to author were licensed under the more restrictive CC BY-NC-ND license. Previous research, while lacking dedicated studies on license selection, suggests that authors tend to select more restrictive license variants when given a choice (Fraser et al., 2020; Noorden, 2013; Rowley et al., 2017). On the other hand, we found when hybrid OA was invoiced through agreements, most articles were licensed under the more liberal CC BY license. As several funding bodies mandate CC BY licenses, including
the UK research funders that account for 62% of our “agreement” subsample, this result is perhaps not surprising but suggests the effectiveness of such agreements.

Based on our findings, around a third of the articles were invoiced through OA agreements (e.g., research funders, national library consortia). The predominance of UK funding bodies in this subsample reiterates reports from previous studies that the UK’s OA profile differs markedly from other countries (cf. Jubb et al. 2015; Jubb et al., 2017), pointing to the impact of science policy. To promote OA, the UK implemented centralized APC funding and embraced hybrid OA as a transition model. Within five years of the publication of the Finch Report in 2012, the UK recorded an 18% increase in immediate OA, coupled with a rise in hybrid OA from 2.7% in 2012 to 15.4% of all articles in 2016 (Jubb et al., 2017), which can be attributed to the availability of funding from RCUK. Indeed, RCUK block grants have been the largest single source of APC funds in the UK—the Wellcome Trust, and more recently transformative agreements (Jubb et al., 2017; Tickel, 2018). However, since then publishing expenditures of UK universities have been rising rapidly (Jubb et al., 2017), so that several universities stopped supporting hybrid OA in late 2018-2019 (University of Birmingham, n.d.; Walker, 2019). This development might explain the slight decrease in hybrid articles invoiced to the UK our data showed around that time (see Figure 7).

Through this study we demonstrated the utility and benefits of publisher-provided metadata about hybrid OA invoicing and highlighted the need for extending these to include comprehensive information about licensing and APC waivers. Metadata guidance should also consider the substantial amount of delayed OA content, which needs to be distinguished from hybrid OA. Hence, our study substantiates the recommendations from the Efficiency and Standards for Article Charges (ESAC) Initiative that seek to increase efficiency and transparency through improved invoicing and reporting processes and metadata about OA funding (Geschuhn & Stone, 2017).

While this study advances our knowledge about hybrid OA uptake and invoicing, the limitations leave room for future research. We focused on only one publisher, which limits the generalizability of our findings because Elsevier’s journal portfolio, mix of business models, pricing, and promotion of various options cannot be assumed to be representative of scholarly journal publishing in general. Further, although Elsevier’s invoicing data improves transparency, it seems likely that not all actual OA funding
bodies are disclosed. For instance, most articles were invoiced to authors, but it remains unclear if the APCs were paid by the authors themselves or through institutional OA funds or research grants. Research into this topic would improve our understanding of OA funding outside of publishing agreements. Moreover, our study demonstrates that comprehensive mapping of the financial flows of OA publishing requires complex, in-depth country-specific analyses. Such studies would ideally draw on various data sources to consider research funders, the consortia landscape, OA policies, and publishing agreements.

This study provides a snapshot of hybrid OA for Elsevier, the largest journal publisher, prior to the impact of the implementation of Plan S, an initiative to accelerate the transition to OA that will no longer support hybrid OA (cOAlition S, n.d.). While many Plan S signatories have already had strong OA policies, this harmonized approach is likely to affect publishing decisions of funded authors, the licencing of their articles, and the offerings and pricing of publishers at a larger scale than before. Because the new requirements apply to research funded from 2021 onward, a comparative study on articles invoiced to Plan S signatories would be a fruitful endeavor.

Conclusion

The primary aim of this empirical study was to investigate Elsevier’s hybrid OA publishing from 2015-2019 to better understand the volume and invoicing of hybrid OA and to present a novel, data-driven approach for such analyses. Our results indicate that although the number of hybrid OA articles has increased over time, its uptake has remained low. Notably, hybrid APCs were most often invoiced directly to the authors, followed by agreements, where only a few funding bodies were the primary drivers of hybrid OA. Finally, our findings highlight that publisher-provided metadata about the invoicing channels of (hybrid) OA can facilitate research into and increase the understanding of the financial flows of OA publishing.

Since the beginning, hybrid OA has been a challenging subject to study due to the lack of standardized ways publishers flag such content and APC funding data being limited self-reported data, surveys, and other secondary sources. This study presented a novel approach to studying APC invoicing that is based on publicly available publisher-provided metadata, which can be used on its own or in combination with
other public data sources to gain more detailed and comprehensive insights into hybrid OA uptake and invoicing. If more publishers reported OA invoicing on the article level and in a machine-readable format, this would increase transparency and improve monitoring of the scholarly journal landscape over time. As hybrid OA has become a central element of OA policies of research funders and libraries, consumer organizations could require that invoicing information is added to the article-level metadata. As long as publishers do not provide this data in a structured and comprehensive format, they prevent benchmarking prices and therefore hinder competition.

From recent science policy developments in Europe it appears that Big Deals have gained support and remain firmly in place in the form of transformative agreements. Through this study we can affirm that hybrid OA is complex as the financial flows involve research funders, libraries, consortia, and authors. However, it is on publishers to increase the transparency of OA publishing, including hybrid OA and transformative agreements, by providing instantaneous open data about OA uptake and invoicing.

Data Availability

The source code data analysis is available on GitHub:

https://github.com/njahn82/elsevier_hybrid_invoicing

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