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Abstract

For many decades, the hyperinflation of subscription prices for scholarly journals have concerned scholarly institutions. After years of fruitless efforts to solve this "serials crisis", open access has been proposed as the latest potential solution. However, also the prices for open access publishing are high and are rising well beyond inflation. What has been missing from the public discussion so far is a quantitative approach to determine the actual costs of efficiently publishing a scholarly article using state-of-the-art technologies, such that informed decisions can be made as to appropriate price levels. Here we provide a granular, step-by-step calculation of the costs associated with publishing primary research articles, from submission, through peer-review, to publication, indexing and archiving. We find that these costs range from less than US$200 per article in modern, large scale publishing platforms using post-publication peer-review, to about US$1,000 per article in prestigious journals with rejection rates exceeding 90%. The publication costs for a representative scholarly article today come to lie at around US$400. We discuss the additional non-publication items that make up the difference between publication costs and final price.

Introduction

The affordability problem of scholarly publishing, i.e., the hyperinflationary price increases with stagnating library budgets, has been discussed for decades (see, e.g., Chan 2004; Harnad et al. 2004; Douglas 1990; Fisher 2008; Houghton 2001; Tananbaum 2003; Rose-Wiles 2011). In recent years, perhaps precipitated by some so-called 'gold' open access (OA) journals charging article-processing charges (APCs; fees usually charged to authors or their institutions upon acceptance for publishing an article and making it openly available), the *average cost of an article* has emerged as a useful measure with which to compare different business models. However, most authors refer to the *prices* charged by the publisher, not the actual *cost* to the publisher (e.g., Van Noorden 2013; Schimmer et al. 2015; Odlyzko 2013; Johnson et al. 2018). One consequence of this mis-attribution is a potential overestimation of the actual costs of scholarly publishing due to the inclusion of the business models and pricing strategies of publishers into the calculation. To close this gap, here we provide a bottom-up calculation of the cost of efforts and services which are required to achieve a certain service level in order to publish an academic journal article. We compare our *cost* estimate with the current *pricing* schemes of publishers.

Traditionally, access to scholarly publications has been provided through a subscription model. Non-disclosure agreements, commonly used by subscription publishers today (with the explicit intent to increase prices (Tempest 2013)), make it difficult to calculate per-article prices at the level of journals, publishers or countries. However, it is known how many scholarly articles are being published every year on a world-wide basis (2.4 million in 2017, (White 2019)) and there are converging estimates on the subscription revenue spent world-wide each year (approx. US$10 billion; Van Noorden 2013; Schimmer et al. 2015; Odlyzko 2013; Johnson et al. 2018). Dividing these two figures leads to a widely agreed per-article price of approx. US$5,000 paid largely by libraries for the subscription system (Johnson et al. 2018). Both figures are reportedly slightly higher today, but the final per article price is relatively unchanged and still remarkably close to a long-standing US$4,000/article estimate (Odlyzko 1995; Johnson et al. 2018). Taken together, with both the revenue and the publication volume increasing over the last decades, the per-article price of the subscription system has remained relatively constant between US$4,000-5,000, further validating the value of this measure.

While most OA journals do not charge APCs (or other author-facing fees, such as submission fees) and instead finance their services via alternative routes (71% of journals listed in the Directory of Open Access

Journals, DOAJ), most OA articles are being published in the minority of journals which do charge APCs (58%, Crawford 2019). So far, in contrast to subscription prices, APCs are commonly not covered by non-disclosure agreements. On the contrary, most journals publicly list their APCs. Moreover, in those cases where APCs are paid by research organizations, universities or academic libraries on behalf of their authors, there are data available on a more granular basis compared to the subscription-based business model. For instance, Jahn and Tullney calculated from APCs for 7,417 journals which have been paid by 30 German academic libraries between 2005 and 2015 an average APC of 1,298€ (~US$1,470)(Jahn & Tullney 2016). In contrast, Schimmer et al. (2015) project an average APC of 2,000€ (~US$2,260) for their scenario of transitioning to a full OA system. In a sample covering the USA and Canada, APCs averaged US$1,775 (Solomon & Björk 2016). Confirming these numbers, Morrison (2018a) finds that the most common APC in her sample is US$1,780. In the UK, JISC reports average APCs around 1,700£ (~US$2,240)(Shamash 2017). Covering all DOAJ-listed journals, Crawford finds an average APC paid of US$1,569 (Crawford 2019). Interestingly, this year, the German DEAL consortium agreed to pay 2,750€ (~US$3,110) per article in their “publish & read” contract with the publisher Wiley (Haufe 2019). Thus, the prices incurred vary from zero to several thou-

sands of $/£/€, an additional reason why these numbers - while accurate - are not useful for a reliable calculation of what the scholarly publishing of public research could or should cost.

From the figures available, it is straightforward to hypothesize that publishers, by and large, determine their price structure according to what they estimate the market to be able to carry, i.e., with a value-based (or prestige) pricing strategy in a market with status consumption (Goldsmith et al. 2010; Kumcu & McClure 2003). Both the subscription approach and the APC approach share the same basic property, which uncouples the price charged from the costs incurred: non-substitutability. In the subscription system, due to rules such as the Ingelfinger rule (Marshall 1998; Angell & Kassirer 1991) that prevent duplicate publications, each article can be found at only one journal of one publisher exclusively. Hence, due to this lack of competition, subscription pricing need not be coupled to publication costs, but purely to reader demand. Analogously, the more than 34,000 scholarly journals are not only differentiated by the areas of scholarship they serve, they are also stratified in a ranking system where no two journals share the same position, conveying prestige and status to authors. Thus, as duplicate publications are still prevented in OA as in subscription journals, the number of journals in a particular field and prestige stratum effectively equals one. The APC-OA 'market' hence suffers from

analogous non-substitutability problems as the subscription market, leading to market failure and hyperinflation also there (Crawford 2019; Morrison 2018a; Shamash 2017; Khoo 2019). Corroborating these observations are data that also APCs fluctuate with author demand rather than with costs and that authors appear to be price-insensitive (Schönfelder 2018; Andrew 2012; Khoo 2019). In fact, at least two publishers have publicly stated that their pricing was driven not by costs, but by market and competitor analysis (Poynder 2015; Morrison 2018b). Thus, in both systems, monopolistic situations have arisen that let demand, prestige and purchasing power, rather than cost drive the prices. The non-substitutability in these markets appears to be a major contributing factor leading to value-based pricing. This argument entails that in order to arrive at a truly competitive market where the main driver for price is cost (i.e., promoting a cost-plus pricing strategy), the goods in this market need to be substitutable. As scholarly articles are written and reviewed by the scholars themselves, the goods in this market are publishing services.

The editorial, reviewing, processing, production and publication workflows do not differ with regard to the way they are paid, i.e., via subscriptions, APCs or other modes of payment. For example, so-called hybrid journals derive their revenue simultaneously from APCs and from subscription fees. Whereas this business practice, to charge both parties, libraries and

authors of one and the same journal, has been criticized as "double-dipping" (Mittermaier 2015), it simultaneously proves that editorial workflows and production service levels must be identical for both business models. Such internal workflows and service levels are usually set by industry standards and the policy of the publisher. Consequently, when calculating the cost of publishing a scholarly article, to arrive at a cost-plus pricing scheme, besides fixed costs, we only have to consider the workflow and associated services, according to current practice.

In this article, we list the various steps and procedures for a representative publishing workflow according to current industry standards. Each step incurs a cost which can be determined by analyzing the market rates for each service or procedure. These costs comprise the direct costs. We also add several indirect (or fixed) cost items which do not accrue on a per article basis. The final per-article costs are then specified as a range depending on the number of articles published and the service level desired.

Methodology

To arrive at a meaningful figure denoting how much the publication of an article does *costs* on average, it is necessary to arrive at the exact cost for each step in the processing workflow of a manuscript being submitted for publication. These direct or variable

costs then have to be combined with the indirect or fixed costs of running a publishing enterprise, such as staff costs, real estate and energy costs, etc. The former requires granular insight and expertise about the different service levels for the entire publishing workflow. The latter is commonly calculated as staff overhead. In this work, we have therefore calculated the cost for each step in the standard publication workflow under consideration of both fixed and variable costs. Both external and internal expenses have been taken into account as well as overhead costs to cover fixed non-direct company costs of the publishing venture.

Direct or variable costs

Expenses and fees for each individual service have been arrived at from two main sources. Some standard services have been taken from openly available price lists (Table 1).

Service Provider	Services	Permalink to fee page
CLOCKSS	Long-term preservation	https://perma.cc/2SQ2-VQUJ
CrossRef	DOI	https://perma.cc/N7BY-AJC3
Scholastica	Peer-review, publishing, type-setting	https://perma.cc/Z3DS-EZUW
Akron Aps	Peer-review management	https://perma.cc/U8J5-JS4E

Table 1: Publishing services and their fees.

Second, we requested quotes from vendors without publicly available fees, or turned to other sources (ECAT 2009).. For services such as manuscript submission and peer review management systems we considered vendors such as Manuscript Central (Clarivate) and Editorial Manager (ARIES).

Other costs such as internal staff costs (including overhead, EU/US standard) were estimated taking into account not only current market costs we have requested ourselves, but also numbers from major publishing houses (MDPI, Wiley, Springer, DeGruyter, Frontiers, Ubiquity, SciELO, Open LIbrary of the Humanities). While some of these publishers have made

their costs public (Table 2), others have either provided their numbers under the condition of confidentiality or the numbers were gained from internal sources.

Publisher	Permalink to cost structure page
Frontiers	https://perma.cc/WKP4-R4D2
Open Library of the Humanities	https://perma.cc/9LEM-CDRL
Ubiquity	https://perma.cc/8U8K-AYZC
eLife	https://perma.cc/23GC-ARVB

Table 2: Published itemized cost structures from publishers/service providers.

For certain tasks, for example copyediting or typesetting, there are hundreds of individual companies worldwide providing those services on a industry-standard level. In our quote requests, we have considered only those with which we have collaborated in real business life so far or from which we know the performance and service level in detail from co-operations over two decades. Having compared the pricing of those service providers with others, we found only a very small variation of cost for such tasks, which justifies our practical approach. It was never our ambition to perform an exhaustive but always incomplete mar-

ket study of service providers worldwide, but an attempt to provide an authoritative documentation of approximate current publishing costs as a valuable information tool for decision-makers and other stakeholders in policy drafting, contract negotiations or public discourse.

There are three main areas in which production steps have to be considered: content acquisition, content preparation (production) and content dissemination/archiving. Importantly, 'content acquisition' does not imply active acquisition of authors and/or manuscripts.

1. Content acquisition
    a. Searching and assigning reviewers
    b. Communication with reviewers
    c. Communication with authors
    d. Handling of re-submission process
    e. Plagiarism check
    f. Online submission system
    g. CrossRef Similarity Check
    h. CrossRef DOI for article
    i. CrossRef DOI for 2 or more reviews
    j. APC collection
2. Content preparation (production)
    a. Manuscript tracking system
    b. Production system check-in
    c. Technical checking of manuscript
    d. Copyediting
    e. Language editing
    f. Typesetting
    g. Formatting figures/graphs/tables
    h. Altmetric badge
    i. XML and metadata preparation
    j. Handling author corrections
3. Content dissemination/archiving
    a. Web OA platform and hosting
    b. CLOCKSS/Portico
    c. OAPEN
    d. Upload to Scopus, PMC, etc.

Pricing figures have been deducted by openly available price lists of vendors, as for example for Scholastica, Akron Aps, CrossRef, CLOCKSS (see Tables 1, 2). In all other cases where pricing list or fees were not openly available on the web, prices were indicated

after a direct request for proposal or communicated privately. For the latter we have checked with other partners to validate that information. Some service vendors have not split their services in a granular manner but offer a full service for more steps of the publishing workflow. In those cases we have tried to split those costs or consider the full cost as part of one of the scenarios (see below) which cover the complete manuscript acquisition and article production process.

Indirect or fixed costs

The calculation of per-article figures from costs that do not accrue on a per-article basis (e.g., salaries, annual fees, etc.) was based on the following assumptions: (i) The average STM article contains 12 printed pages (Johnson et al. 2018). (ii) We estimated an average STM article to contain 10 non-text items such as figures or tables. (iii) We also assumed an average rejection rate of 50% after conventional (pre-publication) peer-review with at least two reports and ten contact requests to secure one reviewer. (iv) We assume a desk-rejection rate of 10% after editorial review. (v) We also base our staff costs on the granular work load per article and not on full-time equivalents (FTE). These assumptions entail that all editorial duties (on average 7.5 person-hours per submitted manuscript) are handled by in-house staff and none by academic editors, while peer-review is still performed by volunteer academics. In this way, staff costs, including

overhead expenses, are calculated on a per-article basis. Salary costs are based on industry standards in more economically developed countries for the different editorial tasks. Overhead expenses can vary significantly depending on the profit and loss structure of the publisher and include rent, repairs, depreciation, interest, insurance, travel expenditures, labor burden, telephone bills, supplies, taxes, accounting fees, etc. We have estimated an average 33% overhead on top of salary costs. The following publication tasks are commonly covered by annual (membership) fees plus an initial, one-time set-up or installment fee: Web OA platform and hosting, CLOCKSS/Portico, OAPEN, Altmetric Badge and Crossref. Because these costs accrue regardless of how many articles are published (i.e., fixed costs), we have calculated per-article costs for journals with different numbers of articles published per year.

While some general fixed costs are covered by salary overheads (see above), we deliberately chose to not include certain fixed costs: Cost of sales have not been considered because for open access journals no longer sales representatives are required which have to negotiate renewals of subscriptions with libraries on an annual basis. We also excluded management costs as these are highly variable and in large publishers with many journals (and hence articles), per article costs of management are often negligible. We realize that this may be different for publishers which publish

low-volume journals but with nevertheless highly paid executives (see Discussion). Because making an article public (i.e., 'publishing') is distinct from locking it behind a paywall, we have also not calculated the often very significant paywall costs. While innovation (or acquisition of innovative technologies) as well as branding and advertising/marketing are crucial for a company to succeed and thrive in a market in the long term, we have also not included these costs as they are not directly related to publishing scholarly articles. Such costs would include conference attendance, advertisement in print, online, social media and search platforms, as well as search engine optimization (SEO). Similarly, government relations (lobbying) may be considered a necessary expense for any business, but as it does not directly relate to the process of publishing academic papers, we did not include these costs in our calculations either. However, we do discuss the probable extent to which these non-publication costs may affect pricing.

Scenarios

The motivation for the above assumptions was to combine a robust cost estimate (i.e., sourced from measurable time efforts and industry salaries) with an upper bound cost estimate which would come to lie above most academic-run journals. We also calculated a cost estimate for articles handled exclusively by volunteer academics. Prices for journals where volunteer

and compensated editors cooperate, will hence fall between these two extremes.

With a modern, decentralized/federated platform providing publishing functionalities without journals, some of these steps become obsolete, while others remain relevant. Steps that may become obsolete include DOIs, long-term archiving such as CLOCKSS or Portico, indices such as Scopus. Relevant steps remaining are typesetting/copyediting, XML preparation, format conversion, plagiarism checks.

Scenario A	Scholastica including ms submission, standard peer-review, tracking system, OA webpage, hosting
Scenario A2	Scenario A, but PPPR
Scenario B	Generic service providers, ms submission, standard peer-review tracking system; OA webpage, hosting
Scenario B2	Scenario B, but PPPR
Scenario C	Generic service providers for content preparation with online platform; without external submission, reviewing, and tracking system; with DOI; no external hosting/archiving; volunteer editors
Scenario C2	Scenario C, but Scholastica

Table 3: Publishing scenarios for which detailed cost calculations have been performed.

We have grouped the various combinations of tasks and publication options into six broad scenarios, for which we have calculated all associated publication costs (Table 3). These scenarios correspond either to existing publishing options or to options that have been discussed in the literature. For each of the six scenarios, we have also calculated the same costs, but assuming a 90% rejection rate (see raw data file).

All the data we have based our calculations on are available at Figshare (DOI: 10.6084/m9.figshare.8118197).

Results

One of the first findings of our calculations is that in order to employ at least one 50% FTE of an in-house editor, a journal has to publish approx. 100 articles per year or more. Hence, in the following, we will base our estimates on journals publishing at least 100 articles per year (corresponding to 50% FTE) or 1,000 articles (corresponding to 5 FTEs), to show the spread of fixed and indirect costs over the number of articles published.

Our estimate of per-article publishing costs in a conventional pre-publication peer-review (50% rejection rate) scenario where all editorial duties are performed by in-house staff (Scenario B) ranges from US$643.61 for a journal that publishes 100 articles per

year down to US$565.15 for such a journal that publishes 1,000 articles (or more, as the indirect costs become increasingly negligible around this value). These values consist of US$266.53 direct publishing costs (i.e., CrossRef Similarity Check, CrossRef DOI for an article, CrossRef DOI for two or more reviews, copyediting, typesetting, formatting figures/graphs/tables, altmetric badge, upload to Scopus and XML and metadata preparation), US$ 289.91 for editorial staff and US$8.72 to US$87.18 for 1,000 to 100 articles, respectively, in indirect costs (i.e., Web OA platform and hosting, CLOCKSS, OAPEN, Altmetric Badge and Crossref).

These numbers were calculated using generic, full-service providers based in India, where applicable. There are open access service providers that provide packaged deals for the same services as these generic service providers. We have calculated the same steps using a well-known provider in this area, Scholastica (Scenario A). Interestingly, these figures are slightly higher: US$ 374.08 for direct publishing costs and US$5.92 to US$59.18 for 1,000 to 100 articles, respectively, for indirect costs (editorial staff costs remain the same).

While these costs have been calculated for a generic journal with 50% rejection rate, per-article costs will increase with increased rejection rates and de-

crease with less rejections as in, e.g., a post-publication peer-review (PPPR) model. In a journal that uses generic service providers and publishes all submitted manuscripts as PDF preprints with a DOI before performing otherwise identical peer-review as described above (i.e., PPPR with in-house editors and volunteer reviewers), per article editorial services drop from US$289.91 to US$140.69 (Scenario A2/B2), with all other costs remaining nearly identical. Conversely, prestigious journals with rejection rates of around 90% see their costs rise to US$1053.87 for 100 articles per year or US$770.53 for the larger journals with about 1,000 articles per year (generic service providers).

These numbers also show that for a conventional journal today, where academics perform their editorial duties on a volunteer basis (i.e., Scenario B, but no editorial costs as editor salaries are paid for by their academic institutions), direct publication costs come to lie at US$266.53 with generic service providers and total costs depend on the scale at which the journal operates. Small journals with 100 articles would face average per article total publication costs of US$353.71, while journals with 1,000 or more articles would only face costs of US$275.25 or less per published article. Even at the highest convenience for a small, volunteer-run journal, costs come to lie at US$454.63 where a full-service provider (Scholastica)

handles all of the technical aspects of the work (Scenario C2).

The above calculations (summarized in Table 4) demonstrate economies of scale. The more articles are being published, the lower the costs for each article, approaching the fixed costs for each article.

scenario	total	direct	indi-rect	in-house staff
Conventional peer review, Scholastica, 100 articles (A)	723.16	374.08	59.18	289.91
Conventional peer review, Scholastica, 1,000 articles (A)	669.90	374.08	5.92	289.91
Conventional peer review, generic providers, 100 articles (B)	643.61	266.53	87.18	289.91
PPPR, Scholastica, 100 articles (A2)	597.74	369.88	87.18	140.69
Conventional peer review, generic providers, 1,000 articles (B)	565.15	266.53	8.72	289.91
PPPR, Scholastica, 1,000 articles (A2)	519.28	389.88	8.72	140.63
PPPR, generic providers, 100 articles (B2)	469.32	241.45	87.18	140.69
Volunteer editors, Scholastica, 100 articles (C2)	454.63	358.33	47.18	49.12
Volunteer editors, Scholastica, 1,000 articles (C2)	412.16	358.33	4.72	49.12
PPPR, generic providers, 1,000 articles (B2)	390.86	241.45	8.72	140.63
Volunteer editors, generic providers, 100 articles (C)	237.35	141.05	47.18	49.12
Volunteer editors, generic providers, 1,000 articles (C)	194.89	141.05	4.72	49.12

458 **Table 4**: Different scenarios of journal organization, ordered by total per article costs (in
459 US$). The scenarios are labeled with A, A2, B, B2, C, C2 (see table 3).

460

461 Because of the economies of scale and recent
462 calls for the replacement of journals with a modern
463 publishing platform (Brembs 2019; Stern & O'Shea

2019; Grossmann 2015; Nosek & Bar-Anan 2012; Hartgerink 2019), we have also calculated the cost of publishing the annual output of the STM community, approx. 3 million articles, on such a platform that facilitates PPPR organized by academic editors on a single, decentralized, federated platform running modern software solutions. Such a platform would dispose of several production steps which are necessitated by the current balkanization of the literature in different journals published by different publishers, but keep others (see Methodology). In this scenario, the indirect and fixed costs per article approach zero due to the high number of published articles (but see Discussion), such that the only remaining costs would be the direct publishing costs of US$190.17 per published article.

Finally, taking a ballpark cost figure of US$600 for a scholarly article with full editorial services (i.e., scenario A/B) and comparing it to the low end of the average price estimate for a subscription article of about US$4,000, it becomes clear that publication costs only cover 15% of the subscription price (Fig. 1). Assuming a conservative profit margin of 30% (i.e., US$1,200 per article) for one of the large publishers (McGuigan & Russel 2008; Larivière et al. 2015; Beverungen et al. 2012; Harvie et al. 2012), there remains a sizeable gap of about US$2,200 in non-publication costs, or 55% of the price of a scholarly subscription article (Fig. 1).

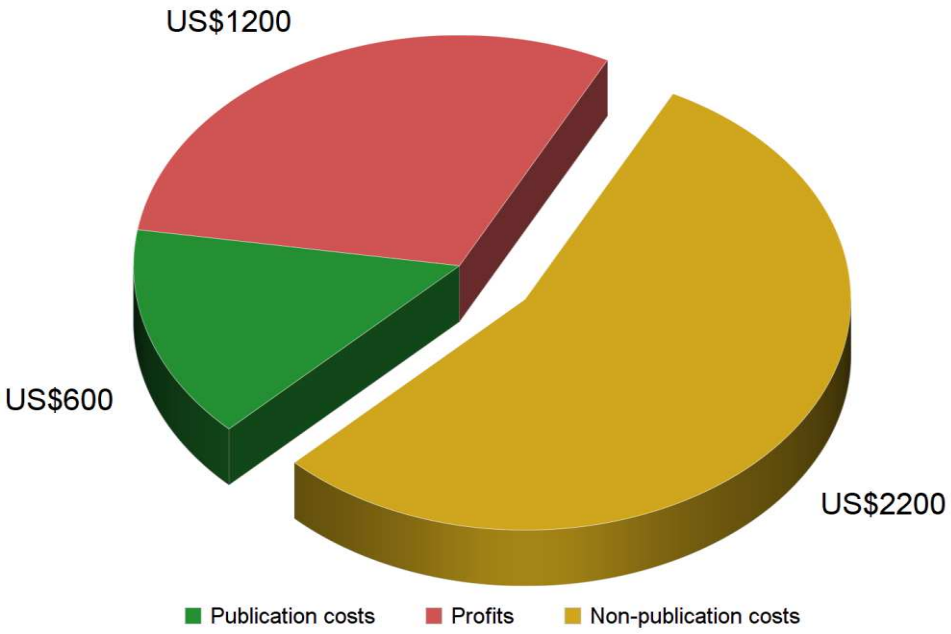

Fig. 1: *Subscription price and cost items*. Assuming the commonly accepted US$4,000 price tag for a subscription article, published profit margins of 30% and our calculation of US$600 in publication costs for a full-service subscription article (scenario A/B, see Table 4), there remain US$2,200 in non-publication costs per article.

Discussion

Since the 1990s, it has been recognized that the prices of scholarly journals were escalating at unsustainable rates (Douglas 1990). In the last 30 years, this "serials crisis" has never been coherently addressed, let alone solved. With this work, we aim to provide more financial evidence for future evidence-based policies addressing the affordability problem of scholarly communication (Chan 2004; Harnad et al. 2004).

Subscription prices and publication costs

Not only current discussions are addressing the affordability problem in the unit of cost per article (Van Noorden 2013; Schimmer et al. 2015; Odlyzko 2013; Johnson et al. 2018; Odlyzko 1995; Jahn & Tullney 2016; Solomon & Björk 2016; Morrison 2018a) and we follow this precedent. Drawing from publicly available price lists and industry-standard service costs, we find that publishing costs per article vary from US$194.89 to US$723.16, depending on the level of service and publishing volume (Table 4). It is important to note that these are conservative estimates, likely to constitute upper bounds, where innovation and changes in practice can be expected to decrease costs.

Perhaps not surprisingly, the convenience of outsourcing the main publishing services to a specialized full-service provider comes with a small increase in cost (scenario A vs. scenario B), when compared to an itemized sourcing of publishing services. In our cost estimate, we have not factored in the management cost of sourcing the itemized services, as we have not included company management in our calculations. Any decision between these two options will thus have to be made after factoring in such costs as well.

Even in the rare, most expensive case, these costs compare very favorably to the current subscription pricing of around US$4,000-5,000. Our highest value encompasses conventional, journal-based pre-

publication peer-review with a generic 50% rejection rate at a small journal (~100 articles per year) where all management of peer-review is performed by in-house editorial staff with no volunteer academic editors. Our data suggest that increasing only the rejection rate, for example from 50% to 90%, leads to an increase in publication costs of around 30-40% (e.g., in scenario B from US$565.15 to US$770.53 for 1,000 article journals or from US$643.61 to US$1,053.87 for 100 article journals). Apparently, this is a consequence of the respective increase of direct personnel expenses for managing the peer review process and communicating with both reviewers and authors for classical pre-publication peer review. As currently most highly selective journals publish on the order of 800-900 research articles per year about US$1,000 per article can be seen as an upper bound of total publication costs at such journals.

Article processing charges and publication costs

The reported average APCs charged by the minority of journals with such fees vary between US$1,400-2,200 depending on the sample (see above and, e.g., Table 2). The large difference between these values and even our most expensive cost estimate is at least partly consistent with our hypothesis that the quasi-monopolistic situation of the publishers, due to the non-substitutability of their goods and services, allows them to adopt a value-based pricing strategy also in the APC-OA case, similar to subscription pricing. It is

therefore straightforward to hypothesize that any policy that fails to address the non-substitutability problem in scholarly communication will also fail to solve the affordability problem and lead to a similar market-failure as in the subscription model. An analogous argument has previously also been endorsed by the European Commission Directorate-General for competition (Tennant & Brembs 2018), even before our calculations were available. Further reducing the odds of APC-OA solving the affordability problem is the fact that authors are not only price-insensitive (Khoo 2019), but seem to prefer publishing in journals that charge APCs as opposed to those that do not, as evinced by the fact that most OA articles are published in the minority of journals that charge APCs (Crawford 2019). Above and beyond authors' preference for journals with APCs over those without, among those APC journals, authors are incentivized to publish in high-APC, rather than low-APC journals, because APCs increase with the prestige of the journal (Tennant & Lomax 2019; Andrew 2012). Consequently, a recent study observed APC increases of 2.5-6 times inflation over six years in their sample (Khoo 2019). This converging evidence all points towards both APC-OA and subscriptions to suffer from analogous flaws which lead to hyperinflation and market-failure in both cases. Our data now add further evidence in support of this hypothesis.

Aiming for a cost-plus market

Starting from current subscription pricing of around US$4,000-5,000 per article (Van Noorden 2013; Schimmer et al. 2015; Odlyzko 2013; Johnson et al. 2018; Odlyzko 1995), we confirm previous estimates that current subscription moneys are sufficient to pay for a complete transition to OA, even at current inflated APCs on the order of about US$2,000 per article (Schimmer et al. 2015; Odlyzko 2013; Johnson et al. 2018; Jahn & Tullney 2016; Solomon & Björk 2016; Morrison 2018a). Calculated globally, this hypothetical transition to APC-OA would cut the US$10 billion world-wide annual subscription budget roughly in half, at least in the short term. At the same time, if there were a way to enforce cost-plus pricing strategies in publishers, even the current prices would at least be 100% above actual publishing costs at the highest level of service and even more for a lower level of service and higher article volume, which is the norm at many journals. Thus, the mere transition to a market where the current value-based pricing strategies are not deployed any more, all else being equal, stands to save the global taxpayer at least 75% of the current subscription budget, or the equivalent of about US$7.5 billion annually. However, the current journal system does not provide for such a solution as journals are non-substitutable (see above).

Replacing journals with a modern, server-based, decentralized solution (Brembs 2019; Stern &

O'Shea 2019; Grossmann 2015; Hartgerink 2019) implements substitutability of services and, hence, competition, providing for the largest savings: even when the volume of articles amounts to 3 million per year (Johnson et al. 2018), the global taxpayer stands to save about 95% of the current subscription budget, or the equivalent of approx. US$9.5 billion annually, on publishing prices.

Cost-plus pricing technically feasible today

There are more conclusions to be drawn from the evidence we provide here. For one, while the current APC-OA prices would, if applied universally, address the affordability problem and substantially lower the cost to the taxpayer in the short term, the available evidence suggests that the current value-based pricing strategy of publishers (together with the price-insensitivity of authors (Khoo 2019)) is likely to quickly eat into these gains and again lead to unsustainable inflation, as in the subscription case.

Second, because the workflow we model consists of verifiable, modular components, we demonstrate that a cost-plus pricing scheme is possible today. Phrased differently, customers of commercial publishers can use these numbers as tools in contract negotiations to demand more cost-oriented contracts. However, at the same time, as long as the ultimate leverage in such negotiations, namely to walk away and

opt for the goods and services of a competitor, remains inaccessible due to the non-substitutability problem, the effectiveness of this tool will remain comparatively limited.

Third, our calculations show that with publishing volumes exceeding 1,000 articles per year, fixed costs shrink below 1% of the direct article costs and become negligible. This was expected and already concluded in a previous analysis (Bogich & Ballesteros 2016). These insights are important for designing a transition towards a scholarly publishing platform instead of journals.

Fourth, due to the limited possibility in dividing labor contracts into arbitrarily small portions, we find that journals with volumes below approx. 100 articles per year would be best served financially if they operated on the concept of volunteer academic editors handling the peer-review, instead of in-house staff.

Targeting the non-substitutability problem

Synthesizing all of these conclusions, it becomes clear that any solution to the affordability problem must aim at eliminating non-substitutability and strive towards large volume strategies. Historically, non-substitutability has been solved with, e.g., industry standards that allow substitution of products and services. For instance, multimedia standards allow for media from any producer to be played on any player.

In the case of scholarly communication, the non-substitutability is granted via prevention of duplicate publications of discoveries in different journals together with prestige stratification of the journals. Both of these factors are conveyed by the journals where the individual articles are published. Consequently, one straightforward approach to mitigate this non-substitutability is to eliminate journals as venues and implement technical standards to allow publication services to become substitutable.

One technical implementation of this principle is to collect all articles in a single, decentralized, federated venue that is governed by the scholarly community and designed using common, evolvable standards to allow for the substitution (and, consequently, competition) of service providers (Brembs 2019; Stern & O'Shea 2019; Grossmann 2015; Hartgerink 2019). This concept mimics other infrastructure arrangements such as water, electricity, HVAC, email, etc. This approach would, at the same time, solve the problem of large publication volume: the STM field is on course to publish about 3 million articles every year (Johnson et al. 2018), allowing fixed costs to effectively converging towards zero in the per-article currency (Bogich & Ballesteros 2016). However, even if the per-article costs of such infrastructure are negligible, they remain a substantial item in absolute terms that scholarly institutions need to pay. In a recent tender, the European Commission provided an indicative estimate for the

cost of "development of the platform, its services and business processes, communication and sustainability" (European Commission 2017), of around 250,000€ per year. Perhaps an order of magnitude higher costs may be estimated to implement and run a system that is scaled for the world-wide scholarly output, arriving at approx. US$3 million per year. Given that there are about 10,000 universities world-wide (Förster 2019) (plus a large number of non-university research institutions) which would stand to participate, these costs to establish and maintain such an infrastructure would likely amount to approx. US$300 per institution per year. Even if only the 3,300 European Union universities (European Commission 2003) were to implement and run the platform by themselves with other institutions only contributing article costs, these indirect costs would amount to less than US$1,000 per year and institution. These numbers demonstrate that even under conservative estimates, the fixed costs of a publishing platform remain within feasible bounds. While these numbers demonstrate not only the immediate feasibility of the transition towards such a platform, but, indeed, the fiscal imperative for it, it is far from clear how the transition should be accomplished practically. Because it is beyond the scope of this article to provide such policy recommendations, we refer to those already provided elsewhere (see, e.g., Brembs 2019; Stern & O'Shea 2019).

Such a solution would preserve the rules aimed at preventing duplicate publication, but eliminate journal hierarchy as a signal for prestige. Given that, at least in the experimental sciences, journal prestige is associated with lower reliability (Brembs et al. 2013; Brembs 2018), it may be argued that eliminating journal prestige ought to be a goal in and of itself, in order to tackle any decline in reproducibility (e.g., Karp 2018; Baker 2016; Schooler 2014; Berg 2018; Sayre & Riegelman 2018; Saltelli & Funtowicz 2017; Lilienfeld 2017; Everett & Earp 2015; Brembs 2019).

Non-publication costs

If the lowest publication costs for journals with volunteer editors constituted merely 5-10% of current subscription prices and publicly reported publisher profits only amount to an additional 30-40%, which non-publication costs are publishers currently facing and taxpayers paying for? While these costs are opaque and variable between publishers and, indeed, between journals, some estimates can be made from publicly available data. If one assumes revenue of about US$4,000 per subscription article (i.e., on the low end of the converging estimates), a conservative 30% profit margin (i.e., US$1,200 per article) for one of the large publishers (McGuigan & Russel 2008; Larivière et al. 2015; Beverungen et al. 2012; Harvie et al. 2012) and generous publication costs of US$600 per article (scenario A/B; table 4), then there remains a sizeable gap of about US$2,200 in non-publication

costs per article - more than the sum of publication costs and profits combined, or 55% of the subscription cost of a scholarly article (Fig. 1). While some of these costs may be considered necessary for any business, none of them are associated with publishing primary research articles (see Methods).

Running a business: Management

While our cost calculations include generic running costs such as rent, repairs, depreciation, interest, insurance, travel expenditures, labor burden, telephone bills, supplies, taxes, accounting fees, etc., we have explicitly omitted some indirect costs such as management cost and paywalls. For instance, according to their 2016 tax statement, the New England Journal of Medicine spends 4% of its publication revenue on their top ten management staff alone (which would translate to about US$160 per article if applied to our example above; Fig. 1).

Preventing access: Paywalls

Subscription journals also face costs associated with paywalls. It's difficult to estimate the cost of such technology for publishers, but the cost of a new paywall for the New York Times was reported to lie between US$25-50 million (Pulley 2011; Kramer 2011). Alternatively, as the functional distinction between subscription articles and OA articles is precisely the missing paywall in OA articles, one could also assume that publishers arrive at their current APC pricing of

around US$2,000 by subtracting paywall costs from their subscription price. This assumption would entail paywall costs of approx. US$2,000 per article (i.e., the difference between APC and subscription pricing).

On top of the technical cost of a paywall, one may also consider the legal fees for defending paywalls for this cost item. Publishers have a track record of litigation with regard to articles outside of their paywalls and regularly seek damages in court for actual or perceived threats to their subscription business model (Hansen 2019; Chawla 2017; Van Noorden 2017; Association Of American Publishers 2015; Cox 2018; Flaherty 2013; Schiermeier 2017). These costs accrue by seeking to enclose the scholarly literature within the paywalls of publisher via alternative routes in addition to the digital paywalls.

News, advertising, sales, marketing, public relations: branding

Another cost item is publishing non-research content. For instance, for 2016, PubMed lists a total of 1,632 articles published by the New England Journal of Medicine, while Clarivate Analytics only counts 328 articles for their Impact Factor. Assuming that only the latter articles amount to primary research publications, this journal's revenue also pays for 1,304 non-research articles. Similar numbers also hold for other prestigious journals (e.g.: Nature: 880/2765, Science: 805/1938; research/total), often with their own journalist and editorial staff commissioning articles and/or

reporting themselves on research and policy news. However, the number of journals where this can constitute a significant fraction of their total costs is presumably small, likely restricted to the most prestigious journals.

Prestigious journals also often practice active author or materials acquisition, by traveling to conferences and laboratories, building networks in a strategy to entice the next exciting research finding to be published in their journals. Active author acquisition accrues costs both in terms of travel and time spent networking and communicating with authors that is not covered in our cost estimates (see Methods).

Sometimes, new journals also need to engage in such author acquisition practices, which, perhaps, can be best subsumed under general marketing or public relations costs required for building and maintaining a brand. These marketing costs also include, e.g., advertising in various venues targeting both authors and subscribers. For many publishers it is also common to promote their brand at conferences and institutions with, e.g., hosted speakers, travel grants or sponsored awards.

Because of the complex, time-consuming negotiations with libraries on ever tighter budgets due to the hyperinflationary subscription price increases, publishers also need to employ expert sales teams. The task of these sales teams is not only to find the

most irresistible way to package and bundle subscription journals and/or databases, but also to device the most inexorable psychological strategy for their negotiations with librarians. These sales teams need to operate in close connections with the various advertising, marketing and public relations teams of the publisher to accomplish a coherent brand image. One may argue that in times of OA, these sales costs are not necessary expenses any more and more associated with paywall costs than with publication costs. On the other hand, in an OA world, one may argue that branding was never more important for author acquisition.

New technologies: innovation and acquisitions

Publishers also need to invest in innovation, in order to stay current with their technologies and functionalities. While scholarly publishers have been quick to transition from print to web-based technologies in the past, the digital functionalities of most of the scholarly literature today lag at least a decade behind current functionalities of other digital objects outside of the scholarly literature. The level of investment in innovation thus remains unclear and its effects questionable. Instead of investments into their own technological innovation, publishers today appear to acquire companies that have invented desired functionalities around the scholarly workflow, with the goal to provide services beyond publications (Bosman & Kramer 2018; Crunchbase 2019; Posada & Chen 2018; Campfens 2019).

Government relations: Lobbying

Most international publishers, as any other corporation, also spend significant amounts of money on government relations (i.e., lobbying). Some of these corporations employ staff at the vice president level not only in the most important research nations, but also at the level of supra-national bodies such as the European Commission (Jonathan Tennant 2018). These staff, in turn, employ assistants and other members of their teams. Obviously, the task of these employees is to protect current revenue streams, e.g., subscription or APC income. For instance, one publisher, Elsevier, spends more than 400,000€ per year on lobbying at the level of the European Commission alone (Anon 2018). The consequences of such efforts have been observable, e.g., in the so-called "Finch Report" in the UK (Finch 2012), which surprised many commentators with its publisher-friendly recommendations (see, e.g., Prior 2013; Jonathan Tennant 2018).

Lack of competition: Inefficiencies

Finally, with profit margins exceeding 30% in many cases, there may be less pressure to optimize the workflow to cut down further on already marginal publication costs (on the order of 15% of total costs in the example above, Fig. 1). It is thus conceivable that large publishers, where the economies of scale already have decreased costs, are operating at such low efficiencies that their publication costs may come to lie higher than we calculated.

Which non-publication costs should remain bundled up with publishing?

Regardless of all of these estimates necessarily remaining vague and imprecise, the fact remains that the scholarly community must eventually make a number of decisions, if it is to tackle the affordability problem. Which of the above non-publication costs such as lobbying, start-up acquisition, executive salaries in the millions of US$, non-research article publishing, marketing/advertising, sales/negotiations, inefficiencies etc., should remain bundled up with the process of publishing scholarly research articles? Which of these costs are avoidable, which necessary and which even desirable? Are profit margins of 30-40% on taxpayer funds tolerable?

In fact, one may even ask whether many of the services we list as part of the scholarly publishing standard are actually necessary for scholarly publishing. After all, journals such as the Journal of Machine Learning Research, Discrete Analysis or the Journal of Open Source Software publish their articles with internal costs below US$10 (Jon Tennant 2018). Likewise, the preprint archive arXiv publishes their articles at similar costs (Cornell University Library 2010).

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