RESEARCH ARTICLE

Discipline-specific open access publishing practices and barriers to change: an evidence-based review [version 1; referees: awaiting peer review]

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v1 **First published:** 11 Dec 2018, **7**:1925 (https://doi.org/10.12688/f1000research.17328.1)
Latest published: 11 Dec 2018, **7**:1925 (https://doi.org/10.12688/f1000research.17328.1)

Abstract

Background: Many of the discussions surrounding Open Access (OA) revolve around how it affects publishing practices across different academic disciplines. It was a long-held view that it would be only a matter of time for all disciplines to fully and relatively homogeneously implement OA. Recent large-scale bibliometric studies show however that the uptake of OA differs substantially across disciplines. This study investigates the underlying mechanisms that cause disciplines to vary in their OA publishing practices. We aimed to answer two questions: First, how do different disciplines adopt and shape OA publishing practices? Second, what discipline-specific barriers to and potentials for OA can be identified?

Methods: In a first step, we identified and synthesized relevant bibliometric studies that assessed OA prevalence and publishing patterns across disciplines. In a second step, and adopting a social shaping of technology perspective, we studied evidence on the socio-technical forces that shape OA publishing practices. We examined a variety of data sources, including, but not limited to, publisher policies and guidelines, OA mandates and policies and author surveys.

Results: Over the last three decades, scholarly publishing has experienced a shift from “closed” access to OA as the proportion of scholarly literature that is openly accessible has increased continuously. The shift towards OA is however uneven across disciplines in two respects: first, the growth of OA has been uneven across disciplines, which manifests itself in varying OA prevalence levels. Second, disciplines use different OA publishing channels to make research outputs OA.

Conclusions: We conclude that historically grown publishing practices differ in terms of their compatibility with OA, which is the reason why OA can be assumed to be a natural continuation of publishing cultures in some disciplines, whereas in other disciplines, the implementation of OA faces major barriers and would require a change of research culture.

Open Peer Review

Referee Status: *AWAITING PEER REVIEW*

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Keywords
Open Access, Open Science, Publishing, Scholarly Communication, Science Policy, Communication Technologies, Scientometrics, Meta-Synthesis

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Author roles: Severin A: Conceptualization, Data Curation, Formal Analysis, Methodology, Project Administration, Writing – Original Draft Preparation, Writing – Review & Editing; **Egger M**: Supervision, Writing – Original Draft Preparation, Writing – Review & Editing; **Eve MP**: Writing – Original Draft Preparation, Writing – Review & Editing; **Hürlimann D**: Supervision, Writing – Original Draft Preparation, Writing – Review & Editing

Competing interests: AS works for the Swiss National Science Foundation (SNSF). ME is president of the National Research Council of the SNSF. MPE is co-founder, CEO and finance director of Open Library of Humanities. DH is founder and editor of the OA law journal sui-generis.ch.

Grant information: The author(s) declared that no grants were involved in supporting this work.

How to cite this article: Severin A, Egger M, Eve MP and Hürlimann D. **Discipline-specific open access publishing practices and barriers to change: an evidence-based review [version 1; referees: awaiting peer review]** *F1000Research* 2018, **7**:1925 (https://doi.org/10.12688/f1000research.17328.1)

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Introduction

As a response to perceived limitations of the subscription-based model of scholarly publishing and propelled by technical possibilities provided by the internet, Open Access (OA) presents a new model of academic publishing[1]. OA takes different forms but generally offers free and unrestricted access to the outputs of academic research with relaxed constraints on reuse, as opposed to publications being "locked away" behind subscription paywalls[2]. Having gained global relevance, the potential implications of OA for academic publishing continue to generate debate in the academic community. Many of these discussions revolve around the question of how OA affects publishing practices in different academic disciplines[3].

The foundation for OA was laid in high-energy physics when Paul Ginsparg established the arXiv open repository for preprints[4]. OA soon appeared to constitute an "inescapable imperative"[5] for several reasons: first, OA gained early momentum based on a combination of grass-root advocacy initiatives promoting the unrestricted access to publications on the one hand and funding organisations, universities and national governments implementing OA mandates and policies that require scholars to make their outputs publicly accessible on the other hand[6]. Second, OA has the potential to enhance scholarly communication by speeding up the dissemination of research outputs, by expanding readership and by increasing the impact of research outputs[7]. From an information-processing perspective, scholars across all fields should see these benefits and use OA communication channels uniformly[5]. These trends suggested that it would only be a matter of time for all academic disciplines and fields to fully adopt OA and to converge on a stable set of relatively homogeneous OA publishing practices[8]. In contrast to these expectations, recent bibliometric studies show that academic disciplines vary considerably in terms of their OA publishing practices[9,10].

Bibliometric studies investigating disciplinary OA publishing practices are in large part descriptive and, as such, do not analyse the mechanisms that shape discipline-specific OA publishing practices. This limitation becomes relevant as vast amounts of resources and efforts are committed to the development, maintenance and advancement of OA communication channels. In the absence of a valid theory of how academic disciplines adopt OA, resources may be dedicated to ventures that are not sustainable. We aim to address this by answering the following questions: (1) How do different academic disciplines adopt and shape OA publishing practices? (2) What discipline-specific barriers to and potentials for OA publishing can be identified? In order to answer these questions, we first synthesise relevant bibliometric studies that were aimed at assessing the prevalence and patterns of OA publishing practices across academic disciplines. Adopting a social shaping of technology perspective, we then develop an analytical framework that consists of socio-cultural and technological factors that generally shape publishing practices. We apply this analytical framework to the case of OA publishing and examine evidence on the forces that represent barriers to and potentials for OA, causing OA publishing practices to differ across disciplines. Doing so, we examine and aggregate evidence from a variety of primary data sources including, but not limited to, OA mandates and policies, infrastructures of scholarly communication technologies and author surveys.

Methods

Prevalence and patterns of open access publishing practices: Meta-synthesis of bibliometric studies

The objective of our review is to identify and synthesize large-scale bibliometric studies on the prevalence and patterns of OA publishing across academic disciplines. Such studies usually analyse similar samples of academic publications, including data from Web of Science (WoS), Google Scholar (GS) and Scopus, but employ different methods for identifying disciplinary publishing practices within these databases. This relates to definitions of OA, included OA routes, covered publication years and employed search strategies for OA full texts. For this reason, we conducted a meta-synthesis. The aim of a meta-synthesis is to qualitatively integrate, compare and analyse methodologically heterogeneous studies, thereby allowing the emergence of interpretive themes[11]. In this study, we synthesised the results from bibliometric studies to identify patterns of OA publishing practices across academic disciplines. The search was pre-planned and comprehensively, as it aimed to seek all available studies. No date limits were employed. The searches were conducted in August to October 2018. Bibliometric studies were searched in a systematic way. This involved, first, the querying of the online data bases ScienceOpen, Scopus, WoS and GS. The search was conducted using the following search string: "Discipline" AND "Publish*" AND "Open access" OR "OA". The selection of the search terms was based on the topic literature on scholarly communication. Second, reference lists and bibliographies of all included studies were evaluated manually for additional publications. Having identified key experts within the field, their GS profiles were also searched for material. In an initial screening stage, two independent reviewers screened titles and abstracts of studies and decided on whether to include respective studies in the review. Studies were excluded that did not meet our selection criteria, as outlined in Table 1. This procedure resulted in a total of 11 studies. In a second screening stage, we assessed the full text of the included studies. In order to gain the data of interest to our review, we analysed the "Results" sections of primary studies and extracted data on reported proportions of publications that were OA, including both the overall OA proportions and the relative uptake on OA routes.

Mechanisms and factors shaping open access publishing practices: Narrative review of sociotechnological forces

Our goal in this section is to explain the patterns of OA publishing practices that we observed in the previous section. To do this, we performed a narrative review of the mechanisms and factors that shape OA publishing practices in different academic disciplines. Thereby, we aim to identify discipline-specific barriers and potentials for OA. We recruited an interdisciplinary team of researchers covering the broad academic disciplines natural and technical sciences, medicine and health-related sciences, social sciences and law, arts and the humanities. Each co-author of our team examined evidence on factors that shape OA publishing practices within their own areas of research training. In doing so, we did not perform a systematic review of the literature. Instead, we developed an analytical framework of socio-cultural and technical factors that generally shape publishing practices. Each co-author used this framework as a tool for identifying the socio-technical mechanisms and factors that shape OA publishing practices within their own discipline. The

Table 1. Selection criteria literature search.

Criterion	Description
OA publishing practices	The study examines the overall prevalence of OA and the uptake of OA routes rather than only assessing the overall free availability of scholarly outputs.
Academic disciplines	The study examines OA publishing practices across broad academic disciplines, including the medical and life sciences, natural sciences, social sciences and law and humanities.
International scope	The study assesses OA publishing practices across countries. The scope is not limited to a national setting.
English language	The study is written in English.

evidence included in this review was identified and selected through queries of online databases, including ScienceOpen, Scopus, WoS and GS. Reference lists and bibliographies of relevant studies were evaluated manually for additional evidence. Having identified key experts within the field, their GS profiles were also searched for material. Each co-author contributed original content on OA in their discipline and participated in the reviewing and editing process.

Results

Prevalence and patterns of open access publishing practices: Meta-synthesis of bibliometric studies

The characteristics of the studies included in our review are presented in Table 2. In general, studies were concerned with the questions of (1) how much of the scholarly literature in a academic discipline is openly accessible, and (2) via which OA route scholarly outputs are made openly accessible. Earlier studies analysed random samples of academic publications from bibliometric databases, such as Scopus or WoS, whereas more recent studies examined these databases in full. Making use of automated web search strategies, studies assessed whether openly accessible versions of sampled scholarly publications could be found on the web, for example through GS. On this basis, studies determined OA levels and the relative uptake on different OA routes across disciplines. Earlier studies distinguished between Green OA, which refers to articles published in subscription-based journals, but for which either the accepted or the published version can be retrieved from an open repository, and Gold OA, which describes articles published in OA journals, that is, journals in which all articles are openly accessible. More recent studies also include Hybrid OA, which refers to articles free under an open license in a subscription journal, and Bronze OA, which describes articles free to read on the publisher page without an open license[12] [1].

Table 3 shows the main findings of the studies included in our meta-synthesis. Looking at the overall prevalence of OA for all disciplines, we see that the system of academic publishing has experienced a shift from "closed" access to OA: OA levels have increased steadily across all disciplines, from 20.4% of all scholarly outputs reported as OA in 2008[15], to 23% in 2010[9] and more than half of all scholarly outputs being OA in publication years later than 2010: 53.7% for publication years 2011 until 2013[16], 54.6% on average in years 2009 and 2014[17], 66& for publication years between 2009 and 2017[18] and 55% in 2014[19]. Two studies determined the prevalence of OA to be less than 50% for publication years later than 2010: Piwowar *et al*. determined that on average 36.1% of the scholarly literature was made OA in the time period between 2009 and 2015 and Bosman and Kramer found this share to be 29.4% for 2016[12,20]. Looking at how different disciplines implemented OA over time, we can distinguish between three phases. Dated between the early 1990s and the mid to late 2000s, the first phase can be characterised as a phase of formation: A few fields related to the natural and technical sciences took on a pioneering role in implementing OA, amongst these particularly mathematics (reported OA levels of 25.6% and 42% in 2008 and 2010, respectively[1,9]) and physics and and space-related research fields (OA levels of 32.9% for earth sciences and 23.5% for physics & astronomy in 2008, and 37% for earth & space and 27% for physics in 2010[1,9]). An exception to this are the fields engineering and chemistry, which feature OA prevalence rates that consistently are lower than all natural and technical sciences and lower than most other disciplines, including the social sciences and the humanities[1,9]. The social sciences were also fast in embracing OA, featuring OA prevalence levels only slightly below those reported for the natural and technical sciences (16% OA in sociology in the time from 1992 to 2003, followed by economics with 13.5% OA and business with 9% OA[21]; 23.5% OA and 37% OA observed in the social sciences for publication years 2008 and 2010, respectively[1,9]). Medicine and health-related research fields were substantially slower in implementing OA than most natural and social sciences (OA levels of 6.2% in medicine between 1992 and 2003[21]; 21.7% for medicine and 15.2% for other areas related to medicine in 2008[1]; 17%, 14% and 12% OA reported for health, clinical medicine and biomedical research in 2010, respectively[9]). As such, medicine and health-related fields implemented OA to an even smaller degree than the humanities have in the early years of OA (19% OA reported for humanities in 2010[9]). The second phase of OA is dated between the mid 2000s and the mid 2010s and can be characterized as a period of transformation. In medicine and health-related research fields, OA uptake increased substantially, causing OA levels in these fields to equal

[1] It has been discussed controversially whether or not this type of publication is is in fact OA. A case has been made that such publications are not (Bronze) OA, but "free-to-read" only[13], whereas others argue that Bronze OA is a sub-category of OA as OA is not a binary category, but encompasses a range of components that determine the degree of openness of a certain publication outlet[14]. Following the latter argument, we use the term Bronze OA throughout this publication and acknowledge the fact that there are varying degrees of openness.

Table 2. Studies included in the meta-synthesis: Methodological approaches.

Study	Data sources	No. of analysed publications	Publication years	Definition of OA
Larivière and Sugimoto (2018)	Papers published between 2009 and 2017 that are indexed in WoS and have a DOI, combined with Unpaywall	12,683,296	2009 – 2017	Gold and Green
Piwowar *et al.* (2018)	Random sample of recent journal articles indexed in WoS, combined with oaDOI database	100,000 articles	2009 – 2015	Gold, Hybrid, Bronze, Green
Bosman and Kramer (2018)	Full WoS database, combined with oaDOI database	12.3 million articles and reviews	2010 – 2017	Gold, Hybrid, Bronze, Green
Science-Metrix (2018)	All articles in WoS and Scopus, combined with 1science database of OA articles	13.2 million articles	2006 – 2015	"Gratis" OA (Gold, Green, Other)
Martín-Martín *et al.* (2018)	All documents with a DOI from WoS, Social Sciences Citation Index and Arts & Humanities Citations Index, combined with GS	2.6 million documents	2009 and 2014	Gold, Hybrid, Bronze, Green
Jamali and Nabavi (2015)	First ten hits from queries of minor Scopus subject categories in GS	7244 articles	1996 – 2013	Any full text accessible through GS (Gold, Green, Other)
Khabsa and Giles (2014)	GS	Capture-recapture approach	No limit	Any full text accessible through GS (Green, Gold, Other)
European Commission (2014)	Scopus, combined with searches of DOAJ, ROAR, OpenDOAR, PubMedCentral, and other sources of freely downloadable papers	513,753 articles	1996 – 2013	Gold, Green, Other
Gargouri *et al.* (2012)	Random samples of articles indexed in Thomson-Reuters-ISI, combined with robot crawling web for OA full-texts	107,052 articles	1998 – 2006 and 2005 – 2010	Any full text accessible on the web (Gold, Green, Other)
Björk *et al.* (2010)	Random sample of articles from Scopus, combined with Google searches for OA full-texts	1837 articles	2008	Any full text accessible on the web (Gold, Green, Other)
Hajjem (2006)	CDROM version of ISI's Science and Social Science Citation Indices, combined with robot crawling of the web for OA full-texts	1,307,038 articles	1992 – 2003	Any full text accessible on the web (Gold, Green, Other)

Table 3. Studies included in the meta-synthesis: Main findings.

Study	% OA by discipline (year)	% OA route by discipline (year)			
		Gold	Green	Hybrid	Bronze
Larivière and Sugimoto (2018)	All disciplines: 66% (2009–2017) Biomedical Research: 85% Clinical Medicine: 79% Health: 73% Mathematics: 67% Earth and Space: 57% Psychology: 56% Physics: 56% Biology: 51% Professional Services: 42% Social Sciences: 39% Chemistry: 35% Engineering and Technology: 29%	Not assessed	Not assessed	Not assessed	Not assessed
Piwowar *et al.* (2018)	All disciplines: 36.1% (2009–2015) Biomedical Research: 58.5% Mathematics: 52.7% Clinical Medicine: 47.8% Health: 41.8% Earth and Space: 40.4% Biology: 32.7% Physics: 31.6% Psychology: 29.7% Social Sciences: 25.1% Professional Fields: 20.6% Engineering and Technology: 17.4% Chemistry: 15.5%	All disciplines: 7.4% (2009–2015) Biomedical Research: 15.3% Health: 11.7% Mathematics: 11.2% Clinical Medicine: 10.3% Biology: 7.3% Earth and Space: 5.6% Psychology: 4.7% Engineering and Technology: 4.2% Physics: 3.1% Humanities: 3.0% Chemistry: 2.8% Arts: 2.4% Professional Fields: 1.4% Social Sciences: 1.3%	All disciplines: 11.5% (2009–2015) Physics: 23.6% Mathematics: 22.7% Social Sciences: 18.7% Psychology: 17.6% Health: 14.1% Professional Fields: 13% Biomedical Research: 10% Clinical Medicine: 9.8% Earth and Space: 8.5% Engineering and Technology: 8.3% Chemistry: 7.9 % Biology: 7.2% Humanities: 6.3% Arts: 4.9%	All disciplines: 0.6% (2009–2015) Mathematics: 9.4% Humanities: 8.6% Biomedical Research: 8.1% Clinical Medicine: 6.3% Biology: 4.2% Health: 3.0% Earth and Space: 2.7% Chemistry: 2.3% Physics: 2.1% Psychology: 2% Professional Fields: 1.8% Engineering and Technology: 1.8% Social Sciences: 1.8% Arts: 0.6%	All disciplines: 12.9% (2009–2015) Biomedical Research: 25.2% Earth and Space: 23.7% Clinical Medicine: 21.5% Biology: 14% Health: 13% Mathematics: 9.4% Arts: 6.7% Psychology: 5.4% Professional Fields: 4.4% Social Sciences: 3.3% Humanities: 3.2% Engineering and Technology: 3.2% Physics: 2.9% Chemistry: 2.5%
Bosman and Kramer (2018)	All disciplines: 29.4% (2016) Life Sciences & Biomedicine: 41.7% Social Sciences: 17.3% Physical Sciences/Technology: 14.8% Arts & Humanities: 13.9%	Not assessed	Not assessed	Not assessed	Not assessed

Study	% OA by discipline (year)	% OA route by discipline (year)			
		Gold	Green	Hybrid	Bronze
Science-Metrix (2018)	All disciplines: 55% (2014) Health Sciences: 59% Natural Sciences: 55% Applied Sciences: 47% Economic & Social Sciences: 44% Arts & Humanities: 24%	All disciplines: 23% (2014) Health Sciences: 33% Natural Sciences: 15% Applied Sciences: 13% Economic and Social Sciences: 8% Arts and Humanities: 7%	All disciplines: 31% (2014) Health Sciences: 33% Applied Sciences: 29% Natural Sciences: 15% Arts and Humanities: 9% Economic and Social Sciences: 8%	Not assessed	Not assessed
Martín-Martín *et al.* (2018)	All disciplines: 54.6% (2009, 2014) Medical and Life Sciences: 60% Natural Sciences: 50% Social and Behavioral Sciences: 49.9% Engineering Sciences: 40.2% Language, Information and Communication: 36.3% Law, Arts and Humanities: 32.3%	All disciplines: 7.3% (2009, 2014) Medical and Life Sciences: 8.2% Law, Arts and Humanities: 7.3% Language, Information and Communication: 5.7% Natural Sciences: 3.5% Engineering Sciences: 3.5% Social and Behavioral Sciences: 1.7%	All disciplines: 10.8% (2009, 2014) Medical and Life Sciences: 19.4% Social and Behavioral Sciences: 15.9% Natural Sciences: 15.3% Engineering Sciences: 8.7% Law, Arts and Humanities: 5% Language, Information and Communication: 4.4%	All disciplines: 1% (2009, 2014) Law, Arts and Humanities: 1.8% Medical and Life Sciences. 1.4% Language, Information and Communication: 1.2% Social and Behavioral Sciences: 0.5% Natural Sciences: 0.5% Engineering Sciences: 0.3%	All disciplines: 13.2% (2009, 2014) Medical and Life Sciences. 20.8% Natural Sciences: 7.5% Engineering Sciences: 3% Social and Behavioral Sciences: 5.3% Law, Arts and Humanities: 0.1% Language, Information and Communication: 0%
Jamali and Nabavi (2015)	All disciplines: 61.1% (2004–2014) Life Sciences: 66.9% Social Sciences: 60.8% Physical Sciences: 60% Health Sciences: 59.7%	All disciplines: 49.4% (2004–2014) Life Sciences: 60.9% Health Sciences: 56.4% Physical Sciences: 40.4% Social Sciences: 40.4%	All disciplines: 8.8% (2004–2014) Physical Sciences: 18.3% Social Sciences: 14.3% Life Sciences: 2.5% Health Sciences: 0.5%	Not assessed	Not assessed
Khabsa and Giles (2014)	All disciplines: 24% (all years) Computer Science: 50% Multidisciplinary Sciences: 43% Economics and Business: 42% Geosciences: 35% Physics: 35% Environmental Sciences: 29% Mathematics: 27% Medicine: 26% Biology: 25% Arts and Humanities: 24% Chemistry: 22% Social Sciences: 19% Agricultural Science: 12% Engineering: 12% Material Science: 12%	Not assessed	Not assessed	Not assessed	Not assessed

Study	% OA by discipline (year)	% OA route by discipline (year)			
		Gold	Green	Hybrid	Bronze
European Commission (2014)	All disciplines: 53.7% (2011 – 2013) General Science & Technology: 89.7% Biomedical Research: 70.6% Mathematics & Statistics: 67.6% Biology: 66.2% Physics & Astronomy: 59.4% Earth & Environmental: 57.8% Psychology & Cognitive Sciences: 57.7% Public Health & Health Services: 57.2% Clinical Medicine: 56.3% Sciences Economics & Business: 54.9% Information & Communication Technology: 54.0% Agriculture, Fisheries & Forestry: 53.8% Social Sciences: 43.7% Enabling & Strategic Technologies: 39.3% Chemistry: 38.5% Built Environment & Design: 37.5% Arts, Humanities & Social Sciences: 35.9% Philosophy & Theology: 34.7% Engineering: 34.6% Historical Studies: 34.4% Communication & Textual Studies: 30.9% Visual & Performing Arts: 23.3%	All fields: 12.1% (2011–2013) Gen. Science & Technology: 58.0% Biology: 17.0% Agriculture, Fisheries & Forestry: 16.1% Public Health & Health Services: 15.8% Clinical Medicine: 14.8% Biomedical Research: 12.4% Information & Communication Technologies: 12.4% Mathematics & Statistics: 11.4% Chemistry: 9.5% Enabling & Strategic Technologies: 9.3% Social Sciences: 8.7% Communication & Textual Studies: 8.7% Earth & Environmental Sciences: 8.1% Historical Studies: 7.2% Psychology & Cognitive Sciences: 5.6% Economics & Business: 5.4% Philosophy & Theology: 5.1% Physics & Astronomy: 5.1% Engineering: 4.1% Built Environment & Design: 3.5% Visual & Performing Arts: 2.8% Gen. Arts, Humanities Social Sciences: 2.6%	All fields: 5.9% (2011–2013) Physics & Astronomy: 25.6% Mathematics & Statistics: 24.3% Economics & Business: 11.3% Information & Communication Technologies: 8.7% Earth & Environmental Sciences: 5.6% Social Sciences: 5.2% Philosophy & Theology: 5.1% Built Environment & Design: 4.6% Gen. Science & Technology: 3.9% Biology: 3.7% Psychology & Cognitive Sciences: 3.6% Communication & Textual Studies: 3.6% Gen. Arts, Humanities & Social Sciences: 3.5% Engineering: 3.2% Public Health & Health Services: 3% Visual & Performing Arts: 2.9% Agriculture, Fisheries & Forestry: 2.8% Enabling & Strategic Technologies: 2.7% Historical Studies: 2.5% Clinical Medicine: 2.2% Biomedical Research: 2.1% Chemistry: 1.8%	Not assessed	Not assessed

Study	% OA by discipline (year)	% OA route by discipline (year)			
		Gold	Green	Hybrid	Bronze
Gargouri *et al.* (2012)	All disciplines: 23% (2010) Mathematics: 42% Earth & Space: 37% Social Sciences: 37% Professional Fields: 29% Physics: 27% Engineering & Technology: 23% Psychology: 23% Biology: 22% Humanities: 19% Health: 17% Clinical Medicine: 14% Arts: 14% Biomedical Research: 12% Chemistry: 9%	All disciplines: 2% (2005–2010) Biomedical Research: 8% Clinical Medicine: 5% Health: 5% Mathematics: 2% Physics: 2% Earth & Space: 2% Biology: 2% Engineering & Technology: 1% Psychology: 1% Social Sciences: 1% Chemistry: 1% Arts: 1% Humanities: 1% Professional Fields: 1%	All disciplines: 21% (2005–2010) Mathematics: 43% Earth & Space: 36% Professional Fields: 29% Physics: 26% Engineering & Technology: 23% Social Sciences: 35% Psychology: 27% Biology: 22% Humanities: 14% Health: 12% Chemistry: 10% Clinical Medicine: 9% Arts: 9% Biomedical Research: 6%	Not assessed	Not assessed
Björk *et al.* (2012)	All disciplines: 20.4% (2008) Earth Sciences: 32.9% Mathematics: 25.6% Physics & Astronomy: 23.5% Social Sciences: 23.5% Medicine: 21.7% Biochemistry, Genetics & Molecular Biology: 19.9% Engineering: 18.4% Other areas related to Medicine: 15.2% Chemistry and Chemical Engineering: 12.9%	All disciplines: 8.5% (2008) Medicine: 13.9% Biochemistry, Genetics & Molecular Biology: 13.7% Other areas related to Medicine: 10.6% Mathematics: 8.1% Earth Sciences: 7% Social Sciences: 5.6% Chemistry and Chemical Engineering: 5.5% Engineering: 4.8% Physics & Astronomy: 3%	All disciplines: 11.9% (2008) Earth Sciences: 25.9% Physics & Astronomy: 20.5% Social Sciences: 17.9% Mathematics: 17.5% Engineering: 13.6% Medicine: 7.8% Chemistry and Chemical Engineering: 7.4% Biochemistry, Genetics & Molecular Biology: 6.2% Other areas related to Medicine: 4.6%	Not assessed	Not assessed
Hajjem *et al.* (2006)	All disciplines: Not reported (1992 – 2003) Sociology: 16% Biology: 15% Economics: 13.5% Business: 9% Management: 7% Psychology: 7% Health: 6.2% Political Science: 5.3% Education: 5.3% Law: 5.1%	Not assessed	Not assessed	Not assessed	Not assessed

or surpass OA prevalence in the social sciences and humanities (26% OA determined for medicine for publication years until 2013, while 24% OA showed for arts and humanities[22]; 59.7% OA in health sciences between 2004 and 2014, while 60.8% of publications in social sciences were OA[16]). For the early period of this phase, OA levels in the natural and technical sciences remained well above those observed in other disciplines (Observed OA levels were 50% in computer sciences, 35% in both geo-sciences and physics, 29% in environmental sciences and 27% in mathematics in publication years until 2013[22]; 60% OA in physical sciences in the time from 2004 to 2014[16]). Because of higher OA growth rates in medicine and health towards the end of this phase, these fields soon overtook the natural and technical sciences in embracing the idea of OA. Particularly biomedical research took on a leading role in embracing OA (70.6% OA in biomedical research, 67.6% OA in mathematics & statistics, 66.2% for biology, 59.4% for physics & astronomy and 58.8% for earth and environmental sciences, closely followed by public health & health services and clinical medicine with OA levels of 57.2% and 56,3%, respectively, in the period from 2011 to 2013[10]). During this period, the gap between the natural and technical sciences and medicine on the one side and the social sciences and humanities on the other side widened. The humanities in particular published research outputs to lesser degrees OA than other disciplines (35.0% OA in arts, humanities & social sciences, 34.7% in philosophy & theology, 34.4% in historical studies for publication years 2011 to 2013)[10]. The third phase of OA can be dated after the early 2010s and is a phase of stabilisation, in which differences in the OA publishing patterns across disciplines have become established. Studies consistently show that medical and health-related research fields are taking the leading roles in embracing OA, featuring OA uptake levels that are well above those reported for other disciplines (Reported OA levels are 60% in medical and life sciences on average for 2009 and 2014[17]; 59% for health sciences in 2014[19]; 58.5%, 47.8% and 41.8% for biomedical research, clinical medicine and health in publication years from 2009 to 2015, respectively[12]; 41.7% for life sciences and biomedicine in 2016[20] and 85%, 79% and 73% for biomedical research, clinical health and health in publication years from 2009 to 2017, respectively[18]). The medical sciences are closely followed by disciplines from the natural and technical sciences (50% OA for natural sciences on average in 2009 and 2014[17]; 55% OA for natural sciences in 2014[19]; 52.7% OA for mathematics, 40.4% OA in earth and space, 32.7% OA in biology and 31.6% OA in physics between 2009 and 2015[12]; 14.8% for physical sciences / technology in 2016;[20]; 57% OA for mathematics, 56% OA for earth and space, % 56% OA for physics and 51% OA for biology in publication years from 2009 to 2017[18]). OA uptake in the social sciences is close behind the natural sciences (Reported OA levels are 49.9% for social and behavioural sciences in 2009 to 2014[17]; 55% for economic and social sciences in 2014[19]; 25.1% in social sciences between 2009 and 2015[12]; 17.3% in social sciences for 2016[20]; 39% for social sciences between 2009 and 2017[18]). Law, arts and humanities show the lowest OA uptake across all disciplines (OA prevalence rates determined to be 32.3% for law, arts and humanities between 2009 and 2014[17]; 24% for arts and humanities in 2014[19]; 13.9% for arts and humanities in 2016[20]).

Looking at the relative uptake of OA routes for all disciplines, we observe that most OA is published via the Green route, that is, published as journal articles for which the accepted or the published version can be retrieved from an open repository. Gold OA journals are also of importance for scholarly publishing, even though the relative uptake on Gold OA remains well below Green OA for most publication years (Relative uptake levels were 11.9% Green OA and 8.5% Gold OA in 2008, respectively,[1], 21% Green OA and 2% Gold OA in publication years from 2005 to 2010[9], 5.9% Green OA and 12.1% Gold OA between 2011 and 2013[10], 10.8% Green OA and 7.3% Gold OA on average in publication years 2009 and 2014[17], 8.8% Green OA and 49.4% Gold OA in publication years between 2004 and 2014[16], 31% Green OA and 23% Gold OA in 2014[19] and 11.5% Green OA and 7.4% Gold OA in publication years between 2009 and 2015[12]). Studies that also assessed the relative uptake on Hybrid OA and Bronze OA have revealed, that, first, Hybrid OA generally is of little importance for scholarly publishing, with 1% or less of all scholarly outputs being published as articles free under an open license in subscription journals. Second, the importance of Bronze OA is comparable to that of Gold OA. Relative uptake on Bronze OA was determined to be an average 13.2% for publication years 2009 and 2014 and 12.9% for publication years from 2009 to 2015[12,17]. Looking at the relative uptake on OA routes by discipline, we observe that there is little consistency in reported uptake levels across the studies included in our review, which likely is due to methodological differences in how studies determined how much of the scholarly literature in a specific discipline is published through different OA routes. Nevertheless, we are able to determine the relative importance of the different OA routes for each discipline: For the medical sciences, we observe that publication in pure OA journals (Gold OA) plays a more important role for making research findings openly accessible than both the archiving of articles in repositories following publication in subscription journals (Green OA) and the publication of articles free under an open license in subscription journals (Hybrid OA). Two more recent studies have revealed that the publication of articles free to read on the publisher page without open license (Bronze OA) also is of substantial relevance for OA in the medical sciences, featuring similar prevalence levels as Gold OA. For the natural and technical sciences, we see that there are substantial differences in the OA publishing patterns between different fields: scholars in physics, mathematics, astronomy and biology make large shares of their research outputs openly accessible through the Green route of OA, followed by Bronze OA, Gold OA, and, with some distance, Hybrid OA. In contrast, for scholars in chemistry and biology, Gold OA journals are of greater importance than any other OA route. For scholars in the social sciences, Green OA is of greater importance for OA publishing than Gold OA, Bronze OA and Hybrid OA. In the humanities and law, scholars make research outputs openly accessible predominantly through publication of articles in Hybrid OA journals, followed by Green OA, Bronze OA and Gold OA.

Analytical framework: Social shaping of technology

Previous studies have analysed discipline-specific publishing practices from a range of perspectives. In general, these

perspectives originate from science and technology studies (STS), which look at how society, politics and culture shape research and technological innovation, and vice versa. Depending on their understanding of the direction of this relationship, these perspectives can be located on a scale that ranges from technological determinism at the one extreme to social constructionism of technology (SCOT) at the other extreme[23]. These perspectives emphasize particular sets of criteria as relevant for analysing publishing practices while other sets of criteria are considered irrelevant or ignored[5]. Technological determinism suggests that technology is the driving force behind social and cultural change[24]. Studies adopting this perspective accordingly focus on the infrastructures and technical aspects of scholarly communication channels in explaining how OA is implemented across disciplines. Social and cultural factors are believed to be of less or no relevance in explaining the emergence of OA[5]. SCOT perspectives view technology as a social phenomenon constructed by the society producing and using it. In order to analyse OA publishing patterns, one would have to first understand the social relations within which respective technologies are used[25]. Both positions have been shown to suffer from limitations in explaining scholarly publishing practices[2]. The so-called "social shaping of technology" (SST) perspective that takes an intermediate standing between these extremes proves to be more useful for analysing OA publishing practices. SST is a theoretical stance that conceives the relationship between technology and society as one of mutual shaping[26]. Instead of evolving according to an inner technical logic or a single social determinant, technology is believed to be a social product patterned by the conditions of its creation and use[27]. Central to technical change are choices made by social actors and groups during the generation and implementation of new technologies. This process involves a set of conscious and unconscious choices between different technical options[28]. Which options social actors select is affected by both technical considerations and a range of social and cultural aspects. Thus, social choices influence the contents of technologies. At the same time, technologies have social implications as they shape human action and behaviour[26]. Following this, scholarly publishing practices can be understood as socio-technical ensembles: the ways in which scholarly outputs are published is affected by the operational choices made by scholars during the creation, implementation and use of respective communication technologies. These operational choices are influenced by both technical considerations and socio-cultural aspects. As communication technologies are implemented and used, they in turn affect the ways in which scholars communicate and disseminate their research findings. It follows that, in order to explain discipline-specific OA publishing practices, it is necessary to examine the socio-cultural and technical factors that affect publishing choices within particular disciplines. Based on these assumptions, we have developed an analytical framework that places focus upon technical factors and socio-cultural factors alike when analysing patterns of OA publishing practices. The analytical dimensions entailed in this framework are illustrated in Table 4.

[2] For a comprehensive discussion of the merits of these perspectives in explaining publishing practices see Kling & Kim (2000) and Oostveen (2004).

Open access in the medical sciences

Initially, medicine and health-related disciplines were reluctant to adopt OA publishing, resulting in OA levels to be well below those observed in the natural and social sciences. From the mid-2000s onwards, however, the uptake on OA increased substantially and particularly biomedicine and clinical medicine took on leading roles in embracing OA. Research outputs are predominantly made OA by publication in Gold OA journals, whereas Hybrid OA, Bronze OA and Green OA are of little importance for these disciplines. Factors facilitating OA can be identified as strong OA mandates combined with either funder-operated repositories or available funding for article processing charges (APCs), the richness in high-quality and prestigious OA journals and the wide circulation of publications in these outlets. A major barrier to OA in the medical sciences are authors' concerns over the quality of peer review in OA journals, which is related to the emergence of fraudulent journals and publishers.

A) Author behaviour and attitudes – Several surveys and interview studies have shown that in biomedicine and the life sciences, a large majority of authors support OA publishing, but the reputation of journals, their impact factor, and the quality and speed of peer review are more important factors determining the choice of publication outlets than the OA status[29–31]. For example, in 2004, Sara Schroter and colleagues interviewed authors who submitted articles to the BMJ. Almost all authors supported the concept of OA, but many were concerned about poor quality research being published for a fee, and OA was not a factor of importance when selecting a journal[30]. More recently, the 2014 international author survey conducted by publisher Taylor & Francis showed that investigators working in Science, Technology and Medicine (SEM) mentioned wider circulation than publication in a subscription journal as an advantage of OA, but were strongly against to the use of their work for commercial gain without their explicit permission[32]. Authors expected rigorous peer review and rapid publication in return for paying for OA publication[32,33]. Surveys among academics from lower income countries indicate that the funding of APCs is an important concern[34,35]. A study from India found that the most important factors influencing the selection of medical or dental journals were that the journal is indexed in widely used bibliographic databases, has an online submission system, a satisfactory impact factor and peer review, and that APCs are affordable[36]. The importance of affordable APCs may explain why authors from resource-limited settings are over-represented among publications in fraudulent journals that charge small fees but do not provide proper peer review or add value through editing[37].

B) Publisher behaviour and policies – As private profit-oriented companies, most traditional publishers are driven by maximizing income to satisfy their shareholders[3]. Consequently, as the OA model is unlikely to generate the level of income and profit that can be achieved with the subscription model, few commercial medical publishers have converted their subscription journals to OA. This also applies to academic or professional societies[29]. Policies on prior publication remain tight for most of these journals. Some journals have now moved to allowing

Table 4. Framework of analysis.

Analytical Dimension	Description and Criteria
Author behaviour and attitudes	The publication outlets that scholars choose to publish the outputs of their research in and how they perceive these outlets, depending on the importance attached to the following criteria: a) quality control mechanisms and standards thereof b) speed of work and result-sharing c) impact of publication outlets d) prestige of publication outlets e) terms of academic promotion
Publisher behaviour and policies	The degrees to which publishers (i.e. commercial publishers, university presses, scholarly societies and others) decide to make full journal volumes or selected papers either closed access or OA and the timing of that, reflected in the following publishing policies and guidelines: a) lengths of embargoes b) policies on prior publication c) copyrights and licensing d) APC levels
Infrastructures of scholarly communication channels	The characteristics of publication outlets (i.e. e-print servers and repositories, academic journals, digital libraries and academic social networks), described by: a) availability b) technical features c) uptake by scholars
Structural and institutional factors	Characteristics of research activities and conduct, described by: a) types of research (i.e. basic vs. applied research) b) types of work products and research outputs c) topic of research d) research costs e) funding structures
OA mandates and policies	The strength and effectiveness of OA mandates and policies by public funding agencies, research foundations and organisations, private companies and others, depending on their specific conditions: a) degree of obligation (i.e. mandate vs. recommendation) b) type of mandated or recommended OA route c) existence of "opt-out" opportunities for specific disciplines or research outputs d) permissible embargo periods for archiving in a repository following publication

their authors to self-archive submitted manuscripts without an embargo period, while self-archiving of accepted versions of a publication remains subject to a standard embargo period of 12 months. Pioneers among OA medical journals include the Journal of Clinical Investigation, which in 1996 became the first major journal to be freely available on the web. Of note, publication in the journal was free to authors initially, but APCs were introduced after the journal lost 40% of its institutional subscribers[38]. The BMJ followed suit in 1998, but moved some content (including editorials and education and debate articles) behind a pay wall in 2005[39]. The number of OA journals increased considerably from 2000 onwards, with the arrival and rapid growth of OA publishers such as the not-for-profit publisher Public Library of Science (PLoS) or the commercial publisher BioMedCentral (BMC). The launch of OA journals by major biomedical research funders[40–42] and the emergence of mega-journals are other factors that have influenced uptake of OA publishing in medical research fields[43].

C) Infrastructure of scholarly communication – OA publishing in the medical sciences focuses on Gold OA journals and only a small number of OA institutional and subject repositories has emerged. This can be explained as follows. First, sufficient funding is available for publication in Gold OA journals. Second, journal publications are of central importance in academic hiring and promotion decisions within the medical sciences. Third, there is a large number of high-quality Gold OA journals for authors to publish their research in. The uptake on open repositories in general is low, but an exception to this is the PubMed Central (PMC), which archives full-text scholarly articles and plays a central role in the medical and life sciences. PMC has experienced rapid growth in the late 2000s as the National Institutes of Health (NIH) introduced an OA policy that mandates its grantees to deposit the final peer-reviewed version of an article based on NIH-funded research in PMC. The embargo was initially 12 months after publication, but was later shortened to 6 months[44] and journals have since moved to be compliant with this Green OA mandate. Submissions into the PMC undergo indexing and formatting procedures, which produces advanced metadata and unique identifiers[45]. Of interest, even though not of the same relevance as PMC, is also the PeerJ Preprint section, which allows authors to submit preprints and postprints from the biological and medical sciences.

D) Structural and institutional factors – The main type of work products in the medical sciences are journal articles.

Like the natural sciences, research in the medical sciences and related fields in most parts is funded by project-specific grants, which makes it fairly easy to integrate processing charges for publication in OA journals into existing funding structures. Further, medical research is in large part funded by third-party funding, for example by the World Health Organization (WHO) and the Wellcome Trust. These organizations have strong OA mandates while, at the same time, providing both convenient open repositories for depositing articles and sufficient funds for covering processing charges for publication in OA journals[46].

E) OA mandates and policies – Evolving national and institutional OA policies, OA mandates by major funders of (bio-)medical research and the availability of funding for APCs have accelerated the uptake of OA publishing in the medical and life sciences. A substantial number of national governments have moved to require scholars in the medical and life sciences to make their articles OA if based on publicly-funded research by either publishing in OA journals or by making publications OA by depositing the accepted or the published version of an article in a repository. Usually, scholars are granted embargo periods of 6 or 12 months to comply with the latter[18]. Besides national governments and research institutions, major funders of medical research play an active role in promoting OA. Besides the NIH, this includes the WHO and the Wellcome Trust. Since 2014, journal articles and book chapters based on WHO-funded research have to be published in either an Gold or Hybrid OA journal or in a subscription journal that allows the author to deposit the accepted version in PMC no later than 12 months after publication[47]. Similarly to the NIH, the Wellcome Trust requires articles to be published in OA journals where a journal makes this option available and to be deposited as the accepted version in an open repositories no later than 6 months after publication. Both funders state that they will withhold or suspend payments if articles are not made OA. Both funders provide repository infrastructures (PMC for NIH and PMC or PMC Europe for Wellcome Trust) and funds for covering APCs[46]. In contrast to the USA, the policy environment in the UK favoured gold and hybrid OA, with particularly high uptake in the life sciences and rapidly increasing costs[48].

Open access in the natural and technical sciences

For most publication years, the natural and technical sciences show the highest OA prevalence rates amongst all disciplines. There are, however, substantial differences in the OA publishing patterns between different subdisciplines of the natural and technical sciences. Journals in the fields of physics, mathematics, astronomy, information technology and biology were the early pioneers of OA and continue to make large shares of their research outputs OA. In contrast, engineering and chemistry feature OA prevalence rates that are consistently much lower than in other fields of the natural and technical sciences and even slightly lower than OA levels observed in the social sciences and humanities. While Green OA seems to be of central relevance for OA publishing within physics, astronomy, biology, information technology and mathematics (followed by Bronze, Gold and, by some distance, Hybrid OA), scholars in chemistry and biology make larger shares of their research OA through publication in Gold OA journals than in open repositories. Factors facilitating OA in the natural and technical sciences can be identified as the long-existing culture of preprint distribution, availability in funding for APCs and high levels of awareness of and familiarity with OA publishing. Barriers to OA are concerns about the quality of OA journals and high degrees of industrial integration in some fields.

A) Author behaviour and attitudes – The distribution of preprints has a long tradition in many fields related to the natural sciences, particularly in physics, mathematics, astronomy, information technology and biology, where scholars commonly share their manuscripts before submitting these for publication to journals. Before it was possible to make documents available electronically, a paper-based culture of preprint distribution developed in the 1960s, especially in high-energy physics[49]. With the emergence of the Internet, scholars began sharing electronic versions of their preprints informally via electronic mail and when Paul Ginsparg established the open repository arXiv in 1991, scholars started making their preprints openly accessible through centrally self-archiving them in arXiv[4]. Surveys have revealed that, to scholars within these fields, rapid publication, high visibility and large readership appear to be the most important factors when it comes to choosing a publication outlet, and that scholars associate these features with depositing preprints in open repositories[33,50]. Adding to this, scholars in the natural sciences generally show high levels of familiarity with the concepts of OA in general and Green OA in particular[15,51]. As a consequence, Green OA has become the most popular way of making research outputs OA in physics, mathematics, astronomy, information technology and biology. Publishing in journals (closed-access and Gold, Hybrid or Bronze OA) is less prominent for scholars within these fields. In contrast, scholars in chemistry and engineering value publication in journals over self-archiving in repositories, which is the reason why Gold OA plays a bigger role than Green OA in these fields[50]. Despite the preprint culture in some of the natural sciences, 40% to 50% of all research outputs overall remain closed-access today. Chemistry and engineering show particularly low uptake levels on OA. This might be due to the fact that scholars within these fields still have concerns about the quality of peer review in OA journals and are concerned that this might translate into low-quality publications in these outlets. Consequently, OA journals within the natural sciences have not yet been able to match the reputation of subscription journals[52].

B) Publisher behaviour and policies – Commercial publishers as well as learned societies in the natural and technical sciences have been slow in embracing the idea of OA. This relates to two factors: First, publishers face a potential loss of revenues in switching from a subscription model to an APC model, as has been shown in a number of market analyses[53,54]. Second, general concerns about the quality of OA journals are not only shared by scholars but also by publishers and learned societies[52]. As a result, most of the major commercial publishers, as well as learned societies in the natural sciences, have been reluctant to either convert their existing subscription journals to

OA and to set up new OA journals. An exception to this are few large publishing houses that have started setting up new OA journals in disciplines that do not have a culture of preprint distribution, such as chemistry or engineering. In disciplines where there is a culture of preprint distribution, publishers have started relaxing policies on prior publication and enable manuscripts deposited in repositories to be directly submitted to their journals[52].

C) Infrastructure of scholarly communication – In physics, mathematics, astronomy, information technology and biology, scholars are used to sharing their research outputs openly making use of open repositories, particularly arXiv. Originally established within high energy physics, arXiv now is used by scholars in most fields of the natural sciences and its concept has eventuated in a number of discipline-specific repositories in other fields, including the social sciences. Even though repositories do not employ formal mechanisms of quality control, scholars within the natural sciences use them to first, disseminate their research outputs without publication delays, and second, stay informed about ongoing research within their fields[4]. In the light of this publication culture, relatively few OA journals have emerged within these fields. In fields where there is a smaller culture of self-archiving in repositories, most particularly in chemistry and engineering, the number of OA journals has grown slowly but steadily in recent years. These journals cover a variety of specific subject areas, are peer-reviewed, and, for the most part, are published in English. Exemplary journals in engineering are the International Journal of Antennas and Propagation, the Journal of Engineered Fibers and Fabrics, Journal of Scientific and Industrial Research and Thermal Science[55]. Chemistry journals that enjoy popularity are the Archive for Organic Chemistry, Beilstein Journal of Organic Chemistry, Chemistry Central, Catalysts and ChemistryOpen[52].

D) Structural and institutional factors – The main types of work products in the natural and technical sciences are journal articles, electronic preprints and conference proceedings, which are published records of conferences, congresses or other meetings. Researchers from the natural sciences have reported that the process of self-archiving electronic preprints and conference proceedings is little time-consuming and that they generally experience little difficulties in making research outputs OA using open repositories[50]. In addition, and similar to the medical sciences, research in the natural sciences is in large parts funded by project-specific grants, which would make it fairly easy for scholars to integrate fees for publication in Gold or Hybrid OA journals into existing funding structures. A structural factor that limits the uptake on OA within the natural and technical sciences is that some of these fields, particularly chemistry and engineering, are industry-oriented. This adds to the fact that, particularly within engineering, the focus is rather national than international as products developed by engineers are, for the large part, produced for domestic markets. As a consequence of these factors, large numbers of publications within these fields are more practice- than science-oriented and are published in closed-access journals that are partly financed by advertising[55].

E) OA mandates and policies – Reflecting the ambition to make research outputs OA, there are strong OA mandates for the natural and technical sciences. Usually, these fields are subject to similar OA requirements as the medical sciences: scholars are usually required to make their outputs OA if based on publicly-funded research by either publishing in OA journals or by depositing the accepted or the published version of an article published in subscription journal in a repository. By default, scholars are granted embargo periods of 6 or 12 months to comply with the latter[18]. Besides national and international funding agencies, CERN and the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP) play leading roles in promoting OA. SCOAP is an international partnership of funding agencies, research centers and libraries that was launched with the aim of providing funding for the conversion of high-energy physics journals from a subscription model of publishing to OA. Within this scheme, libraries and research centers either pay reduced subscription fees for participating journals or stop paying altogether. Saved monies feed into a central fund, which is used to pay publishers up front to publish OA articles[56]. Doing so, the initiative enables scholars to make their research outputs OA without straining their own research funds. By 2014, five journals had been converted within the framework of SCOAP[49]. The OA policy of CERN requires its scholars to publish their articles, wherever possible, in journals covered by SCOAP. When circumstances require publication in journals that are not covered by SCOAP, the APCs must be covered by funds from outside the CERN Budget, for example through EU projects or by other institutions. Where this is not possible, authors may request special permission and funds from CERN[57].

Open access in the social sciences

Overall, the OA uptake in the social sciences is higher than in most disciplines of the humanities, but remains below the medical and natural sciences. Publishing in Gold OA journals plays a less important role than the archiving of publications in institutional and subject repositories following publication in a subscription journal. For scholars within the social sciences, open repositories appear to be of central importance for making research outputs openly accessible, closely followed by publication in Gold OA journals, and, with some distance, Hybrid and Bronze OA. The low uptake on OA is due to a variety of reasons, including low levels of awareness, concerns about quality and prestige of OA journals, the central role of monographs for career advancement and difficulties in accessing funding for APCs and Book Processing Charges (BPCs). Having said that, the social sciences are currently experiencing a cultural shift towards conducting science more openly, which manifests itself in an increasing embracement of OA.

A) Author behaviour and attitudes – Author surveys consistently have revealed that the awareness of OA publishing is lower for the social sciences than for the medical and natural sciences, and that OA publication outlets have not yet fully become part of the workflow for social scientists[51]. The knowledge of OA journals and repositories however appears to grow amongst social scientists with particularly young researchers reporting

high levels of OA awareness and engagement[58]. Most social scientists support the idea of OA in principle, but stringent quality control, further improvement of the manuscript before publication and journal prestige still appear to outweigh OA in authors' journal selection criteria[59,60]. As a consequence, OA publishing activity remains low for the social sciences. This is also due to the fact that some social scientists and their learned societies are still opposed to OA, which relates mainly to concerns about quality of peer review and editorial services in OA journals[61]. Relevant to the appreciation of OA in the social sciences is also the importance attached to monographs. While in the natural and medical sciences, the large part of research findings is disseminated via journal articles, the monograph has a central place in the culture and ecology of publishing in most of the social sciences and is highly relevant to career advancement[60,62]. Monographs have been shown to be less likely to be published OA. Amongst other factors, this relates to authors' concerns over restricted editorial services and doubts whether unestablished OA publishers and formats are able to translate their effort in writing a monograph into reputational gain within the scientific community[63].

B) Publisher behaviour and policies – Few publishers in the social sciences have decided to convert their existing subscription-based journals to OA or to set up new OA journals. Key academic journals in the social sciences remain closed access. Amongst other factors, this relates to publishers fearing that their academic authors will not be able to access funding for APCs or that switching to an APC model will result in a loss of prestige – both of which are main factors affecting authors' choice of publication venue[60]. For some journals, such as the Historical Social Research or the Zeitschrift für Soziologie, it has become common practice to make their contents automatically OA after an embargo period of two years either by enabling access to their articles on their own website or by depositing them in an OA repository[64]. In addition to this, a large variety of new economic models of OA publishing has emerged that offers viable alternatives to author-payment model in the social sciences and humanities. To name only two, this includes Knowledge Unlatched (KU) and the Open library of Humanities (OLH). OLH is based on a business model that is called "Library Partnership Subsidy" and which asks libraries to pay a relatively small annual subscription fee to enable OA to scientific publications. The model originally was aimed at journals in the humanities and social sciences, but has been expanded to monographs[63]. The goal of KU is to create a financially sustainable route to OA for monographs through a global co-operated model where libraries use their existing acquisition budgets to enable OA to monographs[63]. Another innovative business model of OA publishing that has gained some popularity in the social sciences and humanities is the so-called "freemium" model. This model makes HTML versions of articles and books openly available to everyone, while PDF and ePub formats are accessible only to subscribing libraries and research institutes[65]. One well-known example of this is OpenEdition. While long-term access to research outputs is questionable within these models, OpenEdition and others managed to convince otherwise conservative publishers to create open versions of their journal volumes and monographs[66].

C) Infrastructures of scholarly communication – The social sciences are currently experiencing a considerable growth of open repositories, resulting in authors being able to choose from more than 200 different OA repositories, the most of which are institutional or subject repositories[67]. While subject repositories have become a fairly established part of the workflows for social scientists, institutional repositories are less often used and predominantly host faculty working papers and theses. Prominent examples of subject repositories are the Social Science Research Network, the Social Science Open Access Repository and SocArXiv. Because OA preprint repositories do not employ peer review, however, social scientists have been slow to adopt Green OA. Gold OA journals are of even less importance for the social sciences. Key academic journals in most countries remain closed access[68]. The few existing OA journals in large part are restricted to highly specified sub-disciplines with limited impact and small readership. One notable exception to this was the launch of SAGE Open in 2011, which has brought to the social sciences the OA mega journal model already popular in the natural and medical sciences[69]. In addition to this, a number of OA journals were launched by academic or professional societies, such as Socius: Sociological Research for a Dynamic World launched by the American Sociological Association in 2016[50].

D) Structural and institutional factors – Similar to most disciplines of the humanities, monographs are one of the main work products in the social sciences and highly relevant for academic promotion and career advancement. Besides author concerns over prestige and standards of editorial services of OA monograph publishers, the high costs and procedural complexities associated with producing monographs are important factors restricting the uptake on OA of monographs in the social sciences[70]. In addition to this, social scientists have reported to face significant difficulties in access to grant funding for both APCs and BPCs, as most research in the social sciences is not done by means of project-specific funding that is commonly used to compensate APCs in the natural and medical sciences[31].

E) OA mandates and policies – Scholars in the social sciences face similar OA requirements as scholars within the natural and medical sciences do. Some special regulations can be identified, however. First, monographs are generally not included in OA mandates. Most public funders limit themselves to recommending OA for monographs. One of the few exceptions to this is the SNSF, which demands the OA publication of monographs and provides respective funding for BPCs[63,71]. Second, the social sciences commonly are granted longer embargo periods for the archiving of a journal article after publication in a subscription journal. While embargo periods of 6 or 12 months are the default for the natural and medical sciences, social scientists usually have to deposit journal articles in institutional or subject repositories after up to 12 or 24 months following publication[18,72].

Open access in the humanities

Generally speaking, OA uptake in the humanities is lower than in most areas of the natural, medical and social sciences. This is partly due to the fact that these disciplines exist in a "dry

climate" of funding for gold OA models that rely on APCs[73]. Low uptake is also due, though, to the fact that the monograph plays such a central role in many humanities disciplines, but the funding challenges for open access to such outputs remains an unresolved problem at scale[74,75]. Hybrid OA is of central importance for the humanities, followed by Green OA, Bronze OA and Gold OA. Given that the humanities focus on the study of human cultures and artforms, it is, though, nonetheless surprising that more humanists do not seek to reach general public audiences through broader availability of their research work.

A) Author behaviour and attitudes – As in many academic fields, authors operate within a symbolic economy of prestige that is usually among the prime motivations in choice of publication venue[76]. The relative prestige of publications is determined by a scarcity correlation (usually achieved through peer review) with the shortage of evaluative labour on hiring, tenure, and grant panels, although most humanities fields use an informal hierarchy of publications rather than quantitative measures such as the Impact Factor[75]. Although institutional signups to the San Francisco Declaration on Research Assessment may help to change this through a shift to evaluation at the article level, the focus on the Impact Factor in that declaration may make it harder to alter evaluative cultures in these disciplines. Further, academics and learned societies in the humanities disciplines have often been opposed to open access, for a variety of reasons that range from concerns over misunderstanding, worries about open licensing and plagiarism, or fears for the standing of their members[77,78]. In addition to this, humanities scholars show fairly low levels of awareness of OA and potential OA publication outlets in their fields[79]. That said, there are signs of a cultural shift with new economic models that do not rely on author payments, such as KU, the OLH, Open Humanities Press, Open Book Publishers, Punctum Books, and others appearing to have some traction with at least some humanities scholars. Although it is tempting to posit that humanities scholars are simply less driven by technological change than their counterparts in scientific disciplines, and thereby less inclined towards digital (and, therefore, open) publishing solutions, this is a generalized assertion that is hard to substantiate.

B) Publisher behaviour and policies – The main concern driving humanities publishers is ongoing sustainability of their operations. In switching to an APC or BPC model, often undifferentiated from scientific publications, publishers fear that their academic authors will not be able to pay. It is also clear that highly selective publication models, which are common in the humanities, are more difficult to run, economically, on an OA basis. Hence there is little movement towards a fully gold OA ecosystem, although it is unclear what impact the recently announced pan-European initiative, Plan S, may have upon this. That said, most humanities publishers are compliant with green OA mandates, such as the UK's REF policy[80]. On the other hand, it is also the case that some humanities scholars have argued that a longer citation half-life (particularly for monographs) should translate to longer embargo periods within these disciplines, although this does not necessarily match up to sales half-lives[81]. Despite some disciplines having healthy cultures of offline working paper circulation (philosophy, for instance), preprints have not taken off in the humanities and policies on prior publication remain tight, especially in the most prestigious venues.

C) Infrastructure of scholarly communication – In addition to institutional repositories, there has been a growth in recent years of OA subject repositories, such as the MLA Commons, which is operated by one of the largest subject associations in the humanities. There has also been a prominent culture, for many years, of scholar-led OA journal and book publications[76]. Postpublication peer-review remains rare and usually elicits scant participation without active intervention, with a few notable exceptions and experiments[82,83]. There is no infrastructure at a comparative scale to arXiv in the humanities disciplines. Furthermore, for long-form reading, print remains a crucial resource and scholars often report that they do not wish to read works of 80,000-words length in a purely digital format.

D) Structural and institutional factors – The high costs of producing monographs are a key structural factor that currently limits OA in the humanities[62,70]. Further, most research work in the humanities does not receive project-specific funding, making it difficult to integrate processing charges into a grant. That the humanities disciplines are often of lesser importance in institutional hierarchies also means that it can be difficult to secure funding for articles. The slow cycle of producing long-form outputs is also problematic for OA, as the time investment (and hoped-for credit on publication) is greater than those of a journal article, leading scholars into more conservative prestige-seeking behaviours. There are also substantial challenges around third-party rights and re-use of images, particularly within disciplines such as Art History. Museum policies on licensing have not kept pace with digital publication practices and still often rely on "number of copies" as a metric determining pricing for re-use. Under such a paradigm, it can be difficult (or very expensive) to negotiate re-use rights for unlimited online dissemination. Finally, some disciplinary spaces, such as creative writing, have developed outward facing cultures that rely on sales. Creative writing scholars are often assessed on whether they can produce a "bestselling novel", which works poorly under an OA model. The production of such artifacts may, however, have a research process behind them and various institutional policies will regard such objects as scholarly undertakings. The extent to which such work should be exempted from OA mandates remains, therefore, an ongoing debate.

E) OA mandates and policies – In national cultures, such as that in the UK, the humanities are subject to similar OA requirements as the social sciences, involving monographs being excluded from OA mandates and embargo periods of 12 or 24 months for the archiving of journal articles after publication in a subscription-journal. A few research foundations, such as the Wellcome Trust, will pay for Gold OA to monographs in the medical humanities. It appears likely, given recent moves among European funders, that policies around lengthened embargo periods for the humanities will be harmonized with other disciplines down to zero in coming years.

Open access in law

The transition to OA of legal literature can be said to be still in its infancy. Legal studies feature some of the lowest OA prevalence levels. In part, this is because of low levels of awareness and little demand for OA publishing outlets amongst legal scholars and practicing lawyers. Those who would most benefit from the OA movement (e.g. law schools unable to subscribe to a wide range of law journals and practitioners in smaller law firms) have little influence over publication behavior. Further, despite the rising importance of international law, the relevance of national legal systems remains high, causing most law journals and law books to focus on the legal situation in a specific country and to be managed by publishing houses in that same country. Often, legal scholars know their publisher(s) personally and tend to publish in a relatively small number of journals -– most of which are closed access.

A) Author behaviour and attitudes – Generally speaking, legal scholars have been reluctant to adopt OA despite agreeing that the research field would benefit from journals that publish OA articles[84–86]. Even though the field is slowly moving towards OA, many authors of legal publications either are not aware of OA or have little to no incentive to publish their research in OA journals or public repositories[87]. In legal studies, it is common practice that academics and practicing lawyers publish in the same legal journals or legal commentaries. Some practicing lawyers might even prefer to publish in law journals behind paywalls, thereby guaranteeing an exclusive access to their knowledge and ensuring that potential clients are not able to find the relevant information themselves[88]. Because of the high relevance of national legal systems, large parts of the legal literature is written in the languages of these countries and published in law journals or books operated in the same countries. Accordingly, the argument that OA enables a worldwide readership is of limited relevance in the field of law. On the other hand, many legal issues are of interest not only to academics and practicing lawyers, but also to the media and politics. According to Hunter (2005), scholarship in law "is arguably the most useful to the public and that has the greatest effect on public policy". The role of electronic media in supporting scholarly communication and dissemination of research findings is growing but the most important databases (e.g. HeinOnline and LexisNexis in the United States or BeckOnline in Germany) are paywalled[89].

B) Publisher behaviour and policies – In the U.S., many or most law reviews are published by law schools, not by for-profit publishers[89–91]. In contrast to commercial publishers, law schools do not have the usual incentives to oppose OA. Hence, a large and growing number of US law journals are OA. The situation is very different in jurisdictions outside the US where legal scholarship is generally published by commercial publishers[84,91]. Due to the small demand for OA publishing on part of legal scholars, there are little to no incentives for for-profit publishers to set up new OA journals or book series or to convert existing subscription-based journals to OA. There are some notable exceptions, however. In recent years, some OA law journals have been set up that are predominantly community-driven and operated independently from commercial publishers (e.g. JIPITEC in the EU, Forum Historiae Iuris in Germany or sui generis in Switzerland). According to the DOAJ, there are about 200 OA law journals. OA law journals from the US are in large part not listed, although it is not clear why this is the case. The Creative Commons list of OA Law Adopting Journals lists 37 OA law journals but most of the 18 Harvard Law School Journals (all but one of them are OA) are missing[92].

C) Infrastructure of scholarly communication – Most OA journals and open repositories are operated by universities and their law departments. Most universities in the U.S. have their own repositories and also publish their own legal OA working paper series. This idea gains some traction in other countries, for example in Germany, the Netherlands or Italy. Prominent examples of universityled OA journals involve Stanford Technology Law Review, Harvard Human Rights Journal, Bucerius Law Journal or the International Journal of Communications Law & Policy. There is only a limited number of disciplinary repositories and the uptake of repositories such as LawArXiv appears to be slow. In the US and in international law, the most popular disciplinary repository for law professors is SSRN, which is now owned by Elsevier. In English-speaking legal scholarship, scholars find it even difficult to build reputation without being represented in SSRN[93]. A growing number of universities is further providing support for setting up OA journals or transforming closed to OA journals (for example, by providing an OJS infrastructure). Since practicing lawyers and legal scholars work almost exclusively with texts, OA infrastructures do not have to fulfill demanding technical requirements.

D) Structural and institutional factors – There are three types of work products in legal research: monographs, journal articles and commentaries covering a specific law. PhD theses in the field of law are predominantly published as monographs. Many universities routinely make PhD theses OA (for example Harvard University in the U.S. University of St.Gallen in Switzerland). While the authors of legal books are mostly academics, this remains different for journal articles and legal commentaries where both academics and practitioners contribute. As a result, not only scholars and universities, but also practicing lawyers need to be convinced to move towards OA. One possible way to foster OA amongst legal scholars might be to encourage academics and practitioners to publish in different journals and commentaries. In this scenario, academics could publish their works in scientific OA journals and practitioners could keep on using closed access journals and commentaries, which, however, would be more practice-oriented. Research project costs often are smaller in the field of law compared to other disciplines. As legal scholars are not dependent on third party funding, so that funder OA requirements have only limited potential to incentivize OA publishing.

E) OA mandates and policies – OA mandates by public funding agencies, research foundations and private companies only have limited impact in the field of law since legal research is relatively inexpensive and therefore does not depend on third party funding in large parts[90]. As law is often considered as a discipline related to the humanities, scholars in this field face the same OA requirements as the social sciences and humanities, including relatively long embargo periods for Green OA and

monographs that are excluded from OA requirements. It can be assumed that OA mandates by universities, if mandatory, will have a greater potential to foster some change in the field of legal academia than OA mandates by public funders. An important alternative to top-down OA mandates are OA policies from law schools (for example the Harvard Law School Open Access Policy) and non-binding statements promoting OA. In 2009, the directors of the law libraries of 12 US Universities signed the Durham Statement on Open Access to Legal Scholarship. This statements urges law schools to make the definitive versions of journals and other scholarship produced at the school immediately available upon publication in stable, open, digital formats, rather than in print[94].

Discussion and conclusion

Over the course of the last three decades, OA to the scholarly literature has emerged as a new norm of scholarly publishing. As a response to perceived limitations of the subscription-based model of scholarly publishing and propelled by technical possibilities offered by the Internet, OA promises the removal of major barriers in assessing, distributing and re-using research findings[6]. OA publishing has grown substantially across different types of publication outlets, academic disciplines and research contexts, resulting in growing shares of scholarly publications being made openly accessible. While there is little doubt about the notion that OA is of global relevance with the potential to revolutionize the ways in which scholarly publications are shared, many of the discussions surrounding OA still revolve around the question of how it affects publishing practices across different academic disciplines. This question has become increasingly relevant against the background of first, funding organisations, governments and universities implementing OA mandates and policies that require scholars across all disciplines to make their research outputs OA and, second, vast amounts of resources being dedicated to the development, maintenance and advancement of respective publishing infrastructures.

Reviewing bibliometric studies that assessed OA prevalence and publishing patterns across broad academic disciplines in the first part of this review, we examined how different disciplines have adopted OA publishing over time and identified discipline-specific patterns of OA publishing. In the second part of this review, and based on a social shaping of technology perspective, we examined a variety of data sources and identified discipline-specific barriers and potentials for OA. Doing so, we explained the publishing patterns and trends observed in the first part of this review. We found that, over the last three decades, scholarly publishing has experienced a shift from closed access to OA. The proportion of scholarly literature that is openly accessible has increased continuously across all disciplines, resulting in overall OA levels well above 50% for publication years after 2010. Most OA appears to be published as journal articles in subscription journals for which the accepted of the published version can be retrieved from an open repository (Green OA). Publication of articles in pure OA journals (Gold OA) is also of importance for scholarly publishing, even though the relative uptake on Gold OA remains well below Green OA for most publication years and academic disciplines. Hybrid OA generally is of little variance for OA publishing, with 1% or less of all scholarly outputs being published as articles free under open licenses in subscription journals. The importance of Bronze OA is comparable to Gold OA, featuring similar levels of uptake. Having compared OA publishing patterns for the broad academic disciplines natural and technical sciences, medical sciences, social sciences, law and humanities, we found that the shift of scholarly publishing towards OA occurs uneven across disciplines in two respects. First, the growth of OA has not been uniform across disciplines; scholars in different disciplines differ substantially in how much they embrace the idea of OA, which manifests itself in varying proportions of openly accessible research outputs across disciplines and sub-disciplines. Second, academic disciplines have not converged on a set of homogeneous OA publishing practices, but differ substantially regarding the OA publishing channels scholars use to publish their research outputs OA. This unfolds as follows: scholars in medical and health-related sciences initially were reluctant to adopt OA publishing, but soon the OA uptake in these disciplines increased substantially and particularly biomedicine and clinical medicine took on leading roles in embracing OA. Medical scholars make research outputs openly accessible predominantly by publishing them in journals: The Gold OA route is of central importance for OA in medical sciences, followed by Hybrid, Bronze, and, with some distance, Green OA. Factors facilitating OA and shaping OA publishing practices in these disciplines are strong OA mandates combined with both funder-operated repositories and available funding for APCs, a richness in highquality OA journals and the perception of authors that OA journals allow for a wider circulation of publications than subscription journals do. The medical sciences are closely followed by the natural and technical sciences in embracing the idea of OA. Within this broad discipline, however, we found different patterns of OA publishing both in terms of OA prevalence rates and OA routes: Scholars in physics, mathematics, information technology, astronomy and biology were the early pioneers of OA and continue to make large shares of their research outputs OA, whereas scholars in engineering and chemistry are more reluctant to make research outputs openly accessible. Further, while Green OA plays an important role for scholars in physics, mathematics, information technology, astronomy and biology (followed by Bronze, Gold, and with some distance, Hybrid OA), scholars in engineering and chemistry publish most OA through the Gold OA route. OA in physics, mathematics, information technology, astronomy and biology has been facilitated by an existing culture of preprint distribution and by high levels of familiarity with OA publishing in general and Green OA in particular. Barriers to OA in chemistry and engineering can be identified as concerns about the quality of OA journals, which are shared by scholars, publishers and learned societies alike, as well as high degrees of industrial integration within these fields. The OA uptake in the social sciences is well below the medical and natural and technical sciences, but remains above OA prevalence rates that we observed for the humanities and law. For scholars within the social sciences, open repositories appear to be of central importance for making research outputs openly accessible, closely followed by publication in Gold OA journals, and, with some distance, Hybrid and Bronze OA. We identified several factors that shape OA publishing practices within the social sciences. Most importantly, this

includes authors' concerns about the quality and prestige of OA journals, the central role of monographs in terms of academic career advancement and difficulties in assessing funding for APCs and BPCs. These factors also explain why most OA within the social sciences is published via the Green route. We observed signs of cultural change particularly in young scholars, who embrace the idea of conducting science more openly. Humanities features OA uptake levels well below the social sciences. Most OA within the humanities is published as Hybrid OA, followed by Green OA, Bronze OA and Gold OA. The most important factors shaping these publishing practices are comparable to those identified in the social sciences, including a dry climate for APC and BPC funding, the central role of monographs, which are less likely to become OA, and authors, publishers and scholarly societies being opposed to OA. Just like in the social sciences, there is, however, some movement with new economic models that do not rely on author payments appearing to have some traction with humanities scholars. OA in law is still in its infancy with legal scholars making only small proportions of their research outputs OA. In large part, this is due to low levels of awareness and little demand for OA within the academic community. Of relevance is also that OA mandates and policies only have limited impact on publishing behaviour as legal studies in large part do not depend on third party funding. The financing of publication fees for publishing in OA journals appears to constitute a major barrier to OA within the humanities, social sciences and law. We believe that new OA models that do not rely on author payments represent a viable alternative to financing OA within these disciplines. This includes models such as the OLH or other crowd funding initiatives, such as KU.

These findings indicate that, as OA is implemented and used across different academic disciplines, it is shaped by the scholars that use respective communication technologies. In turn, OA technologies shape the ways in which scholars communicate and disseminate their research findings. Our findings also suggest that, in spite of the transformational potential of OA, the shift towards OA is uneven across disciplines and even sub-disciplines. We found that academic disciplines feature distinctive research cultures that have grown historically and manifest themselves in discipline-specific publishing practices. These publishing practices vary fundamentally in terms of their compatibility with OA publishing formats, which is the reason why the implementation of OA can be assumed to be a natural continuation of publishing cultures in some disciplines, while in other disciplines, the implementation of OA faces major obstacles and requires a change of research culture.

Our review has several limitations and these should be taken into account when interpreting our results. First, most of the bibliometric studies included in our review assessed OA publishing practices across broad academic disciplines, that is, the natural and technical sciences, medical sciences, social sciences, humanities and law. Choosing broad academic disciplines as units of analysis produces data that is fairly coarse-grained. Consequently, there is a chance that relevant differences in publishing practices between sub-disciplines remain undetected. For example, the few bibliometric studies that have assessed OA publishing practices for the natural sciences and related sub-disciplines revealed that there are substantial differences in the OA uptake between physics and chemistry. Therefore, we encourage future bibliometric research to assess OA publishing practices not only across broad disciplines, but to also take into account related sub-disciplines and research fields. Second, only two bibliometric studies in our review have included Bronze OA and Hybrid OA in their analyses, resulting in highly limited data on the relative uptake on these OA routes. This likely limits the robustness of our conclusions. We encourage further research to include Bronze and Hybrid OA in their bibliometric analyses. Third, in explaining OA publishing patterns, we conducted a narrative review by the means of which each co-author identified relevant socio-technical forces that affect OA within their area of research training. A major limitation of narrative reviews is that there is a chance that evidence has been selectively chosen. We tried to keep limitations in objectiveness to a minimum by basing the narrative review on an analytical framework.

Overall, our review is the first to comprehensively explain OA publishing patterns across academic disciplines. We identified patterns and trends of discipline-specific OA publishing practices and revealed barriers and potentials for OA across disciplines. Doing so, we contributed to understanding how different disciplines adopt and shape OA. We encourage further research to investigate the underlying mechanisms and factors that shape scholarly communication in general and OA publishing practices in particular. A profound understanding should inform both OA policies and community-driven efforts in promoting OA.

Data availability

All data underlying the results are available as part of the article and no additional source data are required.

Grant information

The author(s) declared that no grants were involved in supporting this work.

Acknowledgements

Preliminary findings of this study were presented at the 12th Open-Access-Tage: Varieties of Open Access conference, Graz, Austria from the 24th–26th September 2018. Severin, A. (2018, October). Der Weg zu Open Access in den Geistes- und Sozialwissenschaften: Publikationspraktiken, Hindernisse und Potentiale. A copy of the presentation is available in German on Zenodo: http://doi.org/10.5281/zenodo.1441034.

The authors would like to thank Peter Suber for valuable comments to the Law chapter. We would also like to thank Alexander Grossmann for valuable comments on the terminology "Bronze OA".

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