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# Game theory and scholarly publishing: premises for an agreement around open access

Abdelghani Maddi<sup>1</sup>

<sup>1</sup> *abdelghani.maddi@hceres.fr*

Observatoire des Sciences et Techniques, Hcéres, 2 Rue Albert Einstein, Paris, 75013 France.

## Abstract

Stakeholders in research and scientific publishing are gradually joining the Open-Access (OA) movement, which is gaining momentum to become nowadays at the heart of scientific policies in high-income countries. The rise of OA generates profound changes in the chain of production and dissemination of knowledge. Free access to peer-reviewed research methods and results has contributed to the dynamics of science observed in recent years. The modes of publication and access have also evolved; the classic model, based on journal subscriptions is gradually giving way to new economic models that have appeared with the arrival of OA.

The objective of this article is twofold. First, propose a model for the publishing market based on the literature as well as on changes in open science policies. Second, analyze publishing strategies of publishers and institutions. To do so, we relied on game theory in economics. Results show that in the short term, the publisher's equilibrium strategy is to adopt a hybrid-publishing model, while the institutions' equilibrium strategy is to publish in OA. This equilibrium is not stable and that in the medium/long term, the two players will converge on an OA publishing strategy. The analysis of the equilibrium in mixed-strategies confirms this result.

## Keywords

Publishing Market, Open Access, Business Models, Business Strategies, Game Theory, Nash Equilibrium, and Pareto Optimality.

## JEL codes

C7, D4, D5, L82, D83

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<sup>1</sup> Corresponding author : Abdelghani Maddi, Observatoire des Sciences et Techniques, Hcéres, 2 Rue Albert Einstein, Paris, 75013, France, T. 33 (0)1 55 55 61 48.

## Introduction

The arrival of digital technology at the start of the 21<sup>st</sup> century has completely changed the world of scientific publishing (Alt, Militzer-Horstmann and Zimmermann, 2015, 2016a, 2016b; Ponte, Mierzejewska and Klein, 2017). Publishers' business strategies have seen several innovations regarding the pricing of research products (Ponte, Mierzejewska and Klein, 2017). In the traditional model of scientific publishing, also called the "reader-pays" model, readers access publications only through subscriptions to scientific journals (the journal's main source of income) (Schimmer, Geschuhn and Vogler, 2015). One of the only strategies available to publishers in this business model is to adjust the price according to the level of demand in the market which depends greatly on the quality of the journals, in addition to the number of publications received (Björk and Solomon, 2012; Pinfield, Salter and Bath, 2016).

With the advent of Open Access (OA), other business models have emerged. The best known are the "author-pays" and "hybrid" models. In the first one, the research results (publications, data, etc.) are freely accessible to everyone without any geographic or time limit (Sotudeh, Ghasempour and Yaghtin, 2015; Sotudeh and Estakhr, 2018). In this model, it is the authors who pay (usually through their institution or funder) publication fees (*Article Processing Charges – APC*) to make their research freely accessible (Marincola, 2003; Asai, 2020a). In the hybrid model there is a "cohabitation" of the two models "reader-pays" and "author-pays" (Pinfield, Salter and Bath, 2016; Besancenot and Vranceanu, 2017). Le modèle hybride a été largement adopté à partir de 2013 par les cinq plus grands éditeurs mondiaux : Elsevier, Springer, Taylor et Francis, Sage et John Wiley and Sons, qui représentent plus de 70 % du marché de l'édition de revues (Besancenot and Vranceanu, 2017). Thus, in the same journal, there could be OA publications for which the authors have paid fees and publications accessible by subscription. It should be emphasized here that, in the hybrid model, if an institution, involved in the OA movement, subscribes to this journal, it systematically pays twice for its OA articles published there (APC and subscription).

There are other economic models, such as the "sponsor-pays" model when a journal is fully funded by an organization or an association (Koehler, 2006; Fuchs and Sandoval, 2013; Normand, 2018). In this model, neither the authors nor the readers pay to publish or read the articles. There is also the "freemium" model in which the publisher makes all or part of a publication available in a simple format (html or text for example), then remunerating himself on access to more convenient formats (eg pdf) for the reader, or on access to additional information, for a variable price (Mounier, 2011; Despot, Ljevak Lebeda and Tomašević, 2015; Söllner and Mittermaier, 2017).

The proliferation of business models for scientific publishing is a real boon for publishers (Butler, 2013; Van Noorden, 2013; Björk, 2017b). Björk (2017) has shown that, on the one hand, large publishers continue to dominate the market which operates under the rules of an oligopolistic market, and on the other hand, the profits made by the latter have increased considerably with the arrival of the OA. The situation is different for institutions and funders. In addition to the costs of subscriptions that must bear to guarantee their researchers access to publications, they are now increasingly led to pay OA publication costs (APC) which can reach 5,000 euros for a single publication. It is for this reason that some consider that the current system of subscriptions to publishers is becoming anachronistic and it is imperative to go to fully OA model. The concept of the "Big Deal" then appeared to designate licensing agreements

between publishers and institutions (or funders) including both the price of APCs and subscriptions (Ball, 2004; Frazier, 2005; Galbraith and Hess, 2020; Hunter, 2020).

Beyond purely economic considerations, the scientific world is witnessing the rise of a movement in favor of OA which consists in saying that insofar as research is mainly financed by public funds, the results of research should be too (Tennant *et al.*, 2016; Maddi, 2020; Brainard, 2021; Maddi, Lardreau and Sapinho, 2021). In addition, moving to a model entirely in OA allows better equity, in particular for researchers whose institutions do not have sufficient means to finance both subscriptions and APCs (Schöpfel, 2017; Iyandemye and Thomas, 2019; Fosci *et al.*, 2020; Raju *et al.*, 2020).

A new paradigm, around the "Big deal", in the scientific publishing market was then born to allow better dissemination of research products (Bernius *et al.*, 2009). This is about empowering researchers not only to freely access the results of peer-reviewed research, but also to publish "freely" without having to pay for their publication to be open access. Within the scientific community, we commonly speak of the "Read and Publish" and "Publish and Read" license agreements (Editor, 2019; Ottesen, 2019; Olsson *et al.*, 2020; Phaf, 2020). The two concepts are very similar, with the difference that the first places more emphasis on being able to "read / access" freely, while in the second the emphasis is on the ability to publish in OA without paying APCs.

Although the question of the impact of digital transformations on the publishing market is largely invested in the literature, little work analyzes the question from an economic point of view (e.g. market balance). Much of the current research on the publishing market reports on the various existing models and their development (Mazzarol and Soutar, 2001; Bernius *et al.*, 2009; Laakso *et al.*, 2011; Scheufen, 2015; Potts *et al.*, 2017; Magadán-Díaz and Rivas-García, 2018; Clark and Phillips, 2019), characteristics of the competition (Feather, 2006; Björk, 2017b; Ponte, Mierzejewska and Klein, 2017; Hagner, 2018), costs of scientific publishing in the OA era (McCabe, Snyder and Fagin, 2013; Van Noorden, 2013; Pinfield, Salter and Bath, 2016; Bruns, Rimmert and Taubert, 2020), self-archiving practices for research results (Alt, Militzer-Horstmann and Zimmermann, 2016a; Vuong, 2020), the difficulties to switch to an OA model and the negotiation power of publishers, or the future challenges of scientific publishing (Butler, 2013; Monastersky, 2013; Wilbanks, 2013; Lomazzi and Chartron, 2014; Björk, 2017b; Asai, 2020a, 2020b), including in emerging countries (Schöpfel, 2017; Cassi, Dosso and Mescheba, 2018; Iyandemye and Thomas, 2019; Vuong, 2019; Mueller-Langer, Scheufen and Waelbroeck, 2020; Raju *et al.*, 2020, 2020).

The purpose of this article is to examine the issue through the prism of economic market analysis using game theory. First, the objective is to model the publishing market objectively by using the results of the literature and the dynamics observed in recent years both within scientific communities and in terms of public policies. Second, study the possible equilibria to which the market can converge using the principle of "best response" in game theory and the Nash equilibrium. The stability of equilibria and their Pareto optimality is also analyzed.

It is important to clarify that in the present study it is mainly about the so-called "gold" or "diamond" roads of OA. That is, the "author-pays" and "sponsor-pays" business models. The aim is to analyze markets where OA is the result of an institutional effort. The other models: "green" or "bronze" road are dissemination models that reflect the efforts of researchers and journals to make certain publications accessible (self-archiving).

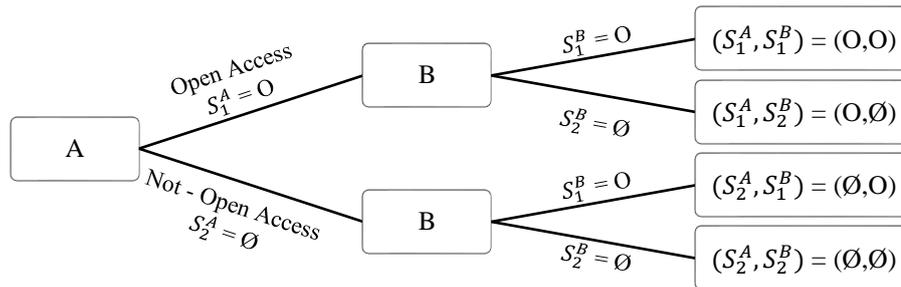
### Literature review: the scientific publishing market in game theory

Although not numerous, the existing studies that use game theory to analyze the publishing market provide a sufficiently developed theoretical framework. The publishing market is defined as the meeting place of three types of economic agents: publishers, authors and readers.

In accordance with the axioms of rationality in behavioral microeconomics, each of these agents implements strategies to maximize its utility. For the authors it is a question of maximizing their “reputation”, source of funding, which depends on both the academic and societal impact, for the readers the maximum utility lies in the appropriate choice of articles to read according to their intrinsic (and not perceived) quality, while for publishers it is about maximizing profits, given the strategies adopted by both authors and readers (Hanuske, Bernius and Dugall, 2007; Bernius *et al.*, 2009; Besancenot and Vranceanu, 2017).

(Hanuske, Bernius and Dugall, 2007) have built a theoretical model from the strategies ( $S_i$ ) of authors who make a trade-off between “publishing in open access” (O) and “not publishing in open access” ( $\emptyset$ ). (Hanuske, Bernius and Dugall, 2007) compare the payoff matrices of the authors in a classical and quantum game by approaching three types of game: a zero-sum game, the "prisoners' dilemma" and a "stag hunt" version of the game. In their model, the payoff is represented by the reputation obtained as a result of the publication. For two researchers A and B the game tree is as follows:

**Fig. 1. Classical tree of the open access game.**



Source: Hanuske, Bernius and Dugall (2007), p. 651.

The global strategic space  $\mathcal{S}$  is the Cartesian product of the two strategies of A and B:

$$\mathcal{S} = \mathcal{S}^A \times \mathcal{S}^B = \{(o,o), (o, \emptyset), (\emptyset,o), (\emptyset, \emptyset)\}$$

The payoff matrix for this game is written:

**Table 1: General open access payoff matrix**

A/B	O	$\emptyset$
O	$(r + \delta, r + \delta)$	$(r - \alpha, r + \beta)$
$\emptyset$	$(r + \beta, r - \alpha)$	$(r, r)$

Source: Hanuske, Bernius and Dugall (2007), p. 652.

The parameters  $\alpha$  et  $\beta$  ( $\alpha, \beta \geq 0$ ) respectively represent the decrease and the increase in reputation depending on the chosen strategy.  $\delta$  represents the advantage that A and B derive if they simultaneously choose to publish in Open Access.

In this game, the reasoning is as follows: in a traditional (non-OA) model, the reputation of researchers' work largely depends on the journals in which they publish. In the context where the study of Hanuske, Bernius and Dugall (2007) is carried out (ie mid-2000s), the major journals in most disciplines have not yet adopted an OA model, or at least a hybrid model. The great transformation took place a few years later (in 2013) as underlined above. Therefore,

publishing OA for an individual researcher was a risk as well-established journals in the market are subscription-based. However, publishing in OA allows better visibility of research and therefore better impact and increased reputation. Hanauske, Bernius and Dugall (2007) have shown that a strategy in favor of OA cannot be chosen at the time the study is carried out, due to a lack of sufficient incentive for researchers to publish freely access (especially from the point of view of the research evaluation where the attention is more focused on impact than on openness). The high level of risk made the researchers stuck in a Nash equilibrium with strategies  $(\emptyset, \emptyset)$ . The authors concluded that high pressure from the scientific community to publish in OA could change the characteristics of the publishing market and make it more open, as is the case in certain disciplines such as mathematics or physics.

The study by (Bernius *et al.*, 2009) came to similar conclusions regarding the lack of incentive for researchers to publish in OA, which slows the process of paradigm shift towards a more open model. Therefore, the emphasis on the impact of publications is so strong that researchers are more or less forced to choose a journal based on its impact factor and not its openness status. In addition, the authors underline the complexity of the landscape on the side of the open access publication with a multitude of approaches and models, which constitutes a brake on the development of the open access model.

(Habermann and Habermann, 2009) provided an improved version of the model of Hanauske, Bernius and Dugall (2007) who develop a two-researcher approach with symmetrical strategies and gains. In the new version proposed by (Habermann and Habermann, 2009) it is rather an asymmetrical game with a conflict of interest between researchers on the one hand and publishers on the other.

Thus, in this configuration, there are two payoff matrices; one for publishers and one for authors. The two players have two strategies: to publish in OA (one notes respectively for the authors and the editors:  $(s_1, p_1)$ ) or to choose the traditional way  $(s_2, p_2)$ .  $R > 0$  represents the gain (reputation) of the authors,  $0 < r < R$  is the decrease in the author's reputation if he chooses the  $s_1$  strategy (for the same reasons mentioned in Hanauske, Bernius and Dugall (2007)). (Habermann and Habermann, 2009) integrate the impact of publications ( $I$ ) as an additional source of gain for both authors and publishers.

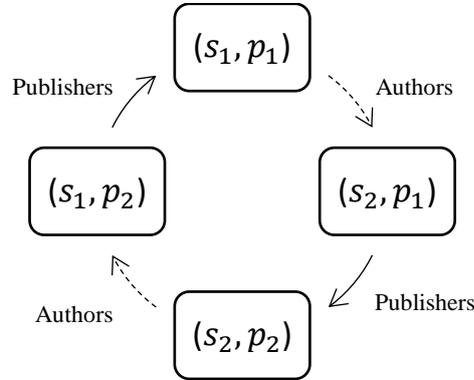
This impact drops by  $0 < \tau < I$  in a traditional model (less visibility). In terms of expenditure, Habermann and Habermann (2009) integrated three types:  $L > 0$  corresponds to expenditure in an OA model. According to the authors,  $L$  is a cost borne equally by the authors and the publishers  $(s_1, p_1)$ .  $G > 0$  represents the price of subscriptions and / or APC paid by researchers. Finally, the authors also integrate  $P > 0$  to denote the high profit of publishers from very expensive journals in a traditional model.

**Table 3: Payoffs of authors and publishers according to strategies**

Strategies	Author's payoff	Publishers payoff
$s_1 \leftrightarrow p_1$	$(R - r) + I - L/2 - G$	$G + I - L/2$
$s_1 \leftrightarrow p_2$	$(R - r) + I - L$	0
$s_2 \leftrightarrow p_1$	$R + (I - \tau) - G$	$G + (I - \tau) - L$
$s_2 \leftrightarrow p_2$	$R + (I - \tau) - G - P$	$G + (I - \tau) + P$

Hanuske, Bernius and Dugall (2007) described an unstable equilibrium with an oscillation in the form of a circle between several strategies:

**Fig. 2: Iterative change in strategies between authors and publishers**



If authors and publishers simultaneously adopt an OA strategy  $(s_1, p_1)$ , authors can increase their gain by changing their strategy from  $s_1$  to  $s_2$  since  $R + (I - \tau) - G > (R - r) + I - L/2 - G$ . The game therefore switches to a strategy  $(s_2, p_1)$ . This new configuration also encourages the editors to modify their strategy to go to  $p_2$ . This will allow them to increase their gains  $G + (I - \tau) + P > G + (I - \tau) - L$ . The global strategy then becomes  $(s_2, p_2)$ . Authors can improve their gain by switching to a strategy  $(s_1, p_2)$  and so on. In this model, equilibrium is therefore a time dependent function.

In the study of (Besancenot and Vranceanu, 2017) the reasoning is completely different. Publishing in OA does not constitute a risk or loss of reputation for authors (as is the case in the previous studies), on the contrary. (Besancenot and Vranceanu, 2017), relied on the bibliometric literature to emphasize that researchers who publish in OA are generally good researchers and that several fundamental journals in different disciplines have adopted the OA or hybrid model from 2013. The authors hypothesized that choosing to publish in OA could serve as a quality signal for the scientific community (readers) and for publishers.

(Besancenot and Vranceanu, 2017) therefore built their model using signal theory. The authors make a trade-off between an OA strategy (noted A) and a traditional strategy (T) (not OA).  $\mu$  is the proportion of high quality papers ( $\theta^H$ ). By deduction,  $(1 - \mu)$  is the number of low / medium quality papers ( $\theta^L$ ). As good articles are less frequent (cf. distribution laws of citations in bibliometrics),  $\mu < 1/2$ .

The gain function, designated by the product between the size of the readership ( $\delta_S$ ) and the quality, of an author of type  $i \in \{H, L\}$ , for a strategy  $S \in \{A, T\}$  is composed of the intrinsic quality  $\theta^i$  and the perceived quality  $E(\theta|[S])$ .  $\lambda$  is a structural parameter to measure the weight of the two terms. The lower  $\lambda$ , the more important the intrinsic quality. The authors assume that  $\lambda < 0,5$ . Finally,  $c$  denotes the price of APCs in an OA (or hybrid) model. Therefore,  $I_S$  takes 0 in a traditional model and 1 in an OA model. The gain function is written:

$$U^i = \delta_S [(1 - \lambda)\theta^i + \lambda E(\theta|[S])] - I_S c$$

For publishers, the payoff is represented by the income  $R$  which depends on the frequency of authors who have opted for OA multiplied by the price of APCs:  $\varphi c$ , plus the frequency of

authors who have opted for a traditional model multiplied by income subscriptions  $(1 - \varphi)E[\theta|T]$ . The editor's gain function is therefore written:

$$R = \varphi c + (1 - \varphi)E[\theta|T]$$

Besancenot and Vranceanu (2017) have defined several types of equilibria for publishers in this market depending on the strategies adopted by the authors. An equilibrium with: opposing strategies, identical strategies and hybrid strategies. The table below summarizes the different situations:

**Table 2: Types of equilibria according to the authors' strategies**

#	Equilibrium type	Publishing market	Function of editors at equilibrium (see Besancenot and Vranceanu (2017), for demonstrations / conditions)	Author' strategies
1	Separating equilibrium	Global	$R_{sep}(c) = c\mu + (1 - \mu)\theta^L$	Opposing strategies: good researchers choose OA and less good traditional.
2	Pooling equilibrium	Open Access	$R_{PA}(c) = c$	All Researchers Choose OA: Occurs when the cost of publishing in OA is not high.
3		Traditionnel	$R_{PT} = E[\theta T] = \mu\theta^H + (1 - \mu)\theta^L$	All researchers choose the traditional model: Occurs when the cost of publishing in OA is high.
4	Hybrid equilibrium	Hybrid 1	$R_{H1}(c) = \theta^L - \mu\lambda\delta_A(\theta^H - \theta^L)\left[\frac{(\theta^L - c)}{c - (\delta_A - \delta_T)\theta^L}\right]$	All the good researchers choose OA, the less good ones choose both (sometimes OA and sometimes traditional).
5		Hybrid 2	$R_{H2}(c) = \varphi c + (1 + \varphi)E[\theta T]$	All the less good researchers choose traditional, the good ones choose both (sometimes OA and sometimes traditional).

(Besancenot and Vranceanu, 2017) have shown that the publishers' preference for a particular equilibrium according to the choices of the authors depends on four elements: quality of the journal, the size of the readership in a traditional model (number of subscriptions notably), the difference in terms of accessibility / readership in the two models (OA and traditional) ( $\delta_A - \delta_T$ ) and the quality gap between high impact and low / medium impact researchers. The table below summarizes the publisher preferences:

**Table 3: Journal types and preferred equilibria**

Journal type	$\delta_T$	Accessibility gap ( $\delta A - \delta T$ )	Quality gap ( $\theta^H - \theta^L$ )	Publisher preferred equilibrium (#)
Leading	High	Low	Low	1
Specialized (good)	High	High	Low	1 et 2
Second tier	Low	High	High	1 et 3

Source: Besancenot and Vranceanu (2017), p. 20.

We can see in the table that the separating equilibrium (# 1: all good researchers choose to publish in OA and the less good ones in non-OA) is preferred whatever the situation. On the other hand, in the case of intermediate quality journals (good / medium quality) where the readership gap between OA and traditional is high (in favor of OA obviously) and the quality gap between good and less good researchers is low, the editors will prefer, in addition to # 1, a model in which all the researchers publish in OA (mixing equilibrium, # 2). Finally, for journals with low impact, low readership and gaps in accessibility and high quality, publishers will prefer, in addition to the separator balance, a traditional mixing balance (# 3).

Until then, the various studies have built their reasoning at the finest mesh level: researchers, while OA publication strategies are largely influenced by institutions. At least, they are the ones bearing the costs of subscriptions and APCs. Institutions and funders devote a large budget to the scientific publishing market and open science; the market is estimated at over 5 billion euros. Therefore, in this article, the reasoning is built from the institutions considered the center of decision, in addition to the publishers.

### Main assumptions

As pointed out previously, in the current publishing market, there are three main economic models: subscription based, open access and hybrid that combines the first two. In this section, we use the literature to model the level of production and accessibility, academic impact and costs / profits in each of the three economic models.

#### *Production and access*

We assume that each model allows producing a number of publications denoted  $P^C$ ,  $P^{OA}$  for the subscription and OA models respectively. In terms of dissemination of publications and their accessibility to the scientific community, each of these two models allows a different level of dissemination that we denote  $A^C$ ,  $A^{OA}$  respectively. In the context of the hybrid model, the number of publications corresponds to the value  $P^H = [\lambda P^{OA} + (1 - \lambda)P^C]$  with  $\lambda$  the proportion of open access publications. Likewise, the number of publications accessible in this model is  $A^H = [\lambda A^{OA} + (1 - \lambda)A^C]$ . Since OA is rather an exception in the hybrid model, one can reasonably assume that  $\lambda < 0.5$ .

In terms of production, as shown in the literature (Schimmer, Geschuhn and Vogler, 2015), a transition to an OA model would increase the overall production of scientific publications as well as their dissemination. Likewise, as shown in (Pinfield, Salter and Bath, 2016; Khoo, 2019), researchers are increasingly inclined to publish in OA even in hybrid journals. Although many institutions and funders advise against publishing OA in hybrid journals (ANR, 2019; Hunter, 2020), the market share of hybrid journals in all OA publications has increased dramatically with the OA movement (Björk, 2012, 2017a; Laakso and Björk, 2016; Besancenot

and Vranceanu, 2017). It is therefore possible to establish the following relations:  $P^{OA} > P^H > P^C$  on the one hand and  $A^{OA} > A^H > A^C$  on the other hand.

### *Academic and societal impact*

There is an abundant literature on academic impact based on the openness status of publications or journals. It is important to distinguish between OA journals on the one hand and OA publications. Overall, open access publications are more visible and therefore on average more cited (Eysenbach, 2006; Norris, Oppenheim and Rowland, 2008; Ghane, Niazmand and Sabet Sarvestani, 2020). On the other hand, from a journal perspective, the literature shows that high impact journals are mostly hybrid. The average impact of open access journals is lower, but still higher than that of completely closed (subscription based) journals. The reason behind these results is that journals that are well established in the market are generally hybrids (Mueller-Langer and Watt, 2014; Clements, 2017; Sotudeh and Estakhr, 2018; Sotudeh, Arabzadeh and Mirzabeigi, 2019). These journals therefore receive more citations than fully open access journals, many of which are recently created.

In short, the academic impact depends on both the accessibility of publications (openness) and the notoriety of the journals. We notice:  $I^j(A, N)$ , with  $I$  the journal impact,  $j$  the publishing model of journal, “A” the degree of accessibility of the publications and “N” the notoriety of the journal. For the three publishing models we establish:  $I^H(A^H, N) \approx I^{OA}(A^{OA}, N) > I^C(A^C, N)$ .

### *Costs and Profits*

From the point of view of publication costs, it is the hybrid model that is the most expensive insofar as for a good part of the publications, the institutions pay both the APCs to publish in OA and the subscriptions to have access to the publications. On the other hand, it can be assumed that in a successful transition to an OA model, the fees that institutions would incur will be lower than the fees paid in a subscription model. The reason why the costs in an OA model would be lower is in the fact that the institutions have an increasing negotiating power, since scientific publications are produced and reviewed by researchers. The added value provided by publishers is decreasing with the rise of self-archiving (and open peer review) of publications with dedicated platforms. The costs in an OA business model are mainly those of APCs, while in a subscription business model they are the subscription prices and finally in a hybrid model the costs are made up of the subscription prices in addition to the total cost of the publications in OA. This cost depends on the number of OA publications in hybrid journals.

We can therefore note:  $C^H(\sum \varphi * APC + S) > C^C(S) > C^{OA}(APC)$ . With  $C$  the publication cost. Conversely, and by deduction, publishers' profits will therefore be higher in a hybrid model and less important in an OA model where institutions and funders carry out negotiations. We therefore note:  $B^H < B^C < B^{OA}$  With B the profits of the publishers.

### **Institutions' payoffs**

The payoffs of institutions and funders depend on the three elements presented in the previous section, namely the number of publications produced and to which they have access, the academic impact and the costs incurred. We note the payoffs of the institutions for the models: OA, hybrid and on subscription  $U_I^H, U_I^{OA}, U_I^C$  respectively. The formalization of the gains is as follows:

- $U_I^{OA} = P^{OA} + A^{OA} + I^{OA}(A^{OA}, N) - C^{OA}(APC)$
- $U_I^C = P^C + A^C + I^C(A^C, N) - C^C(S)$
- $U_I^H = [\lambda P^{OA} + (1 - \lambda)P^C] + [\lambda A^{OA} + (1 - \lambda)A^C] + I^H(A^H, N) - C^H(\sum \varphi * APC + S)$   
 $= \lambda[P^{OA} + A^{OA}] + (1 - \lambda)[P^C + A^C] + I^H(A^H, N) - C^H(\sum \varphi * APC + S)$

To simplify, we note:

$$\text{Institutions' payoffs per model} \begin{cases} U_I^{OA} = \alpha \\ U_I^C = \beta \\ U_I^H = \omega \end{cases}$$

Once the payoffs per model are determined, an order of preference of the institutions should be established according to the relationships described in the previous section. This will allow to determine the institutions order of preferences of the different publishing strategies. Thus, we have shown the following relationships based on the literature:

- $A^{OA} > A^H > A^C$
- $P^{OA} > P^H > P^C$
- $I^H(A^H, N) \approx I^{OA}(A^{OA}, N) > I^C(A^C, N)$
- $C^H(\sum \varphi * APC + S) > C^C(S) > C^{OA}(APC)$

We can deduce that the OA publication strategy weakly dominates the other two strategies. Regarding the relationship between a subscription-based or hybrid model, we note that the hybrid publication model allows better research dissipation, better access to publication and a better impact than the subscription-based model. On the other hand, it costs much more and is not recommended by institutions and donors. Therefore, the cost constraint is so high that in the medium term, in the absence of a deal, institutions would converge to the subscription model to avoid paying twice for AO publications in the hybrid model.

In short, the preference relationship between the different strategies is as follows:

$$U_I^{OA} > U_I^C > U_I^H \leftrightarrow \alpha > \beta > \omega$$

### **Publishers' payoffs**

The payoffs of publishers are made up of the profit they make as well as the reputation of the journals they publish. The reputation of journals is strongly linked to their academic and societal impact, but also the number of contributions they receive. While profit is determined by the quality of the articles published multiplied by the applied price, from which the editorial costs are deducted. Prices depend on the economic model adopted, as does the quantity of publications. On the other hand, the costs can be divided into fixed costs and variable costs. Fixed costs are stable regardless of the publication model adopted, while variable costs depend on the number of publications received and published.

In summary, the profit function of a publisher  $\lambda$  can be written for an economic model  $i$ :

$$\pi_{\lambda_i} = \sum P_{ij} * Pe_{ij} - (FC_j + VC_j(P_i))$$

with  $P_{ij}$  the number of publications of the journal  $j$  in the publishing model  $i$ ,  $Pe_{ij}$  the price applied by the journal  $j$  which depends on the publishing model  $i$ .  $FC_j$  the fixed costs of the journal  $j$ ,  $VC_j$  the variable costs of the journal  $j$  which are a function of the number of publications  $P_i$ . Here, for simplicity, we consider that  $P_i$  includes all the articles received including those that are rejected (because they also generate processing costs).

Regarding reputation, it is mainly linked to the notoriety of the journals presented above:  $I^H(A^H, N) \approx I^{OA}(A^{OA}, N) > I^C(A^C, N)$ .

Therefore, publishers' payoffs can be written for each of the three economic models:

- $U_{\lambda}^{OA} = \sum P_{OAj} * Pe_{OAj} - (FC_j + VC_j(P_{OA})) + I^{OA}(A^{OA}, N) = \pi_{\lambda_{OA}} + I^{OA}(A^{OA}, N)$
- $U_{\lambda}^C = \sum P_{Cj} * Pe_{Cj} - (FC_j + VC_j(P_C)) + I^C(A^C, N) = \pi_{\lambda_C} + I^C(A^C, N)$
- $U_{\lambda}^H = \sum P_{Hj} * Pe_{Hj} - (FC_j + VC_j(P_H)) + I^H(A^H, N) = \pi_{\lambda_H} + I^H(A^H, N)$

To simplify, we note:

$$\text{publishers' payoffs per model} \begin{cases} U_I^{OA} = \alpha' \\ U_I^C = \beta' \\ U_I^H = \omega' \end{cases}$$

Insofar as the costs borne by institutions and funders constitute the revenues of publishers, it can be established using the same reasoning that, on the one hand,  $Pe_{Hj} > Pe_{Cj} > Pe_{OAj}$ , and on the other hand  $P_{OAj} > P_{Hj} > P_{Cj}$ . Likewise,  $I^H(A^H, N) \approx I^{OA}(A^{OA}, N) > I^C(A^C, N)$ .

Since the cost / benefit ratio is the best in a hybrid model where institutions support both an OA and subscription-based model, publishers will prefer to stay on a hybrid model (dominant strategy). Moreover, symmetrically to the reasoning developed in the case of institutions, the bargaining power of publishers would become weaker in the case of an OA model, as would profits. This is partly explained by the fact that in a "read and publish" agreement, institutions will maximize their publication rate without necessarily increasing the earnings of publishers (or even the opposite). It can therefore be reasonably assumed that publishers would rather keep the subscription model than transition to an OA model.

In short, we can note:

$$\boxed{U_{\lambda}^H > U_{\lambda}^C > U_{\lambda}^{OA} \leftrightarrow \omega' > \beta' > \alpha'}$$

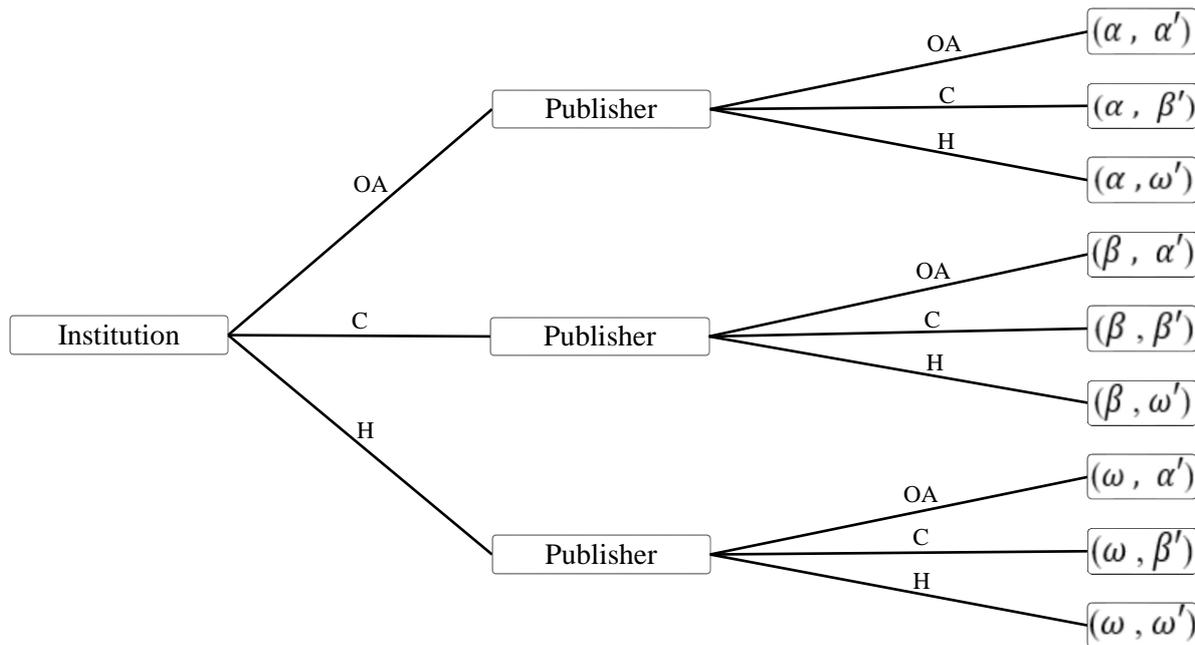
### Equilibria of the game

In this section, we represent the model in a strategic form to analyze the equilibria according to different situations. Each player has three strategies: OA, Hybrid (H) and Subscription-based (C). We study the equilibria in pure strategies in the case of cooperative and non-cooperative game. Then we determine the equilibrium in mixed strategies. The concepts of strategic dominance and Nash equilibrium (best response) are used to determine the equilibria.

*Scenario 1 (short term): Possibility of converging with two different strategies*

This can happen in particular in so-called "cooperative" games. A cooperative game is a game such that players (institutions and publishers) have the opportunity to consult and commit to cooperate before defining the strategy to be adopted. This is particularly a situation where both parties manage to implement their publishing strategy each time (i.e. the two come to an agreement). This assumes that all crosses are possible. Thus, institutions can choose one of the three strategies (OA, C or H), then publishers in turn choose their strategy for each of the institutions' strategies. This sequential game can be represented in the following extensive form:

**Fig. 3: Tree of the game**



In this case, each player obtains the gain corresponding to the chosen strategy. The payoffs matrix (strategic form) can be represented therefore as follows:

**Table 4: General payoff matrix (scenario 1)**

		Publisher		
		OA	C	H
Institution	OA	$(\alpha, \alpha')$	$(\alpha, \beta')$	$(\alpha, \omega')$
	C	$(\beta, \alpha')$	$(\beta, \beta')$	$(\beta, \omega')$
	H	$(\omega, \alpha')$	$(\omega, \beta')$	$(\omega, \omega')$

As shown previously we have the following relations:

- For institutions :  $\alpha > \beta > \omega$
- For publishers :  $\omega' > \beta' > \alpha'$

These relationships mean that both players have strictly dominant strategies. In this case, an OA strategy for institutions and a Hybrid strategy for publishers. In other words, regardless of the choice of the other, each of the two players has no interest in changing strategy. Otherwise, they risk lowering their gains. This is reflected in the matrix by the elimination of the "Hybrid" and "Subscription-based" strategies in the case of institutions, and the "OA" and "Subscription-based" strategies in the case of publishers. The payoffs matrix therefore becomes:

**Table 5: Iterated elimination of strictly dominated strategies (IESDS)**

		Publisher		
		OA	C	H
Institution	OA	$(\alpha, \alpha')$	$(\alpha, \beta')$	$(\alpha, \omega')$
	<del>C</del>	<del><math>(\beta, \alpha')</math></del>	<del><math>(\beta, \beta')</math></del>	<del><math>(\beta, \omega')</math></del>
	<del>H</del>	<del><math>(\omega, \alpha')</math></del>	<del><math>(\omega, \beta')</math></del>	<del><math>(\omega, \omega')</math></del>

If each player chooses his dominant strategy, the two come to an equilibrium  $(\alpha, \omega') = (\text{OA}, \text{Hybrid})$ . In this equilibrium, institutions publish only in OA in hybrid journals (as well as in open archives). Publishers therefore continue to apply subscriptions and receive APCs for OA articles.

For the reasons mentioned above, we can easily show that this equilibrium cannot be stable. While institutions can bear both subscription costs and publication costs in the short term, in the middle / long term it is difficult to sustain. It is important to remember here that the bargaining power of institutions and funders is gradually increasing for several reasons:

- Scientific publications (source of funding for publishers) are produced by institutions and research organizations.
- Peer review is provided by researchers (usually free of charge).
- Institutional and thematic open repositories have experienced considerable growth in recent years (Prosser, 2003; Pinfield, 2005; Ezema, 2011; Aguillo, 2020).
- The scientific community is becoming more and more organized and can integrate the evaluation of its own production (open peer review) (Kriegeskorte, 2012; Pöschl, 2012; Ross-Hellauer, 2017).
- Open access publication becomes one of the research evaluation criteria (DORA, 2012; Huang *et al.*, 2020; Saenen *et al.*, 2020). Thus, researchers have less and less pressure to publish in traditional, high-impact journals.

*Scenario 2 (middle/long term): Necessity for a more lasting agreement*

Although the bargaining power of the institutions is high, they have an interest in reaching an amicable agreement with the publishers. Thus, we can reasonably assume that in the event of no agreement, the institutions will have to put in place mechanisms to control the quality of publications and ensure their sustainability. Considering the fact that the institutions are scattered across the world, such an organization would be very expensive for risky results. To be able to do without publishers, institutions must precisely determine the evaluation standards by community; have an equitable sharing of evaluation costs, and above all a commitment on the part of the various operators to participate in production and evaluation of research.

From the point of view of the institutions, there are two major risks in the event of no agreement with the publishers:

- The degradation of the knowledge creation process due to the proliferation of behaviors of "invisible communities" in the research evaluation. Thus, researchers from the same scientific network can validate each other's publications without a real peer review. Or on the contrary, the increased risk of reprisals and settling of scores between researchers (Teixeira da Silva, 2018).
- The birth of a stowaway behavior, with "predatory" institutions that would benefit from the evaluation and publication process without any contribution.

Consequently, in terms of gains, in the event of no agreement, the institutions would have a lower gain than what they would obtain in the event of an agreement with the publishers. We notice:

$$\alpha'' < \alpha$$

Symmetrically, on the side of publishers, if institutions massively boycott publications in traditional journals, the gain would be much lower. We notice:

$$\omega'' < \alpha'$$

The situation described in this scenario is similar to non-cooperative games in game theory. We can distinguish several possibilities:

- If publishers choose the OA model, the payoff of institutions will be equal to  $\alpha$  whatever strategy they choose.
- If publishers choose the subscription-based model and institutions opt for the OA model, the gain for publishers will be zero while the gain for institutions will be  $\alpha''$ .
- If publishers choose the subscription-based model, and institutions opt for the subscription-based or hybrid models, the gain for publishers will be  $\beta'$  while the gain for institutions will be  $\beta$ .
- If publishers choose the hybrid model and the institutions opt for the OA model, the gain of the publishers will be equal to  $\omega''$  while the gain of the institutions will be equal to  $\alpha''$ .
- If publishers choose the hybrid model and the institutions opt for the subscription-based model, the gain for publishers will be  $\beta'$  while the gain for institutions will be  $\beta$ . Because there will be no open access publication in hybrid journals provided by publishers (as long as institutions have chosen a subscription-based model).
- If both choose a hybrid model, the gains will be  $\omega'$  and  $\omega$  for publishers and institutions respectively.

These different situations can be summarized in the following payoff matrix:

**Table 6: General payoff matrix (scenario 2)**

		Publisher		
		OA	C	H
Institution	OA	$(\alpha, \alpha')$	$(\alpha'', 0)$	$(\alpha'', \omega'')$
	C	$(\alpha, \alpha')$	$(\beta, \beta')$	$(\beta, \beta')$
	H	$(\alpha, \alpha')$	$(\beta, \beta')$	$(\omega, \omega')$

Thus, we can establish the following relationships between the different strategies:

- For institutions :  $(\alpha; \alpha''; \alpha'') \geq (\alpha; \beta; \beta) \geq (\alpha; \beta; \omega)$
- For publishers, there is neither weakly nor strictly dominant strategy in this game.

Since institutions have a weakly dominant strategy (which is OA), the payoff matrix becomes:

**Table 7: General payoff matrix (scenario 2) after IESDS of institution**

		Publisher		
		OA	C	H
Institution	OA	$(\alpha, \alpha')$	$(\alpha'', 0)$	$(\alpha'', \omega'')$

As  $\omega'' < \alpha'$ , publishers will prefer an OA strategy than a “C” or “H” strategy. The matrix therefore becomes, with an equilibrium (OA, OA):

**Table 8: General payoff matrix (scenario 2) after IESDS of publisher**

		Publisher
		OA
Institution	OA	$(\alpha, \alpha')$

Analysis of the two scenarios 1 and 2 shows that his version of the game seems to resemble the well-known "game of chicken" (also known as the hawk–dove game) in game theory. In this type of game, the ideal outcome for each of the two players is that one of them yield. Nevertheless, the consequences of a confrontation (or a standoff) are so negative that the two choose the less aggressive strategy and agree to compromise.

In the case of the scientific scholarly publishing, both players have a strictly dominant strategy with high payouts. For publishers, this is the hybrid model, while for institutions, the OA model. As presented previously, the equilibrium consisting in each choosing its strictly dominant strategy is not stable in the long term. In addition, the consequences of no agreement are negative for both parties. Therefore, the two players, publishers and institutions, will inevitably converge on an agreement around open access in the middle / long term.

### Mixed-strategy equilibrium

Let us now analyze the equilibrium of this game in mixed strategies. In game theory, mixed strategy analysis involves assigning a probability to each of the players' strategies. This provides a more general basis for analysis and allows the study of equilibrium in an uncertain environment (Walker and Wooders, 2008).

Since OA and H strategies are the strictly dominant strategies for institutions and publishers respectively, we analyze the equilibrium (in the long-term scenario) with only these two strategies. Choosing a model based solely on subscriptions is unlikely (if not impossible) in the current scientific context. Thus, institutions will choose an "OA" strategy with probability  $p$ , and an "H" strategy with probability  $(1-p)$ . Symmetrically, publishers will choose an "OA" strategy with probability  $q$  and an "H" strategy with probability  $(1-q)$ . The payoff matrix can therefore be represented as follows:

**Table 9: General payoff matrix (in mixed strategies)**

		Publisher	
		OA ( $q$ )	H ( $1-q$ )
Institution	OA ( $p$ )	$(\alpha, \alpha')$	$(\alpha'', \omega'')$
	H ( $1-p$ )	$(\alpha, \alpha')$	$(\omega, \omega')$

The expected gains are obtained as follows:

- For publishers:

$$\alpha'p + \alpha'(1-p) = \omega''p + \omega'(1-p)$$

$$\alpha' = \omega''p + \omega' + \omega'p$$

$$\alpha' - \omega' = p(\omega'' + \omega')$$

$$p = \frac{\alpha' - \omega'}{\omega'' + \omega'}$$

$$p = \frac{(\pi_{\lambda_{OA}} + I^{OA}(A^{OA}, N)) - (\pi_{\lambda_H} + I^H(A^H, N))}{(\pi''_{\lambda_H} + I''^H(A^H, N)) + (\pi_{\lambda_H} + I^H(A^H, N))}$$

$$\text{Best response for publishers} \begin{cases} \text{if } p = \frac{\alpha' - \omega'}{\omega'' + \omega'} \rightarrow q \in [0,1] \\ \text{if } p > \frac{\alpha' - \omega'}{\omega'' + \omega'} \rightarrow q = 1 \\ \text{if } p < \frac{\alpha' - \omega'}{\omega'' + \omega'} \rightarrow q = 0 \end{cases}$$

This means that publishers will prefer an OA strategy for  $p > \frac{\alpha' - \omega'}{\omega'' + \omega'}$ . In other words, if the probability that institutions choose an OA model exceeds the ratio  $p$ , publishers would benefit from choosing the same strategy ( $q = 1$ ). Whereas if the value  $p < \frac{\alpha' - \omega'}{\omega'' + \omega'}$ , publishers would benefit from choosing the hybrid strategy ( $q = 0$ ).

- For institutions:

$$\alpha q + \alpha''(1 - q) = \alpha q + \omega(1 - q)$$

$$\alpha''(1 - q) = \omega(1 - q)$$

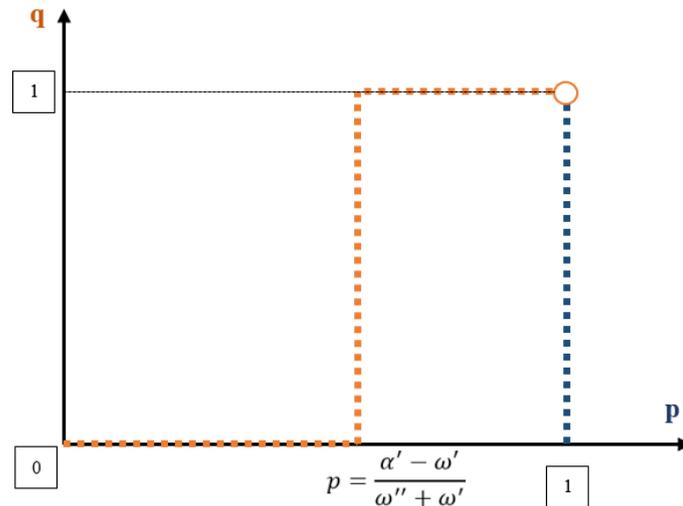
$$\alpha'' = \omega$$

$$\text{Best response for institutions} \begin{cases} \text{if } \alpha'' = \omega \rightarrow p \in [0,1] \\ \text{if } \alpha'' > \omega \rightarrow p = 1 \\ \text{if } \alpha'' < \omega \rightarrow p = 0 \end{cases}$$

On the institutional side, the best answer depends on the order of preference between  $\alpha''$  and  $\omega$ . As shown above:  $\alpha'' > \omega$ . Therefore, the best response from institutions is to play OA regardless of the choice of publishers. In other words,  $p = 1$  for  $q \in [0,1]$ .

Graphically, we can represent the best responses as follows:

**Fig. 4. Graphical representation of the best responses in mixed strategies**



In mixed strategies, equilibrium is obtained when both players choose a strategy with the same probability. As can be seen in figure 4, the two best responses in terms of probabilities intersect in  $p = q = 1$ . This therefore corresponds to a combination of strategies (OA; OA). Therefore, the pure strategy Nash equilibrium of choosing an OA model for both players is also the only mixed strategy Nash equilibrium.

### Conclusion and discussion

Through this paper, we sought to model objectively the scientific publishing market as presented in specialized literature and policy recommendations. Three main economic models currently coexist in the publishing market: the traditional model (subscription-based), the open access model (author-pays) and the hybrid model (which combines the two). Since it is the institutions that bear the publication costs and define the editorial strategies, the choice of publication of the authors depends greatly on that of their institution. It is for this reason that the strategic reasoning has been constructed in this article from institutions. Institutions therefore make trade-offs based on the choices offered by publishers. In order to determine the

preferred model for each of the two players (institutions and publishers), we studied the payoffs they would obtain in each economic model.

We have assumed that the payoffs depend on three things: production and access, academic and societal impact, and finally costs (for institutions) and profits (for publishers). Using the results obtained in the literature we have shown that the model that maximizes the utility of institutions is that of open access. Thus, it allows a better dissemination of research results, and increase the productivity of researchers. This model also allows for better visibility and a relatively high impact. On this last point, it is the hybrid model, which appears the best insofar as many well-established journals on the market are of the hybrid type and therefore receive articles of better quality and obtain a high impact. On the other hand, the hybrid model is the most expensive of all and it is less interesting than the OA model in terms of production and access to publications. On the side of the editors, it is the hybrid model, which maximizes the gains. It is therefore preferred that the subscription-based model, which in turn is preferred over the OA model.

We have shown that there is a Nash equilibrium in which institutions would choose to publish only in OA, while publishers would keep the hybrid business model. This equilibrium is Pareto optimal, because it results from the crossing of two strictly dominant strategies. We have also shown that this equilibrium can only be short-lived, for several reasons. The bargaining power of institutions has increased dramatically in recent years with the breakthrough of the open science movement. Thus, in addition to the fact that it is the institutions that produce and evaluate scientific publications, political attention is increasingly turned to open science, which has become one of the evaluation criteria for researchers. This puts a lot of pressure on publishers who are starting to make some compromises. The hybrid model therefore appears to be unstable in the short term. On the institutional side, it is also difficult and risky to do without publishers, particularly from the point of view of sustainability and quality control of publications. Thus, several perverse effects and abuses can be accentuated if the institutions alone ensure the entire publication process. In particular, the degradation of the evaluation because of the effects of networks and "invisible colleges" on the one hand, and of stowaways on the other.

Institutions and publishers therefore have an interest in converging and reaching an agreement, even if it means making some compromises. Therefore, it has been shown that the "damage" of a no-deal is so high that the two will end up converging on an open-access deal. This is true for both players. Thus, if institutions do not compromise would jeopardize the process of knowledge creation and research assessment. Likewise, if publishers choose to remain in old (subscription-based) or transitional (hybrid) economic models risk a broad boycott of the scientific communities and a drastic drop in their profits.

The analysis of equilibrium in mixed strategies confirms this result. The integration of probabilities in the choice of strategies shows that publishers would converge towards an open access model if and only if the probability that institutions choose to publish in open access exceeds a certain threshold. We then showed that in the long term, the probability of choosing the open access model is always equal to one regardless of the choice of the publishers. This means that there is only one equilibrium in mixed strategy, which is the choice of the open access model for institutions and publishers.

By analyzing market forces and the latest policy developments in research evaluation and funding, this article shows that the world of science is inevitably moving towards an agreement

around open access. The only variable unknown to date is the speed of convergence. This speed of convergence is linked to several factors such as the importance given by funders to open science and the pressure exerted by researchers and scientific communities. While open access publication is starting to be integrated into the evaluation criteria in several countries such as the United Kingdom and France, there is still a long way to go before the journals that are born in open access establish themselves on the market and change the publication practices of researchers. On these questions, there are scientific communities more advanced than others and the transition to a fully open access model could be done step by step and community by community. For the most advanced of them, the transition seems to be close, for others the path is well traced.

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