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# Optimal pricing and quality of academic journals and the ambiguous welfare effects of forced open access: A two-sided model

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We analyze optimal pricing and quality of a monopolistic journal and the optimality of open access in a two-sided model. The predominant aspect of the model that determines the quality levels at which open access is optimal is the nature of the relationship between readers and authors in a journal. In contrast to the previous literature, we firstly show that there exist scenarios in which open access is a feature of high-quality journals. Second, we find that the removal of copyright (and thus forced open access) will likely increase both readership and authorship, will decrease journal profits, and may increase social welfare.

JEL CLASSIFICATION
D2; D4

## 1 | INTRODUCTION

Academic journals act as platforms upon which authors communicate their ideas to readers. As such, journals need to attract both authors and readers in order to be able to provide their service, which is beneficial to both readers and authors. However, the interrelationship between authors and readers on the journal platform is more complex than a simple meeting place where ideas are exchanged. Readers attract authors to a journal, and authors attract readers to a journal, and both are attracted to higher quality journals (Armstrong, 2015; Bergstrom, 2001; Dewatripont et al. 2006). Zheng and Kaiser (2015) explore the determinants of authors' decisions to submit a manuscript to a journal using panel data for economics journals. Their results suggest that authors value not only the quality of a journal, as measured by its impact factor or journal rank, but also the number of readers, as measured by the number of subscriptions. Based on their findings on network effects, Zheng and Kaiser (2015) argue that the pricing of open access journals, that is, no reader fee and a relatively large publication fee, is justified.[1]

The interesting part of the whole issue of academic publishing via journals is the fact that as the intermediary, the journal editors make decisions regarding readers and authors that are crucial to the final outcome of the quality that the journal achieves. Perhaps, the most interesting model of a journal occurs when the journal acts in order to maximize profit.[2] In such a scenario, the journal must decide the subscription price for reader access, the author fee (submission and/or

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[1]See Suber (2012) for a thorough overview of open access publishing. See also Davis (2009 & 2011), Davis et al. (2008), Gaulé and Maystre (2011), and Mueller-Langer and Watt (2018) on the citation effect of (hybrid) open access.

[2]Other objectives may also be considered—the journal might act in order to maximize its impact factor, or it might act in order to maximize readership (diffusion of ideas published).

publication fees), and the overall quality of the journal, all with the objective of achieving maximal profit.[3] It is by no means obvious, for example, that profits will be maximized by maximizing the quality of the journal. Neither is it clear how the reader subscription price should affect the author fee, and vice-versa.

In the present paper, a model of a journal as a two-sided platform is explored in order to consider some of the principal aspects of this complex market. The paper adds to a relatively small literature that considers academic journals in two-sided markets (Jeon & Rochet, 2010; McCabe & Snyder, 2007). We consider a monopolistic journal that provides the service of publishing academic papers for both readers and authors. This approach is based on the observation that prestigious subscription-based commercial journals have substantial monopoly power.[4] As C. T. Bergstrom and T. C. Bergstrom (2004, p. 897) put it: "Another curious feature of the market for academic journals is that publishers of major commercial journals appear to enjoy substantial monopoly power despite the absence of obvious legal barriers to entry by new competing journals."[5] In addition, Brown et al. (2003, p. 2) state that "each journal has a monopoly on a resource vital to scientists—the unique collection of articles it has published. Anyone who depends on the information in a specific article has no choice but to pay whatever price the publisher asks" (see also Armstrong, 2015, p. F11). Our model is related to the monopoly platform model by Armstrong (2006). In contrast to Armstrong (2006), however, the platform's ultimate objective is to choose its "quality" and must also make an optimal choice of both the reader subscription price and the author fee. We also analyze the effects of a removal of copyright on journals, academics, and social welfare. It is in this respect that we believe our analysis is different from existing works such as Jeon and Rochet (2010) and McCabe and Snyder (2007).

We are interested in the following aspects of the journal's management. Is it possible that one of the two prices (the reader price and the author price) can be optimally set to zero? Is it true that a journal that does optimally set the reader price to zero (i.e., an "open access" journal) is characterized by a lower quality level than a closed access journal (i.e., one with a strictly positive subscription price for readers)? How would the removal of copyright in the papers published impact upon the optimal choices of a journal?[6] Above all, we calculate the welfare effects of the removal of copyright in our simulations.

We find several new results that add to the literature. There exist scenarios in which open access (i.e., an optimal reader price equal to zero) is a feature of lower quality journals, and others in which it is a feature of higher quality journals. The predominant aspect of the model that determines the quality levels at which open access is optimal is the nature of the relationship between readers and authors in a journal. Above all, we show that open access can appear as an optimal strategy for both high- and low-quality journals. Second, we find that removal of copyright (and thus forced open access) will likely increase both readership and authorship, but will decrease journal profits, and will have an ambiguous effect on social welfare.

## 2 | MODEL

A "journal" is a set of papers. Papers are written by "authors" (and each author can submit at most one paper) and are consumed by "readers". Here, a reader only has the option to purchase the entire set of papers in the journal as a subscription and cannot disaggregate the journal content for price reductions. Thus, for example, the journal may be thought of as being a single volume (perhaps several issues) of a particular title. The journal chooses quality, $q$, the price charged to readers, $p_r$, and the price charged to authors, $p_a$.

We treat quality as a choice variable of the journal.[7] Quality is taken to represent any given variable, under the control (either direct or indirect) of the journal, and that indicates to the academic community that the papers included have some guarantee of being interesting, valuable, and providing an extension to the existing literature. For example, we could take quality to be the expected number of citations per paper published (the expected impact factor).[8] By making quality a choice variable, our paper is closely related to the paper by Jeon and Rochet (2010), who also let the journal choose quality, although their model is focused upon a not-for-profit journal, whereas we focus on the case of for-profit journals. McCabe and Snyder have a series of papers that study the pricing of academic journals (see McCabe and Snyder, 2005,2007), although in most of their work quality is not a choice variable.[9]

We assume that the journal chooses quality, the reader price and the author price in order to maximize profits. We assume a fully online journal that has no fixed or variable costs, and so profits are equivalent to journal revenue. Given the choice $(q, p_r, p_a)$, the number of readers that the journal attracts is endogenously given by $n_r(q, p_r, n_a)$, and the number of authors that are included in the subscription that is sold to

[3]See Zheng and Kaiser (2015) who provide evidence on the price elasticity of authors in the case of submission fees. Their results suggest that higher quality journals (as measured by journal rank) may find it optimal to charge submission fees. See also Azar (2005) who suggests that the value of a publication in a high-quality journal is relatively high as compared with rather modest submission fees.

[4]See also Attema et al. (2014) on the relationship between journal prestige and author incentives.

[5]In a similar fashion, Bergstrom (2001) provides an explanation why commercial scientific publishers are able to extract huge profits from the scientific community. In particular, commercial, high-quality journals are able to charge very high prices because library demand for top journals is quite price-inelastic. See also Card and Della Vigna (2013) who provide a revealed preference measure of competition between scientific journals. Their results suggest that the top-5 economics journals have significant monopoly power over submissions.

[6]We are interested in this aspect because of the provocative paper by Stephen Shavell (2010) that advocates abolition of copyright in scientific publications.

[7]We do not specifically model how quality is chosen. In reality, it is controlled by the journal via the referee process. Essentially, the referee process sets a minimum threshold (which is our understanding of the quality level chosen) for acceptance of a paper, based on some criteria that is established by the journal editorial board (which could include such things as relationship between the paper and the journal's topical interest, importance and relevance of the results of the paper, and perhaps expected citation rate of the paper once published).

[8]In none of the existing literature is any attention paid to a detailed description of what is to be understood by a journal's "quality", because most academics can easily compare any two journals in terms of their perceived quality, even without having at their fingertips a concrete definition of what quality is.

[9]However, in section 5.4 of McCabe and Snyder (2007), journals are allowed to screen for quality of articles, and they find that journals will specialize in articles of given quality, thereby splitting the market for publications according to quality niches.

readers is endogenously given by $n_a(q, p_a, n_r)$. Both the number of readers and the number of authors are determined in part by the quality chosen.[10] The number of readers (authors) has a direct dependence on the price charged to readers (authors). The dependence of the number of readers on the price charged to authors, and the number of authors on the price charged to readers, is indirect. The number of readers is (partially) determined by the number of authors, and vice versa.[11] Our assumptions reflect reality. Readers choose to read a journal depending on its content (which is given by the number of papers in it, $n_a$, and the quality of those papers, $q$), and the price charged to readers, $p_r$. Authors want to publish in a journal given the quality of the journal, $q$, the audience reached, $n_r$, and the cost involved in publishing, $p_a$ (which clearly could represent the sum of a submission and a publication cost). The fact that the two functions $n_r(q, p_r, n_a)$ and $n_a(q, p_a, n_r)$ are interdependent with the value of each depending (in part) upon the value of the other captures the two-sided market feature of academic journals as platforms for readers and authors.

It is clear that our model is a reduced form analysis, in that we choose not to directly model the complex interrelationships between the readers and the journal, and between the journal and the authors, which lead to the two functions $n_r(q, p_r, n_a)$ and $n_a(q, p_a, n_r)$. Instead, we directly make the assumptions required on these two functions for the model to work in a tractable manner.

We can understand the two functions $n_r(q, p_r, n_a)$ and $n_a(q, p_a, n_r)$ in two different ways, both of which will be exploited in the paper. First, for given values of $q$ and $n_a$, say $\bar{q}$ and $\bar{n}_a$, we should understand $n_r(\bar{q}, p_r, \bar{n}_a)$ to be a "demand" function in the sense that it relates the price for reading to the number of readers who purchase. On the other hand, for given values of $q$ and $p_r$, say $\bar{q}$ and $\bar{p}_r$, we should understand $n_r(\bar{q}, \bar{p}_r, n_a)$ to be a sort of "production" function (i.e., authors are an input into the production of readers), in the sense that papers (here, authors) are what attract readers to a journal. In the same way, $n_a(\bar{q}, p_a, \bar{n}_r)$ is again a demand function, and $n_a(\bar{q}, \bar{p}_a, n_r)$ is a production function (this time, reflecting the dependence of the number of authors that are attracted to a journal on the number of readers of that journal). For $i, j = r, a$ and $i \neq j$, we make the following assumptions:

$$\frac{\partial n_i}{\partial p_i} < 0, \ \frac{\partial n_i}{\partial n_j} > 0, \ \frac{\partial^2 n_i}{\partial n_j^2} \leq 0.$$

Thus, the demand functions are negatively sloped, and the production functions are positively sloped and (weakly) concave. We also assume that

$$\frac{\partial n_r}{\partial q} > 0, \ \frac{\partial n_a}{\partial q} \geq 0.$$

The first of these is a very natural assumption—readers prefer better quality papers. The second is not so obvious, as it depends on how we measure quality, and whether the quality measure is related to author scarcity. Typically, the number of published authors will only be increasing in quality on a given (local) range of quality levels. The greater is the quality of a journal, the greater is the willingness of authors to supply papers to that journal (for the CV impact and for the fact that higher quality journals are likely to reach a larger audience and thus, are more likely to be cited). But assuming that higher quality papers are more scarce than are lower quality papers, the greater is the quality hurdle the fewer will be the papers published from those submitted. Thus, although a high-quality journal will have a larger set of papers from which to choose, they are more selective in their choosing.[12] There may also be some logical ceiling on quality beyond which quality can no longer be increased. Almost certainly, the number of published papers is a nonmonotone function of quality, when the entire range of quality is considered. The assumption used in the present paper is that *for the range of levels of quality that we consider*, the number of published papers is not decreasing in the quality of the journal. This assumption is based on recent empirical evidence (Zheng & Kaiser, 2015). At least in the field of economics journals, those at the top of the quality ladder are typically able to publish many papers, whereas it is the journals of lower perceived quality that may struggle with finding papers to publish.[13] Zheng and Kaiser (2015) use panel data from economics journals to explore the determinants of authors' decisions to submit their papers. They provide empirical evidence that higher quality journals (as measured by the impact factor of a journal) attract more submissions. In particular, Zheng and Kaiser (2015) (p. 1333) find that "increasing the impact factor by 1 will increase the number of submissions by 63.28."

Our assumption that the number of published papers is nondecreasing in journal quality is not innocuous to the results of our model. As we shall see, in the model, we end up with profits being a strictly increasing function of quality, and thus, each journal wants to increase quality as much as possible. However, we should *not* interpret this result as implying that journals will set quality at an infinitely high level. We insist that we are only carrying out a local analysis in terms of quality.[14]

In Figure 1, we show both the demand curve aspect and the production function aspect of the journal platform, taking quality to be

[10]Our strategy of analyzing directly an endogenous functional relationship for the number of users on each side of the market as determined by the number of users on the other side and any other relevant variables, follows closely the way Armstrong (2006) handles an analysis of two-sided markets.

[11]The journal sells space in the journal to authors, so the author price refers to the cost to an author of having one paper included. On the other hand, once the journal content is found, the subscription price to readers gives a reader access to all of the papers in that issue of the journal.

[12]A model of the referee process under which papers are screened for quality is beyond the scope of the present paper. Here, all that is important is to recognize that $n_a$ is the number of papers that end up being published, and that will be determined by the number of papers that are submitted (decreases with author price and increases with number of readers), and the quality of the journal. The assumption that the number of papers published increases with the journal's quality reflects the assumption that submissions of sufficient quality increase in the journal's quality.

[13]We tested this hypothesis by looking at the relationship between impact factor (our proxy for journal quality) and the number of papers published in the top 331 economics journals that are listed in the ISI Web of Knowledge Journal Citation Report. We did this using as the quality metric the 1-year impact factor, the 5-year impact factor, and the journal Eigenfactor. Our regression analysis shows that the coefficient for quality in all three cases is positive and statistically significant with $p$ values ranging from 0.000 (Eigenfactor) to 0.046 (5-year impact factor). Thus, indeed it appears that on average, higher quality economics journals do publish more papers than lower quality ones. Details of the regressions alluded to here are available from the authors upon request.

[14]If we were to carry out a full consideration of the nonmonotone functional relationship between the number of papers published and the journal's quality, then there would exist a sufficiently high level of quality such that profits end up decreasing with quality as it becomes extremely difficult to find papers of sufficient quality to publish. In such a model, there would be a finite optimal level of quality.

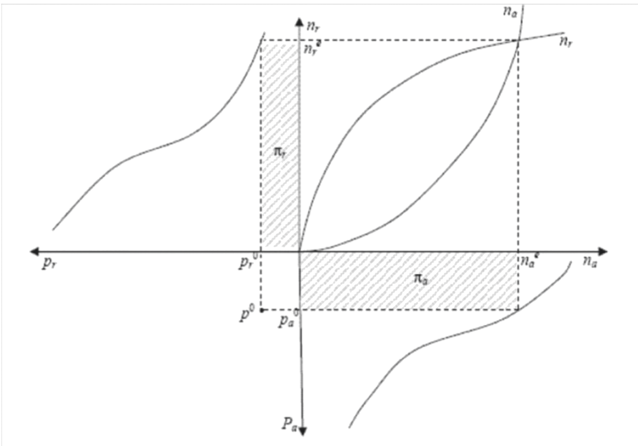


**FIGURE 1** Two-sided market; demand, production functions, and profit

fixed. The upper left-hand (lower right-hand) panel shows the demand curve aspect of $n_r(q, p_r, n_a)$ [$n_a(q, p_a, n_r)$], and the upper right-hand panel shows the production function aspects. Figure 1 highlights a very important aspect of the journals market. It is two-sided, and so the choice of reader price (a determinant of the number of readers) cannot be taken independently from the choice of author price (which is a determinant of the number of authors). There is only one consistent choice in this graph, which is labeled as point $p^0$ in the south-west quadrant. Only with that choice of prices will the number of authors ($n_a^e$) be consistent with the number of readers ($n_r^e$), where the superscripts $^e$ refer to endogenous equilibrium values. Notice that the equilibrium is obtained where the two production function representations intersect.

Imagine that, from the situation drawn in Figure 1, the journal decided to increase the reader price, $p_r$ (leaving the author price unchanged). What would be the effect in the graph? The increase in reader price will cause a shift along the demand curve for the number of readers, thus reducing $n_r$. However, the production function for readers will itself shift, because it is parameterized by the reader price. Because we assume that the number of readers is a decreasing function of the price for reading, the production function will shift downwards. There is a resulting shift along the production function for the number of authors. Next, the demand function for the number of authors is parameterized by the number of readers. The number of readers has decreased, which will shift the demand function for the number of authors inwards. Finally, the number of authors has also been decreased, which will shift the demand function for the number of readers inwards. These shifts will continue until a new equilibrium point is attained. We assume throughout that the equilibrium process just described is stable, in the sense that for any $(q, p_r, p_a)$, the curves adjust such that there is a pair $(n_r, n_a)$ that are mutually compatible.

Finally, then, the journal should study the equilibrium prices for authors and readers as per Figure 1, for all feasible choices of quality. When quality is changed, the location of the curves in Figure 1 will also all shift around, and the resulting profit levels will change. The task of the journal is to choose the best possible quality level, such that with that quality, the optimal prices for readers and authors delivers the maximum overall profit.

## 2.1 | Profits

In the interests of simplicity, we assume that the journal operates with no costs. For instance, Armstrong (2015, p. F9) states that "it is now essentially costless to distribute journal articles to additional readers over the Internet, while before, publishers had to print and send hard copies." Of course, a fixed cost could be easily introduced into our analysis (perhaps to cover the cost of having a website, and any salary costs of the editor, secretaries, etc.). But fixed costs would have absolutely no effect upon the optimal strategies of the journal (outside of shifting the shut-down condition), and so we are justified in ignoring them. On the other hand, it is more debatable that marginal costs are zero. However, we restrict our analysis to a fully online journal, which will have negligible costs of serving readers, and very small costs of serving authors (indeed, many of the costs of servicing authors will be fixed, as in paying and maintaining a website).[15] Again, in the interests of focusing our attention on the issue of the optimal setting of the reader price (the adoption or not of open access), we set the marginal costs to zero.

The profits that the journal makes for any choice of quality can also be represented graphically under our assumption that the journal is fully online only and thus, has no marginal costs. The profits earned by the journal are

$$\pi(q, p_r, p_a) = p_r \cdot n_r + p_a \cdot n_a = \pi_r(q) + \pi_a(q).$$

In Figure 1, we can see the profits made from the reader side of the market ($\pi_r$) and the author side of the market ($\pi_a$). The sum of these two rectangular areas is the total profit. To illustrate, the effect of a unilateral increase of the reader price is to decrease the profit in the author market (because the author price stays constant and the number of authors decreases) and to change the profit in the reader market in such a way that it may increase or decrease, depending on the value of the relevant elasticity (the profit goes from a tall thin rectangle to a shorter but wider one).

# 3 | PROFIT MAXIMIZING DECISIONS

The journal chooses $(q, p_r, p_a)$ in order to maximize profit. We model this recursively. Holding quality at some fixed level, $q$, and given that quality, we analyze the optimal pricing policy of the journal,

[15]Some argument can be made for the costs of refereeing, but of course, in almost all cases, the referee process is undertaken free of charge by other academics and is essentially costless to a journal. The only real cost is the editor's task of locating referees and sending papers out to them and perhaps, the time costs involved in communicating decisions to authors. The tasks of the editor, however, would come under the fixed cost of his/her salary (if indeed the editor charges a salary to the journal). It is also true that there might be some costs in processing and typesetting articles for publication, but even those to a certain extent are carried out free of charge by the author.

$p^*(q)=(p_r^*(q),p_a^*(q))$. Then, given the optimal prices for each quality level, we consider the optimal quality that the journal should choose.

Firstly, though, for any given $(q,p_r,p_a)$, it is necessary to simultaneously solve the two equations $n_r(q,p_r,n_a)$ and $n_a(q,p_a,n_r)$ for the two equilibrium levels of readers and authors, $n_r^e(q,p_r,p_a)$ and $n_a^e(q,p_r,p_a)$. The profit of the journal (assuming that there are no marginal costs of supplying readers or of managing authors[16]) is

$$\pi(q,p_r,p_a)=p_r\times n_r^e(q,p_r,p_a)+p_a\times n_a^e(q,p_a,p_r).$$

The derivatives of this with respect to the two prices are

$$\frac{\partial\pi}{\partial p_i}=n_i^e+p_i\frac{\partial n_i^e}{\partial p_i}+p_j\frac{\partial n_j^e}{\partial p_i},$$

where $i,j=r,a$ and $i\neq j$. Carrying out the implied second derivatives, it turns out that a sufficient condition for profits to be concave in the price $p_i$ is $\frac{\partial^2 n_i}{\partial p_i^2}\leq 0$ and $\frac{\partial^2 n_i}{\partial n_j\partial p_i}\geq 0$. Assuming concavity, the two first-order conditions for optimal choices of the two prices are $\frac{\partial\pi}{\partial p_r}=0$ and $\frac{\partial\pi}{\partial p_a}=0$, the simultaneous solution of which give us the two optimal prices as functions of the quality, $p_r^*(q)$ and $p_a^*(q)$. The indirect profit function is then

$$\pi(q)=p_r^*(q)\times n_r^e(q,p_r^*(q),p_a^*(q))+p_a^*(q)\times n_a^e(q,p_r^*(q),p_a^*(q)).$$

This is what must then be maximized with respect to $q$.

## 4 | A SIMPLIFIED MODEL

In order to see how the model works, we assume three different, but similar, models. Each of the three models is characterized by linear demand functions for both readers and authors, and they differ with respect to the degree of concavity of the two production functions. Specifically, in Model 1, we assume that both production functions are affected by diminishing returns (i.e., they are both strictly concave functions). In Model 2, the production of readers (taking authors as an input) has diminishing returns (i.e., is concave), whereas the production of authors (taking readers as the input) is assumed linear. In Model 3, the reader production function is linear, and the author production function is concave.

In each of the three models, the demand formulation is given by a linear form, with vertical intercept (i.e., maximum feasible price) equal to $\alpha q$. Thus, greater levels of quality correspond to parallel shifts of the two demand curves. We have no particular reason to assume that the effect of a marginal change in quality upon the demand curve of readers is any different to the same effect for authors. So in the interests of keeping our model as uncluttered as possible, we assume that this effect is equal for both sides of the market ($\alpha$).[17]

In the simulations that follow, we have $n_i=f(n_j)(\alpha q-p_i)$, where $i,j=a,r$.[18] We consider two possible shapes for the function $f$: either it is assumed to be linear with slope 1 (i.e., $f(n)=n$) or it is assumed to be the square root function (i.e., $f(n)=\sqrt{n}$), depending on the cases studied. In essence, the idea is that each $n_i$ should be increasing (and maybe concave) in the other $n_j$ to reflect the production function feature of the model, increasing in quality $q$, decreasing in the price $p_i$, and $n_j=0$ should give $n_i=0$. Our formulation certainly does all of that. However, we can further justify our choice of functional forms as follows. For readers, set $\alpha q$ as the gross benefit from reading a single journal article of quality $q$, and so set $\alpha q-p_r$ as the net benefit where $p_r$ is the price to subscribe to the journal. Then, by multiplying this net benefit by $n_a$, we get a simple measure of the total net benefit of subscribing to a journal with $n_a$ papers included. The greater is the net benefit, the greater is the number of papers in the journal. The marginal paper adds linearly to total net benefit in that case, and it adds in a diminishing fashion if instead the multiplication is by $\sqrt{n_a}$. Thus, all our formulation is saying is that the greater is the total net benefit of subscribing (and reading), the more subscribers there will be (i.e., $n_r$ is greater). The function for the number of authors in the model can be defended in a similar fashion. An author who pays $p_a$ to publish in a journal of quality $q$ that is read by a single reader gets a net benefit of $\alpha q-p_a$. Then multiply by either the number of readers, $n_r$, or the square root of the number of readers, $\sqrt{n_r}$, to account for greater readership leading to a greater total net benefit. Then, the greater is the total net benefit, the more authors will enter.

### 4.1 | Model 1: Diminishing returns on both sides

In this model, we assume a perfectly symmetrical situation with diminishing returns:

$$\begin{aligned} n_r &= \sqrt{n_a}(\alpha q-p_r),\\ n_a &= \sqrt{n_r}(\alpha q-p_a). \end{aligned}$$

Notice that these two equations can be written as

$$n_r=\sqrt{n_a}\beta_r, \tag{1}$$

$$n_a=\sqrt{n_r}\beta_a, \tag{2}$$

[16]In our model, the journal operates with no costs. This is an appropriate formulation for a journal that is run online—there will be no marginal cost to servicing readers, and so long as the referee process is not remunerated (as is habitual), there will also be no cost in servicing authors. The only cost that one could validly include in a model of an online journal is fixed costs, which will have no effect on optimal behavior and which we therefore choose not to include.

[17]The assumption of linear demand is, of course, only intended as a first approximation to any real-life scenario. Nonlinear forms increase the complexity of the model enormously, with no real change in the results that are obtained. Basically, the linear form is the least complex way in which we can assure that when there are no readers, $n_r=0$, then no authors are attracted to the journal, so that $n_a=0$. Likewise, no authors implies no readers. This feature can also be incorporated in to nonlinear demand forms, but as stated above, this leads to significant analytical complexity with no real gain in what the models output.

[18]In this general formulation, we have $\frac{\partial n_i}{\partial q}=f(n_j)\alpha>0$, that is, an increase in quality attracts both more readers and more authors to the journal, as per the "local" assumption stated above.

where $\beta_i \equiv \alpha q - p_i$ for $i = r, a$. Recall that both of $n_r$ and $n_a$ are constrained to be positive, so we are restricted to parameter values such that $\beta_i > 0$ for $i = r, a$, that is, we can only consider prices that satisfy $p_i < \alpha q$ for $i = r, a$.

It is easy to show that the solution to the two equations, Equations (1) and (2), outside of the trivial solution at (0, 0), is at

$$n_r = \left(\beta_r^4 \beta_a^2\right)^{\frac{1}{3}},\ n_a = \left(\beta_r^2 \beta_a^4\right)^{\frac{1}{3}}.$$

The profits of the journal are given by

$$\pi = p_r n_r + p_a n_a = p_r \left(\beta_r^4 \beta_a^2\right)^{\frac{1}{3}} + p_a \left(\beta_r^2 \beta_a^4\right)^{\frac{1}{3}}.$$

The profit function is perfectly symmetric in the two prices. That is, the function is of the form

$$\pi = h(p_r, p_a) + h(p_a, p_r)$$

where $h(x, y) \equiv x\left((\alpha q - x)^4 (\alpha q - y)^2\right)^{\frac{1}{3}}$. Thus, it makes no difference to the problem how we label our price variables. In the optimal solution it must be true that $p_r^* = p_a^*$. We can use this insight to help us solve the maximization problem. We add the restriction $p = p_r = p_a$ to the existing restrictions $p_i < \alpha q$ for $i = r, a$. Substituting this first restriction into the objective function gives

$$\pi = 2p\left(\beta^4 \beta^2\right)^{\frac{1}{3}} = 2p\left(\beta^6\right)^{\frac{1}{3}} = 2p\beta^2.$$

Here, $\beta = \alpha q - p$, so that $\frac{\partial \beta}{\partial p} = -1$. The first-order condition for an optimal solution is

$$\frac{\partial \pi}{\partial p} = 0 \Rightarrow 2\beta^{*2} - 4p^* \beta^* = 0$$

where $\beta^* = (\alpha q - p^*) > 0$. This equation solves out to $p^* = \frac{\alpha q}{3}$. The second-order condition on this maximization problem is $-8\beta + 4p < 0$ which is $-8\alpha q + 12p < 0$. At the stationary point (which is unique on the range $p < \alpha q$), we have $-8\alpha q + 12p^* = -8\alpha q + 4\alpha q = -4\alpha q < 0$. Thus, the second-order condition is satisfied at the optimal solution. In short, the two optimal prices for Model 1 are identical linear functions of quality;

$$p_r^* = p_a^* = \frac{\alpha q}{3}.$$

## 4.2 | Model 2: Diminishing returns to authors only

We now assume

$$n_r = \sqrt{n_a}(\alpha q - p_r), \tag{3}$$

$$n_a = n_r(\alpha q - p_a). \tag{4}$$

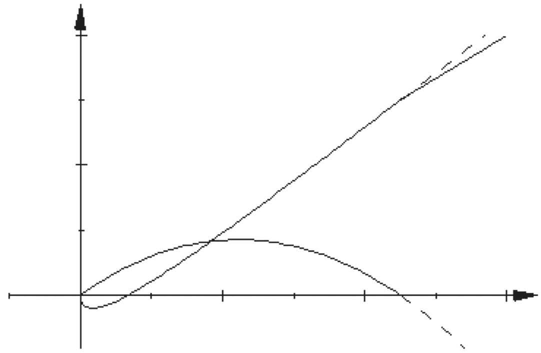


**FIGURE 2** Model 2 optimal prices

In Appendix A, we show that the optimal prices in this model are as follows:

$$p_a^* = \frac{5\alpha q - \sqrt{4\alpha^2 q^2 + 7\alpha q}}{7}, \tag{5}$$

$$p_r^* = \frac{21\alpha q - 4\alpha^2 q^2 - 2\alpha q\sqrt{4\alpha^2 q^2 + 7\alpha q}}{49}. \tag{6}$$

The two optimal prices are graphed in Figure 2.[19] In Figure 2, we can see that we are assuming that it is not possible for the journal to pay readers, that is, the reader price cannot be negative. In reality, the optimal reader price Equation (5) dictates negative reader prices for all quality levels above the quality level $q_0$, which is the strictly positive solution to $p_r^*(q_0) = 0$. Figure 2 shows these negative prices as a dashed curve. Because it is not realistically feasible to pay readers, on that range of quality levels, the journal would be restricted to the corner solution with $p_r^* = 0$, which is indicated by the continuation of the solid curve along the axis. Thus, the optimal reader price is a piecewise function.

This also affects the optimal author price. When the reader price is restricted to 0, the optimal author price is no longer given by Equation (6). As it happens, above $q_0$, the optimal author price is linear and equal to $\frac{\alpha q}{3}$.[20] Thus, the author price graph in Figure 2 is also piecewise, as can be seen by the kink in the optimal author price graph as drawn solid (the dashed curve is the continuation of the optimal author price, which would assume that negative reader prices are feasible).

## 4.3 | Model 3: Diminishing returns to readers only

Our third model is the opposite of Model 2. Specifically, in Model 3, we assume

$$\begin{aligned} n_r &= n_a(\alpha q - p_r), \\ n_a &= \sqrt{n_r}(\alpha q - p_a). \end{aligned}$$

[19] In the simulations that we have done, we took $\alpha = 1$, although it is relatively simple to see that taking any other (positive) value would not alter the shapes of the graphs obtained, only their values.

[20] See Appendix B.

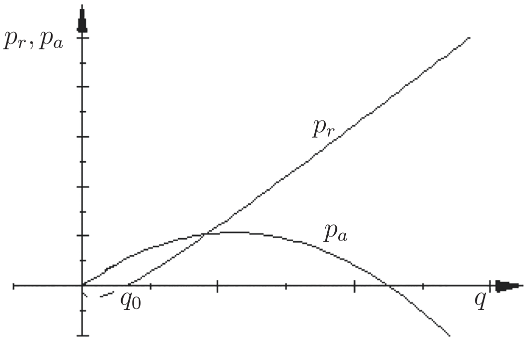



**FIGURE 3** Model 3 optimal prices

Given the symmetry between Models 2 and 3, it is straight-forward to see that the solution will be exactly the opposite as in Model 2, that is,

$$p_a^* = \frac{21\alpha q - 4\alpha^2 q^2 - 2\alpha q\sqrt{4q^2 + 7\alpha q}}{49},$$

$$p_r^* = \frac{5\alpha q - \sqrt{4\alpha^2 q^2 + 7\alpha q}}{7}.$$

These two equations are sketched in Figure 3.

The same comments as for Figure 2 apply, but now, the zone of qualities for which the reader price is set to 0 as a corner solution is $q < q_0$, where $q_0$ is the positive solution to $p_r^*(q) = 0$. On this zone, again $p_a^*(q) = \frac{\alpha q}{3}$.[21]

## 4.4 | Discussion

Our simulations serve to show a couple of important points as regards pricing. It is crucial to the results which of the production technologies has the decreasing returns, when it is only one side that has that feature. First, when both the production of readers using authors as an input and the production of authors using readers as an input are concave production processes, then our simulation points to there being no quality levels for which either price goes to zero. Thus, in that model, there is no scope at all for open access as an optimal pricing strategy. Second, when the production of readers has decreasing returns to the addition of authors, but the production of authors is linear in readers (Model 2), then our simulation reveals that it becomes optimal for the journal to be open access (i.e., to charge readers a price of zero) when the quality of the journal is relatively high. Thus, in this model, open access is a feature of high, rather than low, quality journals. Essentially, when the production of readers is concave in the number of authors, then it becomes more costly to add readers through increases in authors, and so the journal needs to attract readers through a reduction in the reader price (down to 0). Third, when it is the author production process that has decreasing returns to the addition of readers, and the reader production function is linear, then we get the opposite result; open access is a feature of optimal journal pricing only for very-low-quality journals. In this case, it is costly to create authors from readers, but not the other way around, so there is no need to subsidize the reader price (unless quality is so low that readers are not attracted to the journal). These results point to it not being generally true that open access journals are of lower quality.

It is also interesting that our simulations reveal that there is scope for negative author prices in two of our scenarios, something that is rather rare to find in the real-world of journal management. In Model 2, we get very-low-quality journals having to pay authors in order to attract them to publish in the journal, whereas in Model 3, it is very-high-quality journals that pay their authors.

However, recall that we study the case of an online journal, rather than a journal that publishes in hard-print format. This simplifies the analysis as it allows us to realistically assume that the marginal cost of supplying readers is zero. In addition, in order to get crisp theoretical results, it is necessary to make some assumptions regarding the relationships between the different variables and on the way, how the different variables affect the objective function. Rather than making all of the relevant assumptions and then putting forward theoretical results, we have preferred to carry out an analysis based upon numerical simulation. However, the main structural assumptions in the model, which are linear demand and either linear or concave production functions, are relatively standard. Given these structural assumptions, the model only contains a single determining parameter, to which we give a specific value for our numerical simulations. Any number of other simulations can be generated by simply altering the values of this parameter.

## 5 | COMPARATIVE ANALYSIS

We now compare each of our three models graphically, looking at the values of a series of important endogenous variables. We look at the level of profit obtained, the level of social welfare, and the share of total social welfare that is retained by academics (readers and authors), all as functions of $q$.

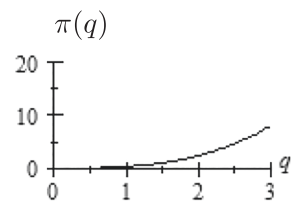
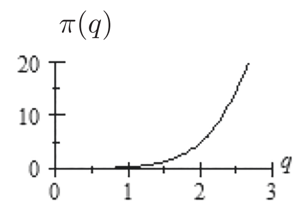
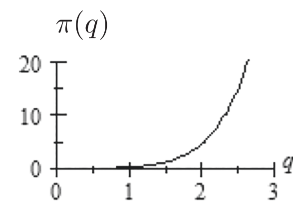
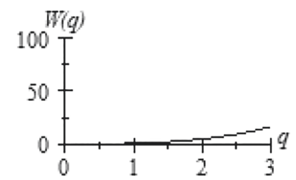
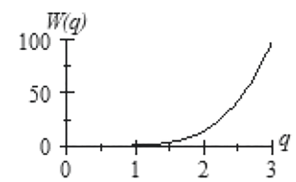
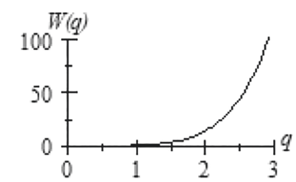
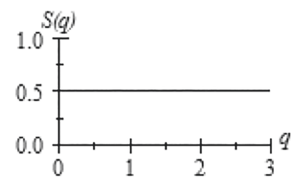
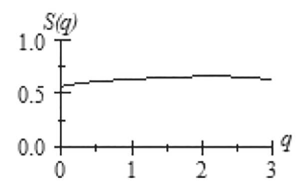
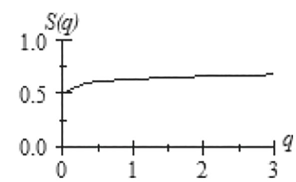
We have already determined above the optimal prices in each of the three models. The other graphs are then all derived from those optimal prices. The easiest way to show the actual equations involved is to recall that the equilibrium numbers of both authors and readers, $n_r^*$ and $n_a^*$ are both functions of the two optimal prices. And because the two optimal prices are both functions of quality $q$, then so are both $n_r^*$ and $n_a^*$ functions of quality. Then, whatever is the model involved, the equilibrium level of profits is just

$$\pi(q) = p_r^*(q) n_r^*(q) + p_a^*(q) n_a^*(q).$$

To calculate welfare, we look at the surplus retained by academics (the set of readers and authors) plus profits. To consider the welfare of academics, we use the concept of consumer surplus. Our demand curves for the journal's services by both readers and authors are

[21]See Appendix B.

**TABLE 1** Comparison of Models 1, 2, and 3

| | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Profit |  |  |  |
| Welfare |  |  |  |
| Share |  |  |  |

linear, thus "consumer surplus" on each side of the market is a triangle. Because our demand curves are $n_i = g(n_j)(\alpha q - p_i)$, for $i,j = 1,2$ and $i \neq j$, where $g(n)$ is either $\sqrt{n}$ or $n$, depending on the model, the vertical intercept (i.e., the price at which quantity goes to 0) is $\alpha q$. The area of the triangle on side $i$ of the market is

$$CS_i(q) = \frac{1}{2} n_i^*(q)\left(\alpha q - p_i^*(q)\right),\ i = r,a.$$

Given this, total welfare is given by

$$W(q) = CS_r(q) + CS_a(q) + \pi(q)$$

and the share of welfare that is retained by academics is given by

$$S(q) = \frac{CS_r(q) + CS_a(q)}{W(q)}.$$

The graphs of the principal variables of the three models are given in Table 1.[22] Recall that in Models 2 and 3, an unrestricted analysis would set negative reader prices for some ranges of quality. This is not realistically feasible, and so in reality, on those ranges of quality, the reader price would be set at 0. This has been taken into account in all of the graphs that appear in Table 1, that is, the graphs for models 2 and 3 are actually piecewise functions. For all of the simulations from here on, we have used $\alpha = 1$.

In all of our models, the level of profit that the journal earns is always strictly increasing in quality. Thus, journal managers will always strive to increase the perceived quality of their publication. In essence, journals will, at some point, run into a capacity constraint on either authors or readers, that will determine the exact level of quality that their journal attains. In that way, our model can also be interpreted as one of monopolistic competition, where the entire population of, say, authors is divided into mutually exclusive subsets, one for each journal. The quality of the journal is then determined by when their allocated number of authors is reached. We have not modeled the details of this process here, but rather it is left on the agenda for future research.

Social welfare as defined by the total sum of consumer surplus on both sides of the market plus journal profits is strictly increasing in journal quality. Thus, the greater is the level of quality that journals can attain, the greater is the level of social welfare. However, the way that welfare is shared among the market participants is again critically dependent upon the modeling assumptions. In our Model

[22] All of the graphs have been generated using the MuPAD 3 package in Scientific Workplace, and they have also all been independently checked using Mathematica. All of the working behind the actual graphs was also done by hand. Details are available from the authors upon request.

1 (diminishing returns on both production functions), the academics and the journal share welfare equally regardless of the quality of the journal. In the other two models, the share of total surplus that is retained by readers and authors falls between limits, both upper and lower. As quality increases the share of welfare retained by academics increases, but is never greater than 0.67 in Model 2 and 0.75 in Model 3. It also never falls below 0.5 in both Models 2 and 3. That is, in those two models, the readers and authors in aggregate always retain a strictly larger share of total surplus than does the journal (so long as quality is strictly positive).

The piecewise nature of the graphs in Table 1 deserves comment. The graphs where the piecewise element has the greatest effect are the graphs of the share of academics' welfare in total welfare. In Figures 4 (Model 2) and 5 (Model 3), we show larger versions of these two graphs. Notice that, in Model 2, the share of academic welfare in total welfare is increasing up to the point at which the reader price goes to zero, and is decreasing after that (the dashed line indicates where this share would go if it were feasible to pay readers). In Figure 5, we can see the detailed graph of academic welfare as a fraction of total welfare in Model 3. In Model 3, the share of academic welfare in total welfare is always increasing, but it is lower than it would be if readers could be paid on the section of the graph for which the journal is open access.

## 6 | THE EFFECTS OF REMOVAL OF COPYRIGHT

We can analyze the issue of copyright by simply noting that when there is copyright protection in place, the journal can act in the market

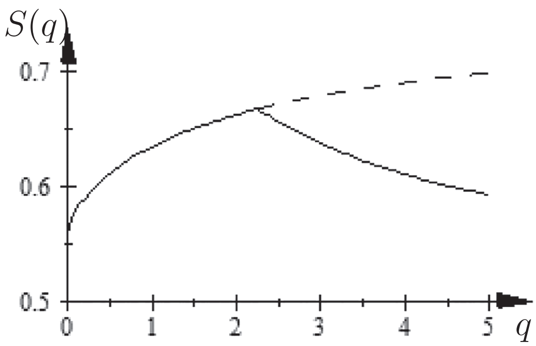



**FIGURE 4** Share of academic in total welfare, Model 2

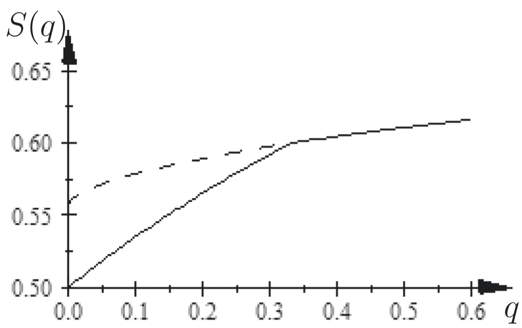



**FIGURE 5** Share of academic in total welfare, Model 3

**TABLE 2** Author prices

| Under no-copyright | | |
|---|---|---|
| **Model 1** | **Model 2** | **Model 3** |
| $p_a^* = \frac{3\alpha q}{7}$ | $p_a^* = \frac{\alpha q}{3}$ | $p_a^* = \frac{\alpha q}{3}$ |

for readers as a monopolist, whereas if there is no copyright, then the journal is far more open to competition from other forms of publishing (including author's own websites). Thus, assume that the models analyzed above are those corresponding to the existence of copyright protection and that when copyright protection is lifted (Shavell, 2010), then the journal no longer gets to choose the reader price, which is fixed at 0. This simplifies the model significantly.

Now, the profit that the journal earns is equal only to what it can earn from authors. In Appendix B, we show that the optimal author prices when copyright is removed are those reported in Table 2.

By comparing these prices with the optimal author prices under copyright, we can see that the removal of copyright serves to increase the optimal author price in all three models. In contrast to the case of copyright protection, now, the optimal author prices in Models 2 and 3 are strictly positive, and linear, for all levels of quality.

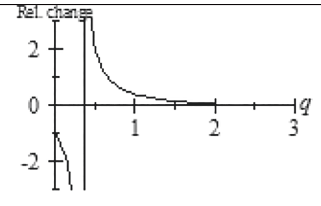
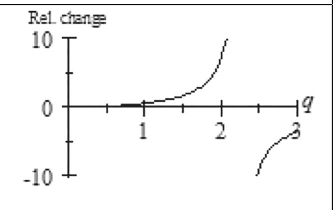
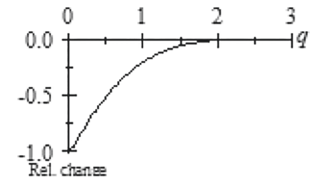
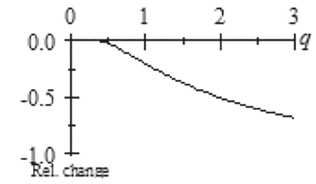
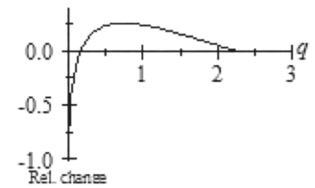
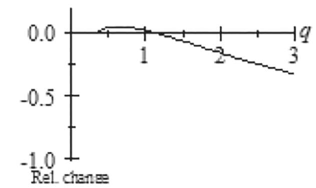
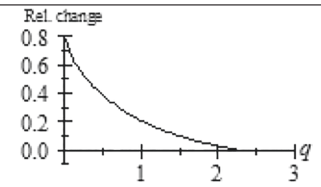
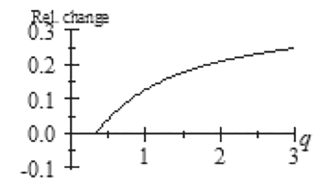
We now compare the three models both with and without copyright. We present some results both in absolute values, and in relative values.[23] We firstly look at the relative comparisons, that is, say we are interested in the variable $z(q)$, where $z$ can represent the optimal author price, profits, welfare, or share of welfare. Let $z(q)_c$ be the value of $z$ under a regime of copyright protection, and let $z(q)_{nc}$ be its value when copyright is removed. Then, we are interested in the relative change in $z$ from the removal of copyright:

$$\frac{z(q)_{nc} - z(q)_c}{z(q)_c}.$$

It turns out that in Model 1, all of the relative changes are independent of the level of quality and thus can be given as a specific percentage change. In the other models, the relative effect from removal of copyright differs as quality changes. In Table 3, all of the graphs shown are piecewise, because even under copyright, the inability to pay readers implies that for the ranges of quality when it would be optimal to pay readers, the reader price must be set at 0. Thus, the removal of copyright has no effects at all on those zones of quality. We can now see that there are some significant differences between Models 2 and 3. While in all of the models, the journal loses profit when copyright is removed (on the zone for which they would like to charge a positive reader price), but the percentage loss in profit is decreasing in Model 2 and increasing in Model 3. That is, in Model 2, the higher is the level of quality of the journal, the smaller is the percentage loss in profits when copyright is removed, whereas in Model 3, the opposite is true.

[23]The absolute values of our variables would be altered by simply changing, for example, our assumption on the value of $\alpha$. However, as we shall see, the absolute value comparison, given $\alpha$, is still interesting.

**TABLE 3** Effect of removal of copyright, relative change

| | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| $p_a^*$ | 28.57% |  |  |
| Profit | −31.41% |  |  |
| Welfare | 15.26% |  |  |
| Share | 40.49% |  |  |

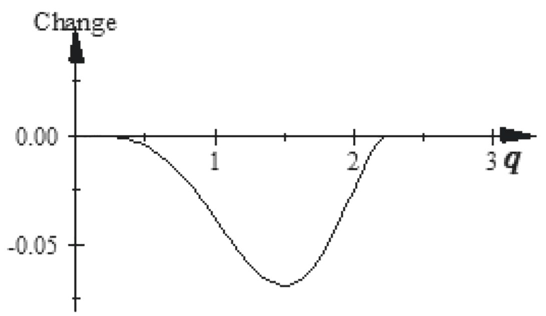



**FIGURE 6** Absolute change in profit from removal of copyright; Model 2

The relative analysis of the effect of removal of copyright on profits is interesting, but more enlightening is the analysis of the absolute loss in profits in Models 2 and 3. In Figures 6 and 7, we show the absolute change in profits for these two models. The important thing to notice about Figures 6 and 7 is the huge difference in the scale of the vertical axis. While in both models, under copyright, the levels of profit attained are the same (see Table 1, row 1), the removal of copyright in Model 2 results in a relatively small absolute loss in profits at **all**quality levels (outside of those for which the reader price under copyright would be set at 0), whereas in Model 3, it results in a similarly small loss for small levels of quality (below about $q = 1.2$) but very large absolute loss in profits for high-quality journals.

Although the relative effect upon journal profit in Model 2 is seemingly large for lower levels of quality, these losses are for very low levels of profit anyway. Removal of copyright in Model 2 hardly affects the profits of journals at any quality levels. However, removal of copyright leads to large profit losses when profits are large in Model 3, a much more devastating result. If, for example, journals did have some fixed costs of operation (as is likely in the real world), then removal of copyright would lead to the closure of only very-low-quality journals in Model 2, but it can lead to the closure of high-quality journals in Model 3. The removal of copyright as suggested by Shavell (2010) may be a rather dangerous strategy in a scenario like that of Model 3.

In the welfare analysis, in Model 2, there is a rather large zone of positive welfare gains in percentage terms, whereas in Model 3, the zone of welfare gains is much smaller, and the relative gains are also smaller. Thus, assuming that social welfare is the policy objective, it would appear that removal of copyright might be a reasonable policy in Model 2, but not in Model 3. This intuition can again be confirmed by looking at the absolute changes in welfare from removal of copyright in Figures 8 and 9. Again, we need to look at the scale of the vertical axis. In Model 2 (Figure 8), although there is a very small negative part of the graph at levels of quality below about 0.2, the scale of

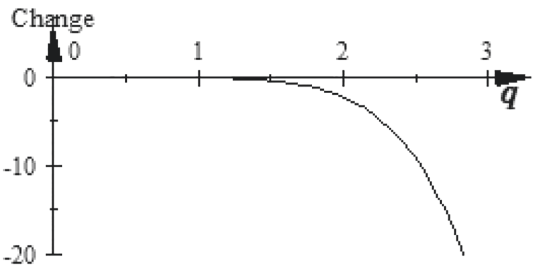



FIGURE 7 Absolute change in profit from removal of copyright; Model 3

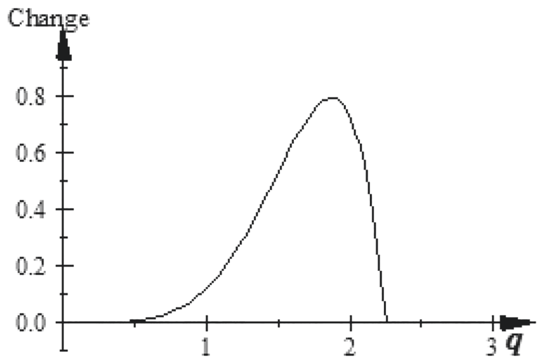



FIGURE 8 Absolute change in social welfare from removal of copyright; Model 2

these losses is totally insignificant compared with the gains at larger quality levels.[24] In short, in Model 2, removal of copyright leads to hardly any danger of welfare loss, and relatively interesting welfare gains for almost all relevant levels of quality.

On the other hand, consider the absolute welfare change in Model 3 (Figure 9). In this graph, there is a positive section between levels of quality of one third and about 1.1.[25] All of the rest of the graph lies below the horizontal axis, and at relatively large numbers, which implies that removal of copyright leads to large welfare losses for those levels of quality. Thus, in Model 3, the removal of copyright can improve welfare for low levels of quality, but the improvement is miniscule, whereas for higher levels of quality, the change in social welfare is negative and significant.

Finally, we comment on the last row of Table 3. The relative change in the share of welfare that goes to academics is decreasing in quality in Model 2 and increasing in quality in Model 3. That is, when copyright is removed, if we are in Model 2, although total welfare is much more likely to go up, the share of this welfare that accrues to academics drops. If we are in Model 3, the share of academic welfare

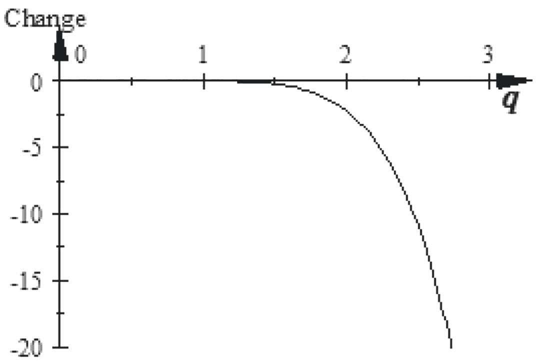



FIGURE 9 Absolute change in social welfare from removal of copyright; Model 3

in total welfare rises when copyright is removed, but it is more likely that total welfare drops. We are also able to perform a welfare analysis for readers and authors separately. If that is done, then it turns out that removal of copyright in either model leads to less author welfare and more reader welfare, and the gain in reader welfare outweighs the loss in author welfare. However, because in reality, readers and authors are generally the same people (academics), it is probably more interesting to consider the sum of welfare going to the readers and authors.[26]

## 7 | A CONSIDERATION OF CAPACITY CONSTRAINTS

Above, we have noted that in order to consider some degree of competition in our model, it would be relevant to impose capacity constraints on both of the two sides of the market. In this way, the journals market can be thought of as operating in an environment of monopolistic competition. A full consideration of capacity constraints in the simulations that we have done of the model would add quite a large number of new scenarios to consider. We feel that it is best to leave a detailed analysis of it to future research, although it is worthwhile to mention here how things would likely play out.

Under a capacity constraint, the journal could count on a certain maximum number of both readers and authors. The number of readers and authors are both increasing functions of quality in all of the model configurations that we have used. Thus, although the journal's profit is also increasing in quality, the journal would not

[24] Indeed, the negative section of the graph cannot even be discerned unless the vertical scale is changed by a factor of about $\frac{1}{100}$.

[25] Again, this positive part cannot be discerned in the graph, unless we change the vertical scale by a factor of about $\frac{1}{100}$.

[26] However, if we were to consider academics at different universities, and because the authorship at some universities is significantly higher than at others (high ranked universities vs. low ranked ones on a scale of publications), then we might want to calculate reader and author welfare separately. At universities with low publication outputs, the academics are mainly readers. These universities would apparently gain significantly from removal of copyright. The same may not be true in universities with a high number of publications. See Mueller-Langer and Watt (2010) for further details.

be able to set quality arbitrarily high, as at some point, it would run out of either readers or authors. In this way, the capacity constraints would determine the final quality achieved in the model.[27]

The introduction of capacity constraints would have important effects when the removal of copyright is considered. Unless the removal of copyright somehow was to alter the binding constraint (something that would seem not to be logical), then the capacity constraints have the potential to intervene in the welfare analysis of the previous section.

Take for example our Model 1. When copyright is removed, social welfare increases by around 15% regardless of the level of quality. However, in that model, the removal of copyright will also increase the numbers of both readers and authors at each level of quality. This in turn implies that the capacity constraint must now bind at a lower level of quality, and so in the end, the final quality that is actually achieved is decreased. Finally, because social welfare is an increasing function of quality, there is an off-setting effect on social welfare that may or may not counterbalance the 15% gain that is initially found by removing copyright.

Model 2 works in a similar way to Model 1 in respect of this capacity constraint effect. Removal of copyright will increase social welfare at almost all levels of quality, but it will also increase the numbers of both readers and authors at each quality level. Thus, the capacity constraint will bind at a lower level of quality, and so final quality achieved will go down.[28] The social welfare gains are, at least partially, off-set by the welfare loss of a lower quality level. On the other hand, in Model 3, the opposite occurs. In the first instance, removal of copyright is likely to increase social welfare at each level of quality, but in that model, the numbers of readers and authors are decreased at each level of quality when copyright is removed (at high enough levels of quality).[29] The capacity constraint then would bind at a higher level of quality than before, implying a welfare gain that (at least partially) off-sets the losses from removal of copyright.

It is impossible to know which of the two effects (the direct welfare effect at each level of quality from removal of copyright, or the indirect welfare effect of the change in quality due to the capacity constraints) is larger. However, studying this effect would make an interesting extension to the present paper.

[27]Another way forward is to include a convex cost function for quality. However, quality is simply a threshold that divides the set of submissions into accepted and rejected papers. There is no direct cost to increasing quality. But there are significant indirect effects, because the quality threshold will affect both the number and average value of submissions. Resolving how these effects play out into an optimal choice of quality is well beyond the scope of the present paper, but we note that however those effects play out, they themselves will be ultimately constrained by the number of authors who are able to write papers of sufficient quality for the journal. Therefore, in the end, it seems likely that a capacity constraint will be the limiting factor on how high quality can be set.

[28]Again, this is assuming that the optimal reader price with copyright was not set at 0. If open access were optimal under copyright, then of course no effect at all happens when copyright is removed.

[29]This only happens in Model 3 when quality is above a certain threshold. However, the threshold is at a relatively low level of quality, and below, this threshold although the number of academics served actually increases, the change is rather infinitesimal.

## 8 | CONCLUSIONS

Our conclusions are the following. First, with regard to the relationship between journal quality and open access in a copyright protected regime (i.e., the status quo), our model suggests that it is *not* true that open access journals will necessarily have lower quality than closed access journals. Indeed, we find that under appropriate profit maximization on both sides of the journal market, there exist configurations under which it is the higher quality journals that will have the open access format together with high author fees (our Model 2). Recent empirical evidence on economics journals suggests that Model 2 might be the most relevant model to the real-world. In particular, Zheng and Kaiser (2015) suggest that, due to network effects running from the reader side to the author side, higher quality journals can charge higher author fees. In addition, Zhang and Kaiser (2015, p. 1319) state that this network effect "may help justify the practice of open-access journals, where subscription is free, but authors pay a hefty fee after manuscript acceptance." However, we also have a model (Model 1) in which open access is never a feature of an optimally priced journal.

Second, regarding the hypothesized removal of copyright as suggested by Shavell (2010), we find that removal of copyright will have a different effect depending upon the configuration of the market. We find scenarios in which removal of copyright will have hardly any effect on profits, but will increase social welfare for almost all quality measures (Model 2), and other scenarios in which removal of copyright will have a serious negative effect on the profits of high quality journals, and that will reduce social welfare (Model 3). Thus, again, we cannot unambiguously support removal of copyright, but nor can we unambiguously support its continued retention. In our Model 1, we find that removal of copyright is unambiguously social welfare improving, but it will also have a serious negative effect on journal profits. If the real state of the world is something like Model 1, then removal of copyright is likely to be a beneficial social policy, but it may have to be accompanied by an alternative business model for publication of scientific work.

All of our conclusions are based upon numerical simulation and particular functional forms, and so should be read with due care. However, the only variable in our model is the effect of an increased level of quality upon the number of readers and authors, that is, the vertical intercept of our demand curves. Different values for this vertical intercept would change the numbers we get, but not the structure of the models. We also remind the reader that the results only apply to a local zone of quality levels, for which increases in quality lead to increases in the number of authors that are accepted for publication.

This paper suggests several directions in which future research could be directed. Firstly, it would be most interesting to verify empirically which, if any, of our three models is most likely to be real-world relevant. Models 1 and 2 provide support for removal of copyright, whereas Model 3 does not. The critical issue is where the diminishing returns lie. Is it the production of readers with authors as an input that suffers diminishing returns, or rather is diminishing returns a feature of the production of authors with readers as an input? We can think of logical reasons to support either argument. Perhaps, an empirical examination could throw some light on this issue. Second, our model has been calibrated with a single parameter for the effect of increased quality upon the demand for journal space by both authors and readers. Although considering different values of this parameter will not alter our model in any significant manner, it would certainly be of interest to consider that the effect is different for authors as for readers. Doing so would unbalance the model and would certainly have the potential to alter some of our conclusions. However, again, it is very hard to think of convincing reasons why an increase in journal quality will attract new readers in a notably different way to how it attracts new authors. Third, the model generates specific formulas for the numbers of readers and the numbers of authors for each quality level. The ratio between these two gives us the number of readers per published paper, something that we may associate with the "impact" of the journal. Further, the impact factor that is habitually used (e.g., by ISI), which is cites per paper published, can be seen as nothing more than readers per paper times the probability that any given reader will end up citing the paper he or she reads in a follow-up paper. It would be of great interest to attempt to identify an appropriate function for the probability of citing (as a function of the quality of the journal article read), so that our model may then be applied directly to an analysis of the validity of the ISI impact factor as an indicator of journal quality. Finally, the journal that we have modeled is an online product only. This simplifies things as regards the costs of running the journal and thus, the journal's profit function. We would, however, be interested in a version of this model being applied to journals with both hard-print and online formats, and above all, a journal with a hybrid-open access policy (a policy in which the author can decide, and pay a corresponding fee to the journal, in order to have the article priced at zero to readers).

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## APPENDIX A: OPTIMAL PRICES IN MODEL 2 UNDER COPYRIGHT PROTECTION

The two simultaneous Equations (3) and (4) in the main text can be written as

$$n_r = \sqrt{n_a}\beta_r, \tag{A1}$$

$$n_a = n_r\beta_a, \tag{A2}$$

where $\beta_i \equiv \alpha q - p_i$ for $i = r, a$. Both of $n_r$ and $n_a$ are constrained to be positive. We are restricted to parameter values such that $\beta_i > 0$ for $i = r, a$, that is, we can only consider prices that satisfy $p_i < \alpha q$ for $i = r, a$. It is easy to show that the solution to the two equations, Equations (A1) and (A2), outside of the trivial solution at (0, 0), is at $n_r = \beta_r^2\beta_a$; $n_a = \beta_r^2\beta_a^2$. The profits of the journal are given by

$$\pi = p_r n_r + p_a n_a = p_r\beta_r^2\beta_a + p_a\beta_r^2\beta_a^2.$$

From the definitions of the two $\beta_i$ functions, we can see that profit is now a third-order function of each price.

Consider first the optimal reader price. The two derivatives of the profit function with respect to $p_r$ are

$$\begin{aligned}\frac{\partial\pi}{\partial p_r} &= \beta_r^2\beta_a - p_r 2\beta_r\beta_a - p_a 2\beta_r\beta_a^2,\\ \frac{\partial^2\pi}{\partial p_r^2} &= -4\beta_r\beta_a + p_r 2\beta_a + p_a 2\beta_a^2.\end{aligned}$$

The first-order condition for a maximum is

$$\frac{\partial\pi}{\partial p_r^*} = 0 \Rightarrow \beta_r^{*2}\beta_a - p_r^* 2\beta_r^*\beta_a - p_a 2\beta_r^*\beta_a^2 = 0$$

where $\beta_r^* = \alpha q - p_r^*$. Extracting the common factor, we have $\beta_r^*\beta_a(\beta_r^* - 2p_r^* - 2p_a\beta_a) = 0$. Since $\beta_r^*\beta_a > 0$, we have

$$\beta_r^* - 2p_r^* - 2p_a\beta_a = 0. \tag{A3}$$

Substituting for $\beta_r^*$, this reads $\alpha q - p_r - 2p_r - 2p_a(\alpha q - p_a) = 0$. The final solution is given by

$$p_r^* = \frac{\alpha q - 2p_a(\alpha q - p_a)}{3}. \tag{A4}$$

This solution is unique on the range $p_r < \alpha q$. Because our solution (A4) is unique, in order to ensure that it is a maximum, we need to show that the second-order condition holds at that solution:

$$\frac{\partial^2\pi}{\partial p_r^2} = -4\beta_r^*\beta_a + 2p_r^*\beta_a + 2p_a\beta_a^2 < 0 \Rightarrow -4\beta_r^* + 2p_r^* + 2p_a\beta_a < 0.$$

Equation (A3) is $2p_a\beta_a = \beta_r^* - 2p_r^*$. Substituting this into our second-order condition, we get

$$-4\beta_r^* + 2p_r^* + \beta_r^* - 2p_r^* < 0 \Rightarrow -3\beta_r^* < 0,$$

which holds for any $p_r^* < \alpha q$. Thus, Equation (A4) is indeed a maximum.

Second, consider the optimal author price. The first two derivatives of the profit function with respect to $p_a$ are as follows:

$$\begin{aligned}\frac{\partial\pi}{\partial p_a} &= -p_r\beta_r^2 + \beta_r^2\beta_a^2 - 2p_a\beta_r^2\beta_a,\\ \frac{\partial^2\pi}{\partial p_a^2} &= -4\beta_r^2\beta_a + 2p_a\beta_r^2.\end{aligned}$$

The first-order condition is

$$-p_r\beta_r^2 + \beta_r^2\beta_a^{2*} - 2p_a^*\beta_r^2\beta_a^* = 0 \Rightarrow -p_r + \beta_a^{2*} - 2p_a^*\beta_a^* = 0. \tag{A5}$$

The second-order condition is

$$-4\beta_a^* + 2p_a^* < 0$$

which, upon substituting for $\beta_a^*$ reduces to

$$p_a^* < \frac{2\alpha q}{3}. \tag{A6}$$

Now, note that Equation (A5) is just

$$-p_r + (\alpha q - p_a^*)^2 - 2p_a^*(\alpha q - p_a^*) = 0$$

or

$$3p_a^{*2} - 4\alpha q p_a^* - p_r + (\alpha q)^2 = 0.$$

Using the quadratic formula, we know that the two roots of this equation satisfy

$$\frac{4\alpha q \pm \sqrt{16\alpha^2q^2 - 12(\alpha^2q^2 - p_r)}}{6}.$$

Simplifying, we get

$$\frac{2\alpha q \pm \sqrt{\alpha^2q^2 + 3p_r}}{3} = \frac{2\alpha q}{3} \pm \frac{\sqrt{\alpha^2q^2 + 3p_r}}{3}.$$

We can see from the second-order condition that the higher of these two roots is a minimum and the lower is the maximum. Thus, the optimal author price is given by

$$p_a^* = \frac{2\alpha q - \sqrt{\alpha^2 q^2 + 3p_r}}{3}. \tag{A7}$$

In order to find the exact optimal prices for readers and authors, both as functions of only the journal quality $q$, we simultaneously solve the two first-order equations (A4) and (A7). To that end, substitute Equation (A4) into Equation (A7):

$$\begin{aligned} p_a^* &= \frac{2\alpha q - \sqrt{\alpha^2 q^2 + 3\left(\frac{\alpha q - 2p_a^*(\alpha q - p_a^*)}{3}\right)}}{3} \\ &= \frac{2\alpha q - \sqrt{\alpha^2 q^2 + \alpha q - 2p_a^*(\alpha q - p_a^*)}}{3}. \end{aligned}$$

Simple steps then give

$$\begin{aligned} 2\alpha q - 3p_a^* &= \sqrt{\alpha^2 q^2 + \alpha q - 2p_a^*(\alpha q - p_a^*)} \\ &\Rightarrow 4\alpha^2 q^2 - 12\alpha q p_a^* + 9{p_a^*}^2 = \alpha^2 q^2 + \alpha q - 2p_a^*(\alpha q - p_a^*). \end{aligned}$$

We get the following second-order equation:

$$7{p_a^*}^2 - 10\alpha q p_a^* + 3\alpha^2 q^2 - \alpha q = 0.$$

Applying the quadratic formula, we get

$$\begin{aligned} p_a^* &= \frac{10\alpha q \pm \sqrt{100\alpha^2 q^2 - 28(3\alpha^2 q^2 - \alpha q)}}{14} \\ &= \frac{5\alpha q \pm \sqrt{4\alpha^2 q^2 + 7\alpha q)}}{7}. \end{aligned}$$

The upper root of this is greater than[30] $\alpha q$. So the unique value of $p_a^*$ is

$$p_a^* = \frac{5\alpha q - \sqrt{4\alpha^2 q^2 + 7\alpha q)}}{7}. \tag{A8}$$

Finally then, we need to substitute this back in to the equation for the optimal reader price (A4):[31]

$$\begin{aligned} p_r^* &= \frac{\alpha q - 2\left(\frac{5\alpha q - \sqrt{4\alpha^2 q^2 + 7\alpha q)}}{7}\right)\left(\alpha q - \left(\frac{5\alpha q - \sqrt{4\alpha^2 q^2 + 7\alpha q)}}{7}\right)\right)}{3} \\ &= \frac{21\alpha q - 4\alpha^2 q^2 - 2\alpha q\sqrt{q(4\alpha^2 q + 7\alpha)}}{49}. \end{aligned} \tag{A9}$$

[30]The upper root is $\frac{5\alpha q}{7} + \frac{1}{7}\sqrt{4\alpha^2 q^2 + 7\alpha q} > \frac{5\alpha q}{7} + \frac{1}{7}\sqrt{4\alpha^2 q^2} = \frac{5\alpha q}{7} + \frac{2\alpha q}{7} = \alpha q$.

[31]The simplification for this was carried out using the package Mathematica.

## APPENDIX B: OPTIMAL AUTHOR PRICES WHEN COPYRIGHT IS REMOVED

*Model 1* When copyright is removed, and the reader price is constrained to be equal to 0, the profit of the journal is given by $\pi = p_a n_a = p_a(\beta_r^2 \beta_a^4)^{\frac{1}{3}}$. We have $\beta_r = \alpha q$, so the profit function can be written as

$$\pi = p_a\left((\alpha q)^2 \beta_a^4\right)^{\frac{1}{3}} = (\alpha q)^{\frac{2}{3}} p_a \beta_a^{\frac{4}{3}}.$$

The first-order condition[32] for an optimal choice of $p_a$ is

$$(\alpha q)^{\frac{2}{3}}\left({\beta_a^*}^{\frac{4}{3}} - \frac{4}{3}p_a^* {\beta_a^*}^{\frac{1}{3}}\right) = 0 \Rightarrow \beta_a^* = \frac{4}{3}p_a^*$$

which, since $\beta_a^* = (\alpha q - p_a^*)$, is the same as

$$p_a^* = \frac{3\alpha q}{7}.$$

Recall that under copyright, the optimal author price was $\frac{\alpha q}{3}$, thus aside from reducing the reader price to 0, the removal of copyright serves to increase the optimal author price by $\frac{3\alpha q}{7} - \frac{\alpha q}{3} = \frac{2\alpha q}{21}$.

*Model 2* There is no need to redo the optimization under the restriction that $p_r = 0$. We only need to use that value of reader price in Equation (A7) in Appendix A. Substituting in $p_r = 0$, and simplifying, we see that the optimal price without copyright is

$$p_a^* = \frac{\alpha q}{3}.$$

Again, the optimal author price increases with the removal of copyright. In contrast to the case of copyright protection, now the optimal author price is strictly positive, and linear, for all levels of quality.

*Model 3* The relevant equation from Appendix A (with the subscripts switched to capture the modelling change) is $p_a^* = \frac{\alpha q - 2p_r(\alpha q - p_r)}{3}$. Clearly, setting $p_r = 0$ give us exactly the same author price as in Model 2, namely,

$$p_a^* = \frac{\alpha q}{3}.$$

[32]The second-order condition is $-\frac{8}{3}{\beta_a^*}^{\frac{1}{3}} + \frac{4}{9}p_a^* {\beta_a^*}^{-\frac{2}{3}} < 0$. This is satisfied if $p_a^* < 6\beta_a^*$. Using the definition of $\beta_a^*$, the second-order condition can be written as $p_a^* < \frac{6\alpha q}{7}$. The solution to the first-order condition satisfies this, and so we can be assured that $p_a^*$ is indeed a maximum.