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Interactions of Publication Volume, Journal Impact, and Article Processing Charges: Comparative Study of China and Global Practices in Nature Portfolio

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Abstract: In the commercial realm, the annual publication volume (PUB) significantly influences the business models of article processing charge (APC)-based open access (OA) journals, though it may negatively impact journal reputation. Despite this, the interactions among APC, PUB, and the Journal Citation Indicator (JCI)—a key marker of journal reputation—have not been thoroughly examined. The objective of this study is to reveal the interactions among APC, PUB, and JCI, determine if there are differences between the interactions inside and outside of China, and uncover the possible mechanisms enabling dominant publishers to set APC prices without compromising their market position. Through cross-correlation and linear regression analyses, our findings reveal distinct APC business models between China and the rest of the international OA journal landscape. Specifically, while both cases demonstrate a proportional relationship between APC and JCI, China exhibits an inverse relationship between APC and PUB, contrasting with the global trend. This suggests that the business model in China sets an "optimized" PUB for Chinese APC-based OA journals, which would pose challenges for journal management and the expansion of the domestic APC-based OA market volume. In the rest of the international context, by contrast, the business model supports a proactive annual increase in APC list prices driven by the proportional relationships between APC and PUB. These insights underscore the need for more nuanced APC business models that can adapt to regional variations in funder requirements and policy expectations.

Keywords: article processing charges; journal citation indicator; annual volume; open access; journal reputation; business model

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1. Introduction

Current implementations of open access (OA) publishing often involve charging article processing charges (APCs), a practice that has been shown to create barriers for researchers with limited resources [1–7]. The yearly publication volume (PUB) plays a crucial role in shaping the business models of OA journals that rely on APCs. However, this can potentially have an adverse effect on the journal's reputation. Despite this, the relationship between APC, PUB, and the Journal Citation Indicator (JCI)—a critical measure of journal reputation—has not been fully explored. The aim of this study is to investigate how APC, PUB, and JCI interact, and to examine whether these interactions differ within and outside of China.

1.1. Brief Literature Review on APC-Based OA Business Models

Existing research primarily focuses on APC expenditures from the perspectives of the demand side and affordability. Studies have proposed that increases in APCs can be associated with growing demand [8,9]. Studies delving into affordability [10–16] reveal associations between APCs and institutional resources, as well as third-party funding, which influence the uptake of APC-based OA publishing.

While the investigation of APC business models remains a prominent area of research, the existing literature often approaches this topic from three distinct perspectives: journal reputation, publisher size, and disciplinary considerations [17–26]. Across these studies, regardless of the specific indicators used to represent journal reputation, e.g., journal impact factors, normalized citation scores, Altmetrics, grant funding, DOAJ Seal, SCOPUS h-index, SCImago journal rank indicator (SJR), eigenfactor, article influence score, and Google h5 index [20,27–32], there is a consistent finding of a positive correlation between journal impact and APCs, although Romeu et al. [33] argued that such a relationship is absent in hybrid OA journals within the field of physics. Additionally, it has been revealed that larger and for-profit publishers tend to impose higher APCs [10,20,21,26]. Concerning disciplinary differences, there is an assertion that disciplines receiving a greater proportion of grant and institutional funding tend to have higher APCs [25,26,34,35].

Schönfelder [21] and Maddi and Sapinho [29] identified that a correlation between APCs and journal impact was only moderate, suggesting that other factors may influence APC pricing decisions. An alternative approach to establishing reasonable APCs involves estimating the actual production cost, taking into account economies of scale. The Fair Open Access Alliance (FOAA) illustrated that significantly lower APCs, not exceeding $50 per page, are viable for sustaining an APC-based OA journal [36]. Grossman and Brembs [37], considering variations in rejection rates, staffing, editorial services, and publishing volume among journals, similarly estimated that fees ranging from $200 to $1000 per article are adequate for supporting an APC-based OA journal. Additionally, Rodrigues et al. [38] discovered that 59% of gold journals listed in the DOAJ charge APCs of $1000 or less, including those with no APC at all, showcasing the feasibility of this average price point when profit generation is not the primary objective.

The dynamic nature of the OA market necessitates ongoing analysis. Recent studies by Zhang et al. [39] and Klebel and Ross-Hellauer [3] have suggested that APCs vary among authors and exhibit geographic and field-specific patterns, albeit relying on static APC values. In contrast, Butler et al. [36] examined annual and historical APC data, along with the number of gold and hybrid OA articles published by major publishers indexed by Web of Science (WoS) from 2015 to 2018. These studies emphasized the unintended effect of APC-based OA publishing, which leads to lower diversity in authorship [40,41], lower visibility, potentially fewer citations, and marginalization of researchers from the Global South [42].

In response to these inequalities associated with APCs, initiatives developed by the ON-MERRIT project [43], CERN [44], Science Europe [45], and UNESCO [46] have proposed strategies to transition towards alternative publishing models that eliminate author-facing charges altogether, such as Diamond OA. Additionally, scholarly publishing experts and OA advocates, including editors of APC-based OA journals, argue that the abolition of or reduction in APCs is crucial for the sustainability of OA [47,48]. Notably, the entire editorial boards of two neuroimaging journals resigned to protest against high APCs [49,50]. However, given the longstanding dominance of large publishing companies in scientific publishing, it is crucial to gain a quantitative insight into the mechanisms governing APC business models employed by successful commercial OA publishers.

Wiley reports its performance using the controversial adjusted EBITDA profit metric, i.e., operating profit as a percentage of revenue [51]. Thus, commercial publishers could focus more on the total revenue and gross profits than the APC listed for each journal, with the former directly related to the annual publication volume (PUB), which is associated with the market influence of commercial publishers. Notably, not all publishers are adept at effectively navigating the market and academic influences within the ever-evolving landscape of the OA market, e.g., publishers like MDPI, Frontiers, and Hindawi have experienced substantial growth in publication volumes per journal and have concurrently raised their APCs significantly, although concerns persist regarding their quality control measures [52,53]. Large and traditional publishers are increasingly entering the OA publishing realm. For instance, Wiley's decision to phase out the Hindawi brand and integrate

its journals into Wiley's portfolio signifies this trend. Moreover, recent mergers and acquisitions, such as BMC, Springer Nature, and Frontiers falling under the same ownership, highlight a broader consolidation within the OA market.

Such market concentration can impact APC business models, as dominant players often dictate fees and profitability within the OA market [54]. For instance, the adoption of a EUR 3000 price point was largely influenced by Springer's launch of the OpenChoice program in 2004, a trend that was subsequently embraced by many major commercial publishers [10,55]. Despite charging lower APCs, *PLOS One* was surpassed by Springer Nature's mega OA journal, *Scientific Reports*, in 2017 [56], underscoring dominant publishers' ability to set prices without compromising their market position [57]. However, the precise strategies employed by publishers to achieve this remain a subject of inquiry.

Therefore, a detailed examination of how the PUB affects APC-based OA journals will reveal shifts in business strategies among major publishers. For example, research [20,58] suggests that dominant publishers might prefer a hybrid-OA model over an APC-based OA model, thereby influencing OA market prices. Khoo's research [57] further indicates that authors may demonstrate price insensitivity in response to rising APCs, resulting in an increase in article volumes. However, a significant literature gap remains in comprehensively understanding the quantitative relationship between higher publication volume and elevated APC pricing for OA journals.

In summary, while previous research has explored APC business models based on factors such as journal reputation, disciplines, and actual production cost, few studies have quantitatively elucidated the relationship between the APC, JCI, and PUB, especially the influence of the PUB on the APC and JCI. This understanding is crucial for fostering the development of transparent, competitive, and reasonable APC business models.

1.2. Why Does This Study Focus on Nature Portfolio and China?

Among the top three largest academic publishers, a distinction can be made based on their sources of APC revenue: Elsevier and Wiley rely primarily on the hybrid business model, whereas Springer Nature prioritizes the gold OA model [36,38,39,59].

Given Springer Nature's dominant position in the APC-based OA market, it warrants close study. However, Springer's OA portfolio exhibits a greater diversity across fields compared with Nature Portfolio (NP). Moreover, mega OA journals of NP, *Scientific Reports* and *Nature Communications*, collectively contributed 39.9% of Springer Nature's total EUR 442.1 million APC revenues from 2015 to 2018 [36]. Therefore, NP was chosen as the focal point in this modeling approach to control for certain sources of bias, such as publisher size, and to highlight the market influence exerted by the PUB of mega OA journals.

In addition, the Journal Citation Indicator (JCI) serves as a representation of journal reputation in the analysis. The JCI differs from Journal Impact Factors (JIFs) as it normalizes for three publication variables, which are subject category, publication year, and document type; e.g., journals with a JCI of 1.5 boast a citation impact 50% higher than the average in their respective category [60].

Furthermore, examining the APC business model in China is essential for several reasons. (1) Sustainability concerns: The limited volume of domestic academic publishing is a significant issue for China [61–64], and China is making efforts by launching several initiatives to build its portfolio of domestic academic journals [65], with the most consistently funded and supported initiative being the China Journal Excellence Action Plan (CJEAP), which typically establishes APC-based OA journals; therefore, the sustainability of such journals becomes increasingly important. Analyzing the interplay between APC, JCI, and PUB will help identify potential challenges and opportunities for long-term viability. (2) Policy alignment: European research funders are key stakeholders in developing an effective market for OA APCs and in negotiating with major international commercial publishers to establish APC business models [10], as seen in initiatives like Plan S. However, these initiatives may not fully address the needs of funders in other countries, such as China. This is particularly relevant in the context of business models used by

large commercial publishers, e.g., NP, for internationally co-published OA journals with Chinese publishers/institutions. Therefore, a comprehensive evaluation is essential to adapting these business models to domestic policies and funding requirements, ensuring that internationally co-published OA journals can flourish within the local context and more effectively serve the host country's needs.

This study aims to address the following research inquiries in order to elucidate how dominant publishers can strategically set APC prices without compromising their market position:

1. How do APC, PUB, and JCI interact within the business model?
2. Are there distinct business models for APC-based OA journals inside and outside of China?
3. Does the business model impose limitations on journal development?

2. Data and Methods

2.1. Data Collection

We selected two sets of variables to analyze the business models of APC-based OA journals: APC 2019-JCI 2018-PUB 2018 and APC 2023-JCI 2022-PUB 2022. This choice was made to mitigate the notable impact of the COVID-19 pandemic on scholarly publishing [66], allowing us to examine changes in the business model over a 5-year period. Additionally, we opted for APC 2019-"JCI 2018-PUB 2018" instead of APC 2019-"JCI2019-PUB2019" because JCI 2018, PUB 2018, and APC 2019 were reported in 2019, suggesting that APC may have a stronger correlation with the JCI and PUB from the previous year than with those from the current year. This approach is consistent with other non-longitudinal/cross-sectional studies on APCs [26,59,67,68].

All journal titles from Nature Portfolio (NP) were obtained from the "Journals A-Z" webpage (https://www.nature.com/siteindex) (accessed on 27 January 2024) on the official website of NP. We included those indexed in the 2022 Journal Citation Reports [69] of Clarivate and labeled as OA journals. Consequently, the dataset includes 9 journal titles from China (excluding Hong Kong, Macao, and Taiwan), referred to hereinafter as S1, and 29 journal titles from outside of China (excluding Hong Kong, Macao, and Taiwan) referred to as S2. S2 excluding three journals (*Nature Communications*, *Scientific Reports*, and *Scientific Data*) is referred to as S3, with its significance discussed in Section 2.2. The details of Tables S1 and S2 are provided in the Supplementary Materials.

All of these 38 journal titles had data for APC 2019-JCI 2018-PUB 2018 and APC 2023-JCI 2022-PUB 2022. For the 38 journal titles, the data sources for APC 2019, JCI 2018, PUB 2018, APC 2023, JCI 2022, and PUB 2022 were as follows:

(1) APC list prices from 2019 were obtained from an open dataset by Morrison [70]. GBP is utilized consistently as the unit of currency throughout the investigation, as it is the original currency presented in this dataset.
(2) APC list prices from 2023 were collected from the DOAJ [71]. DOAJ was utilized to limit results to research articles because some journals differentiate between different article types in their pricing on their own webpages.
(3) JCI 2018, PUB 2018, JCI 2022, and PUB 2022 were all obtained from the InCites dataset [72], which was updated on 15 December 2023, with WoS content indexed through 30 November 2023, and includes ESCI documents. InCites is an analytical tool based on the WoS.

It should be noted that APC business models can vary across different research fields [73]. However, most of the 38 journal titles in this study are from "high-revenue" fields such as biology, medicine, materials science, and chemistry [3,25,26,34,55]. By focusing on journals from these fields and using Nature Portfolio as a representative example of a commercial publisher, its market value of scientific disciplines is kept relatively constant. This approach effectively controls for the influence of the "discipline" variable on APC, as

discipline-specific variations are minimized. Consequently, the impact of discipline-specific factors on APC is assumed to be negligible in this study.

2.2. Data Processing

OriginPro, Version 2021 (OriginLab Corporation, Northampton, MA, USA), was used for statistical analysis. Excel computer spreadsheets (Microsoft, Seattle, WA, USA) were the primary tool for conducting calculations. A *p*-value less than 0.05 was considered statistically significant.

(1) Empirical Setting and Data Preparation

Spearman correlation calculations were conducted for S2 to assess potential interactions and collinearity among the primary variables: APC, JCI, and PUB. The analysis revealed no significant correlation between PUB 2018 and JCI 2018, indicating the absence of multicollinearity. Consequently, the interaction term (PUB × JCI) was introduced as an independent variable in the preliminary model to explore their combined effects on APC. Thus, the independent variables included in the preliminary model were JCI, PUB, and their interaction term (PUB × JCI), and the dependent variable was APC.

(2) Preliminary Model Formulation and Selection

The preliminary linear regression model was formulated as follows:

$$\text{APC} = \beta_0 + \beta_1\ \text{JCI} + \beta_2\ \text{PUB} + \beta_3\ \text{JCI} \times \text{PUB} \quad (1)$$

Given the stronger correlations observed among APC 2023, JCI 2022, and PUB 2022 compared with APC 2019, JCI 2018, and PUB 2018, a stepwise model selection process was applied to the former set of variables. This process aimed to derive a streamlined model for APC 2023-JCI 2022-PUB 2022. Notably, the variable JCI 2022 was excluded during the selection process. The results of this selection process are summarized in Table 1.

Table 1. Outcomes of linear regression of APC 2023 based on variables PUB 2022 × JCI 2022 and PUB 2022 upon a stepwise model selection of JCI 2022, PUB 2022, and PUB 2022 × JCI 2022 of S2.

Dependent Variable and Statistics	Parameter
Intercept (β_0)	2540.769 *** (82.838)
Coefficient for PUB 2022 (β_2)	−0.168 *** (0.038)
Coefficient for PUB 2022×JCI 2022 (β_3)	0.132 *** (0.026)
R^2	0.491
Adj-R^2	0.452
F-test value	12.544 ***

Note: Values in the brackets are standard errors; the significance level is *** $p < 0.001$.

(3) Preliminary Model Evaluation

The model's goodness of fit for APC 2023 of S2 was evaluated using R^2 and F-test values. The R^2 value of 0.491 was deemed reasonable for this type of analysis, while the F-test value of 12.544 ($p < 0.001$) indicated statistical significance.

Interestingly, the coefficient for PUB 2022 is negative, whereas the interaction term PUB 2022 × JCI 2022 exhibits a positive effect. However, JCI 2022 is not statistically significant as an independent variable, suggesting that its impact on APC 2023 operates through its interaction with PUB 2022.

Despite the statistical significance of the model, the coefficients for PUB 2022 and PUB 2022 × JCI 2022 are relatively small. This implies that substantial values of these

variables would be required to produce a significant impact on APC 2023. These findings suggest that the model may have been disproportionately influenced by mega OA journals with high publication volumes.

(4) Handling Influential Data Points

Outlier analysis using Cook's distance identified two influential data points: *Nature Communications* and *Scientific Reports*. These journals significantly affected the preliminary regression model. Upon removing these outliers, the relationships between APC 2023 and the tested variables (JCI 2022, PUB 2022, and PUB 2022 × JCI 2022) were no longer significant.

This finding highlights that the APC model for S2 is heavily influenced by mega OA journals. To enhance the model's accuracy and better represent the majority of journals while mitigating the disproportionate impact of mega journals, outliers identified through Cook's distance were removed in the following steps.

3. Results

3.1. Results of Preliminary Model

The outcomes of the linear regression of APC 2023, after applying stepwise selection, are shown in Table 1. This model achieved a reasonable fit for APC 2023 of S2 with an R^2 value of 0.491 and demonstrated the impact of PUB 2022 and the interaction term PUB 2022 × JCI 2022 on APC 2023.

3.2. Cross-Correlation Analysis

Following the removal of two influential data points, it is worth noting that Spearman correlations for both sets of variables, APC 2023-JCI 2022-PUB 2022 and APC 2019-JCI 2018-PUB 2018, are weakened to the extent that there are no discernible correlations between JCI 2018, PUB 2018, and APC 2019. This observation supports the notion established in the empirical setting that constructing a linear regression model directly linking the APC with the JCI and PUB is impractical, particularly when excluding mega OA journals. Therefore, interaction terms such as PUB × JCI, APC × PUB, and APC × JCI were added to the cross-correlation analysis for a more comprehensive examination of the relationships among APC, PUB, and JCI, as presented in Table 2.

The result in Table 2 reveals that APC 2019 × PUB 2018 exhibits significant correlations (0.973, $p < 0.001$) with PUB 2018, yet shows no correlations with APC 2019. These findings suggest that the interaction between APC 2019 and PUB 2018 is more closely associated with PUB 2018 than with APC 2019. Thus, the focus should be directed more on the interplay between the PUB and APC, rather than the APC alone, since the total revenue (represented by APC × PUB) is dominated by the annual publication volume.

Additionally, although a direct correlation between APC 2019 and JCI 2018 is absent, significant correlations are observed between APC 2019 × PUB 2018 and JCI 2018 × PUB 2018 (0.930, $p < 0.001$), suggesting the importance of exploring correlations between interaction terms. Among the three interaction terms involving APC 2019 × PUB 2018, JCI 2018 × PUB 2018, and APC 2019 × JCI 2018, the most notable correlation exists between APC 2019 × PUB 2018 and JCI 2018 × PUB 2018. A similar relationship is observed for the combination of APC 2023, JCI 2022, and PUB 2022, with a much stronger association. This suggests that the relationship between JCI × PUB and APC × PUB predominantly establishes the link between the JCI, PUB, and APC.

Table 2. Spearman cross-correlation analysis among inspected variables of S2 after removing *Nature Communications* and *Scientific Reports*.

	APC 2019	**JCI 2018**	**PUB 2018**	**APC 2023**	**JCI 2022**	**PUB 2022**	**JCI 2018 × PUB 2018**	**APC 2019 × PUB 2018**	**APC 2019 × JCI 2018**	**JCI 2022 × PUB 2022**	**APC 2023 × PUB 2022**	**APC 2023 × JCI 2022**
APC 2019	1.000	0.337	0.058	0.753 ***	0.336	0.079	0.248	0.233	0.754 ***	0.088	0.165	0.612 ***
JCI 2018	0.337	1.000	0.335	0.296	0.514 **	0.305	0.601 ***	0.399 *	0.809 ***	0.333	0.297	0.493 **
PUB 2018	0.058	0.335	1.000	0.247	0.094	0.691 ***	0.913 ***	0.973 ***	0.245	0.663 ***	0.700 ***	0.169
APC 2023	0.753 ***	0.296	0.247	1.000	0.395 *	0.346	0.385 *	0.397 *	0.682 ***	0.341	0.425	0.783 ***
JCI 2022	0.336	0.514 **	0.094	0.395 *	1.000	0.424 *	0.294	0.157	0.455 *	0.523 **	0.438 *	0.856 ***
PUB 2022	0.079	0.305	0.691 ***	0.346	0.424 *	1.000	0.704 ***	0.656 ***	0.230	0.977 ***	0.988 ***	0.474 *
JCI 2018 × PUB 2018	0.248	0.601 ***	0.913 ***	0.385 *	0.294	0.704 ***	1.000	0.930 ***	0.519 **	0.697 ***	0.717 ***	0.377
APC 2019 × PUB 2018	0.233	0.399 *	0.973 ***	0.397 *	0.157	0.656 ***	0.930 ***	1.000	0.396 *	0.627 ***	0.681 ***	0.289
APC 2019 × JCI 2018	0.754 ***	0.809 ***	0.245	0.682 ***	0.455 *	0.230	0.519 **	0.396 *	1.000	0.245	0.272	0.664 ***
JCI 2022 × PUB 2022	0.088	0.333	0.663 ***	0.341	0.523 **	0.977 ***	0.697 ***	0.627 ***	0.245	1.000	0.970 ***	0.544 **
APC 2023×PUB 2022	0.165	0.297	0.700 ***	0.425 *	0.438 *	0.988 ***	0.717 ***	0.681 ***	0.272	0.970 ***	1.000	0.524 **
APC 2023 × JCI 2022	0.612 ***	0.493 **	0.169	0.783 ***	0.856 ***	0.474 *	0.377	0.289	0.664 ***	0.544 **	0.524 **	1.000

Note: A 2-tailed test of significance was used; the significance levels are *** $p < 0.001$ (background color in dark blue), ** $p < 0.01$ (background color in light blue), and * $p < 0.05$.

3.3. Construction of Modified Model for S3

A modified linear regression model based on the relationship between JCI×PUB and APC×PUB is proposed in Equation (2):

$$\text{APC} \times \text{PUB} = \beta_4 + \beta_5 \text{ JCI} \times \text{PUB} \quad (2)$$

For S2, a thorough examination of residuals (εi) revealed that the modified model's goodness of fit is maximized by excluding three outliers (*Nature Communications*, *Scientific Reports*, and *Scientific Data*), resulting in S3. This exclusion improves the regression analysis by better satisfying key assumptions, including (i) εi exhibiting nearly constant variance; (ii) εi having a mean of 0; (iii) εi being independent of each other; and (iv) εi more closely approximating a normal distribution.

Using this modified model, linear regression models for APC 2019 × PUB 2018 of S3 (referred to as M1) and for APC 2023 × PUB 2022 of S3 (referred to as M2) are constructed.

3.4. Construction of Modified Model for S1

In the context of China, Table 3 reveals correlations between APC 2019 and JCI 2018; however, a stepwise model selection of linear regressions based on Equation (1) reveals only a weak linear relationship between APC 2019 and JCI 2018. Moreover, while no correlation between JCI 2022 and APC 2023 is observed, a correlation between APC 2023 × PUB 2022 and JCI 2022 × PUB 2022 is present. Thus, the importance of understanding the underlying mechanism correlating JCI×PUB with APC × PUB is emphasized again for China. Consequently, linear regression models based on Equation 2 were also developed for APC 2019 × PUB 2018 of S1 (referred to as M3) and APC 2023 × PUB 2022 of S1 (referred to as M4), respectively.

Table 3. Spearman cross-correlation analysis between inspected variables of S1.

	APC 2019	**JCI 2018**	**PUB 2018**	**APC 2023**	**JCI 2022**	**PUB 2022**	**PUB 2018 × JCI 2018**	**APC 2019 × PUB 2019**	**JCI 2018 × APC 2019**	**PUB 2022 × JCI 2022**	**APC 2023 × PUB 2022**	**JCI 2022 × APC 2023**
APC 2019	1.000	0.877 **	0.231	0.573	0.502	−0.043	0.664	0.698 *	0.894 **	0.264	0.179	0.451
JCI 2018	0.877 **	1.000	0.418	0.611	0.783 *	0.133	0.833 **	0.767 *	0.983 ***	0.600	0.317	0.717 *
PUB 2018	0.231	0.418	1.000	0.445	0.067	0.586	0.795 *	0.778 *	0.393	0.377	0.544	0.017
APC 2023	0.573	0.611	0.445	1.000	0.494	0.243	0.569	0.720 *	0.636	0.628	0.460	0.536
JCI 2022	0.502	0.783 *	0.067	0.494	1.000	0.067	0.467	0.350	0.750 *	0.817 **	0.233	0.983 ***
PUB 2022	−0.043	0.133	0.586	0.243	0.067	1.000	0.350	0.233	0.050	0.550	0.950 ***	0.083
PUB 2018 × JCI 2018	0.664	0.833 **	0.795 **	0.569	0.467	0.350	1.000	0.917 **	0.800 *	0.467	0.417	0.367
APC 2019 × PUB 2019	0.698 *	0.767 *	0.778 **	0.720 *	0.350	0.233	0.917 **	1.000	0.800 *	0.383	0.350	0.300
JCI 2018 × APC 2019	0.894 **	0.983 ***	0.393	0.636	0.750 *	0.050	0.800 *	0.800 *	1.000	0.550	0.250	0.700 *
PUB 2022 × JCI 2022	0.264	0.600	0.377	0.628	0.817 **	0.550	0.467	0.383	0.550	1.000	0.667 *	0.850 **
APC 2023 × PUB 2022	0.179	0.317	0.544	0.460	0.233	0.950 ***	0.417	0.350	0.250	0.667 *	1.000	0.267
JCI 2022 × APC 2023	0.451	0.717 *	0.017	0.536	0.983 ***	0.083	0.367	0.300	0.700 *	0.850 **	0.267	1.000

Note: A 2-tailed test of significance was used; the significance levels are *** $p < 0.001$ (background color in dark blue), ** $p < 0.01$ (background color in light blue), and * $p < 0.05$.

3.5. Results of Modified Model

For M1–M4, the estimated parameters are shown in Table 4.

Table 4. The outcomes of the linear regressions are as follows: M1, APC 2019 × PUB 2018 regressed on JCI 2018 × PUB 2018 for S3; M2, APC 2023 × PUB 2022 regressed on JCI 2022 × PUB 2022 for S3; M3, APC 2019 × PUB 2018 regressed on JCI 2018 × PUB 2018 for S1; and M4, APC 2023 × PUB 2022 regressed on JCI 2022 × PUB 2022 for S1.

	Dependent Variable and Statistics	Parameter
M1	Intercept (β_4)	−43,930.739 * (20,032.408)
	Coefficient for JCI 2018 × PUB 2018 (β_5)	2183.145 *** (68.302)
	R^2	0.977
	Adj-R^2	0.976
	F-test value	1021.633 ***
M2	Intercept (β_4)	−90,828.517 * (36,292.666)
	Coefficient for JCI 2022 × PUB 2022 (β_5)	2346.169 (98.799) ***
	R^2	0.959
	Adj-R^2	0.957
	F-test value	563.911 ***
M3	Intercept (β_4)	53,789.281 *** (10,411.996)
	Coefficient for JCI 2018 × PUB 2018 (β_5)	475.701 (40.704) ***
	R^2	0.951
	Adj-R^2	0.944
	F-test value	136.583 ***
M4	Intercept (β_4)	120,594.346 * (42,834.031)
	Coefficient for JCI 2022 × PUB 2022 (β_5)	516.134 *** (54.952)
	R^2	0.926
	Adj-R^2	0.916
	F-test value	88.217 ***

Note: Values in the brackets are standard errors; the significance levels are *** $p < 0.001$, and * $p < 0.05$.

The F-test value of 1021.633, with a p-value < 0.001, indicates the statistical effectiveness of M1; however, the assumption of normally distributed residuals at the 0.05 significance level is not met for M1. Based on the linear regression outcomes of M1, the relationships among APC 2019, PUB 2018, and JCI 2018 of S3 can be represented by the following equations, respectively:

$$\begin{aligned} \text{APC 2019} &= 2183.145 \times \text{JCI 2018} - \frac{43{,}930.739}{\text{PUB 2018}} \\ \text{PUB 2018} &= \frac{43{,}930.739}{(2183.145 \times \text{JCI 2018} - \text{APC 2019})} \\ \text{JCI 2018} &= \frac{\text{APC 2019}}{2183.145} + \frac{20.123}{\text{PUB 2018}} \end{aligned} \quad \text{(M1)}$$

The F-test value of 563.911, with a p-value < 0.001, indicates the statistical effectiveness of M2; the assumption of normally distributed residuals at the 0.05 significance level is met for M2. Based on the outcomes of M2, the relationships among APC 2023, PUB 2022, and JCI 2022 of S3 can be represented by the following equations, respectively:

$$\begin{aligned} \text{APC 2023} &= 2346.169 \times \text{JCI 2022} - \frac{90{,}828.517}{\text{PUB 2022}} \\ \text{PUB 2022} &= \frac{90{,}828.517}{(2346.169 \times \text{JCI 2022} - \text{APC 2023})} \\ \text{JCI 2022} &= \frac{\text{APC 2023}}{2346.169} + \frac{38.713}{\text{PUB 2022}} \end{aligned} \quad \text{(M2)}$$

The F-test value of 136.583, with a p-value < 0.001, indicates the statistical effectiveness of M3; the assumption of normally distributed residuals at the 0.05 significance level is not met for M3. Based on the outcomes of M3, the relationships among APC 2019, PUB 2018, and JCI 2018 of S1 can be represented by the following equations, respectively:

$$\begin{aligned} \text{APC 2019} &= 475.701 \times \text{JCI 2018} + \frac{53{,}789.281}{\text{PUB 2018}} \\ \text{PUB 2018} &= \frac{53{,}789.281}{(\text{APC 2019} - 475.701 \times \text{JCI 2018})} \\ \text{JCI 2018} &= \frac{\text{APC 2019}}{475.701} - \frac{113.073}{\text{PUB 2018}} \end{aligned} \quad \text{(M3)}$$

The F-test value of 88.217, with a p-value < 0.001, indicates the statistical effectiveness of M4; the assumption of normally distributed residuals at the 0.05 significance level is met for M4. Based on the outcomes of M4, the relationships among APC 2023, PUB 2022, and JCI 2022 of S1 can be represented by the following equations, respectively:

$$\begin{aligned} \text{APC 2023} &= 516.134 \times \text{JCI 2022} + \frac{120{,}594.346}{\text{PUB 2022}} \\ \text{PUB 2022} &= \frac{120{,}594.346}{(\text{APC 2023} - 516.134 \times \text{JCI 2022})} \\ \text{JCI 2022} &= \frac{\text{APC 2023}}{516.134} - \frac{233.649}{\text{PUB 2022}} \end{aligned} \quad \text{(M4)}$$

In summary, there has been no fundamental change in the relationship between APC, JCI, and PUB from 2019 to 2023, either in China or internationally; the changes observed are primarily in the parameters. Although all four models (M1–M4) are statistically effective, a closer examination of the residuals reveals that the mechanism linking JCI × PUB to APC × PUB is more robust for the APC business model in 2023 than in 2019, regardless of whether S1 or S3 is considered.

3.6. Divergent Business Models Between S1 and S3

Figure 1 illustrates that for both S1 and S3, the APC and JCI exhibit a consistent direction of change. However, the relationship between the PUB and APC, as well as between the JCI and PUB, contrasts between S1 and S3. In China, the PUB and JCI are directly proportional, while the PUB and APC are inversely proportional. Conversely, in the rest of the international context, the PUB and JCI are inversely proportional, while the PUB and APC are directly proportional. Consequently, the most significant distinctions in business models between S1 and S3 lie in the impact of the PUB on the APC-based OA publishing sectors.

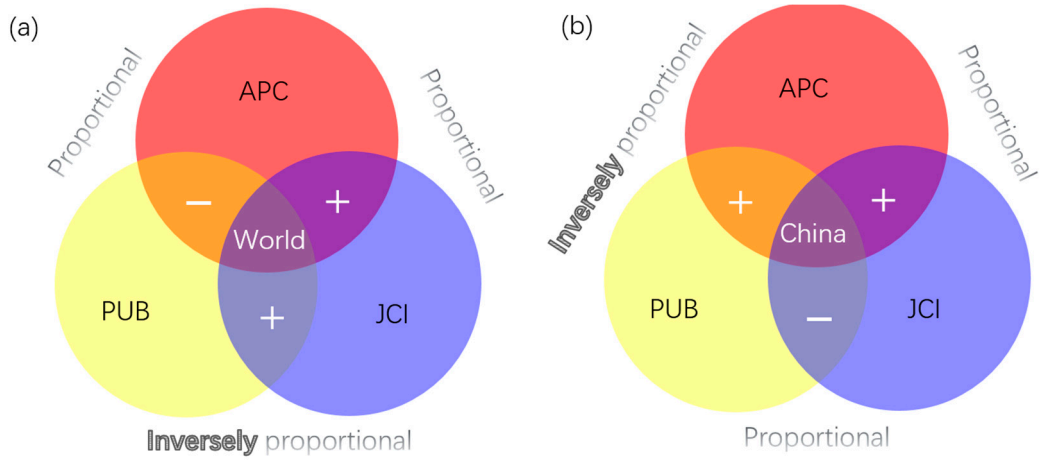

Figure 1. Relationship between the APC, PUB, and JCI for (**a**) the rest of the international context (World) and (**b**) China. Positive and negative signs are in accordance with the coefficients of the variables in the business models M1–M4.

This does not imply that, for S1, PUB development favors the JCI at the expense of the APC. Although the JCI and PUB are directly proportional, the presence of the PUB has adverse effects (as indicated by the negative sign between "PUB" and "JCI" in Figure 1b, given the associated negative coefficients in M3 and M4) on JCI enhancement. This is unfavorable, as it suggests that PUB expansion can only mitigate its negative influence on the JCI but does not contribute to JCI improvement. Conversely for S3, despite the PUB and JCI being inversely proportional, as the PUB increases, its diminishing impact on the JCI is mitigated. Notably, the PUB consistently makes a positive contribution to the JCI (as shown by the positive correlation between "PUB" and "JCI" in Figure 1a, given the associated positive coefficients in M1 and M2). Furthermore, based on M1 and M2, for a significantly large PUB, the JCI is solely correlated with the APC.

3.7. Limitations of Modified Model on S1

S1, M3, and M4 indicate that with a given APC, the PUB increases with the JCI, suggesting that increasing PUB is beneficial for enhancing the academic influence of the OA journal. Moreover, based on M3 and M4, there is a maximum JCI/PUB ratio for a given APC, indicating that an "optimized" PUB, which has the greatest positive impact on JCI, can be identified for a specific APC and JCI.

According to M4, the "optimized" PUB for China in 2022 can be determined by the following equation:

$$516.134 \times \text{JCI } 2022 = \frac{120{,}594.345}{\text{PUB } 2022}$$

Therefore, the highest JCI/PUB ratio and "optimized" PUB occur when JCI 2022 × PUB 2022 equals 233.649, meaning that if JCI 2022 is set to 1, the "optimized" PUB 2022 is approximately 233. Neglecting this point (JCI 2022 × PUB 2022 = 233.649) would lead to a trade-off between PUB 2022 and JCI 2022. On the other hand, the estimated "optimized" PUB 2018 is around 113 according to M3.

The average annual publication volume per journal in S1 was 155.8 in 2022, which is lower than that of the 27 international journals outside of China, at 198.1. This is not to mention the two mega OA journals, *Scientific Reports* and *Nature Communications*, which published 22,607 and 7885 items, respectively, in 2022. Although the "optimized" PUB has doubled from 2018 to 2022 for China, given the expanding global OA market and the benefits reaped by commercial publishers from APC-based OA publishing, it is imperative for APC-based OA journals from China to further increase the PUB. However, emphasizing the need for increasing the PUB adds complexity to designing an optimized model for S1,

as the PUB and APC move in opposite directions. In contrast, there are no constraints or controlling factors for PUB escalation for S3, as indicated by M1 and M2.

4. Discussion

4.1. How Are PUB, APC, and JCI Intrinsically Connected?

According to Figure 1, the underlying mechanism for annual APC increase is related to its proportionality to the JCI, both in China and internationally. However, the divergent business models between S1 and S3 reflect underlying differences in the relationships among APC, PUB, and JCI. The analysis of these relationships through the results from M1 to M4 highlights how regional and international contexts could influence APC business models and operational dynamics, and how dominant publishers could set APC prices without compromising their market position in the international context.

1. International OA journals

Regarding S3, there is a directly proportional relationship between APC and PUB and an inverse relationship between PUB and JCI. This means that as PUB increases, APCs tend to rise. However, higher PUBs have a diminishing effect on JCI. This creates a scenario where journals may increase APCs to compensate for the lower JCI impact associated with larger publication volumes. This model supports a competitive market where commercial publishers aim to balance profit with journal impact, often leading to higher APCs and a focus on maintaining or improving JCI despite rising PUB.

Therefore, in the international scenario, the NP business model suggests that commercial publishers would merely need to manage the relative dynamics between the APC and PUB, ensuring their upward trajectory to sustain the development of the JCI.

2. China-based OA journals

Conversely, regarding S1, the relationship is inverse between APC and PUB and directly proportional between PUB and JCI. This means that as PUB increases, APCs tend to decrease, and higher PUBs are associated with greater JCI. This suggests that increasing publication volumes in S1 may enhance JCI but negatively impact APCs. This model reflects a different set of economic and operational pressures from the international setting, where increasing PUB does not translate into higher APC pricing, possibly due to different funding structures or regulatory constraints in China.

Therefore, in the context of China, an inverse relationship between the APC and PUB sets an "optimized" PUB for APC-based OA journals, presenting challenges in journal management and proving unsustainable for the growth of the APC-based OA market in China.

4.2. Underlying Causes for Regional Disparities and Recommendations

1. Underlying causes for regional disparities

In this study, where the publishing model and publisher size remain consistent due to the involvement of the same publisher (NP), the different business models between S1 and S3 can be attributed to domestic policies and the specific context within China.

China's academic publishing landscape operates under different economic, regulatory, and cultural conditions compared with the international setting. Understanding these unique dynamics is crucial for developing effective business models that cater to the specific needs of Chinese APC-based OA journals. The nine APC-based OA journals in S1 are all co-published internationally between Chinese publishers/institutions and NP. The paradoxical relationship among APC, JCI, and PUB in these journals underscores how China's publishing policies and funding structures can impact the business models of foreign publishers co-producing OA journals based in China. Therefore, as Western funders implement increasingly ambitious mandates for OA, business models in China that are not aligned with the international OA publishing landscape may face sustainability challenges. For instance, there are indications of a merging of hybrid and OA business models [39], particularly with initiatives like Plan S, which would have restricted publishing in subscription

journals unless covered by a "transformative agreement" (TA) [74,75]. However, Plan S offers limited incentives for the scientific community in China and may increase the burden on Chinese publishers. Specifically, it mandates a 15% annual increase in OA adoption for internationally co-published hybrid journals transitioning to OA through TA [76].

Based on these findings, we propose the following recommendations for a diverse range of stakeholders—journal editors, policymakers, sponsoring institutions, and commercial publishers—to foster sustainable development models for APC-based OA journals, both inside and outside of China. By implementing these recommendations, OA publishers can enhance their financial stability and journal impact. By understanding the regional differences in APC business models, funders and indirectly authors in certain cases can assess the APC price relative to the services offered by the publishers. Moreover, such discussions would exert competitive pressure on dominant publishers to reduce APC.

2. Recommendations for international OA journals

Regarding S3, the PUB increases with the APC. Moreover, increasing the annual OA publication volume not only boosts profit but also reduces marginal and average unit costs, thus encouraging commercial publishers to expand their PUB to increase cost-effectiveness. Therefore, as PUB increases, APC adjustments should be proportional to ensure the sustainability of JCI and revenue. This approach helps maintain journal reputation while accommodating rising publication volumes.

3. Recommendations for China-based OA journals

Adopt flexible pricing strategies: When adopting business models, Chinese APC-based OA journals not only consider being in line with international practices but also meet the stringent requirements of domestic funders and sponsoring institutions. For instance, being selected for the CJEAP requires journals to be indexed in WoS within three years, a mark of quality for Chinese journals [65]. This may lead to a business model adjusting APCs based on journal reputation, using JCI as a proxy, rather than relying on the simultaneous increase in APC and PUB to maximize economic benefits, as this study demonstrates. Therefore, the incompatibility between the business model and the development of publication volumes of S1 is evident. It is speculated that adopting the more flexible pricing model used by APC-based OA journals in the broader international context could economically benefit China-based OA journals.

Policy and support: For the business model of S1, securing subsidies or alternative income sources becomes imperative to sustain the upward trend in total revenue of an APC-based OA journal, given the compromise between the APC and PUB. As Western funders impose increasingly ambitious OA mandates, the Chinese business model may face sustainability challenges due to the presence of an "optimized" PUB for a given APC. Therefore, domestic policymakers and funders in China should support the development of tailored OA policies and enhanced business models that address specific regional challenges.

Develop management frameworks: It is suggested that APC business models, OA policies, and mandates tailored to Chinese journals be formulated, independent of those designed by Western publishers and funders. From an economic perspective, most of China's OA journals should avoid heavy reliance on government funding or support from sponsoring organizations to align more effectively with the international landscape. They should enhance their understanding of market competition and opt for appropriate commercial operation models. For instance, to maintain their rankings, journals may find it viable to increase publication volume by attracting higher-quality submissions. Additionally, considering the acceptance rate is crucial, as it directly impacts the calculation of journal management costs. Therefore, there is an urgent need to develop a management framework based on cost-volume-profit (CVP) analysis for journal publishing. This framework would help monitor the annual operational status of journals that charge OA APCs, enhance cost management awareness, clarify publishing expenditures and income, and allow for timely adjustments to PUBs and APCs.

5. Limitations and Future Directions

This is an exploratory study based on a small sample. However, in comparison with global APC trends reported by Morrison, our findings provide valuable insights. Morrison et al. [58] did not find conclusive evidence that funding sources (universities, libraries, or funding agencies) can influence APC models, although Morrison et al. [68] later suggested that future studies should focus on APC trends by country or publisher, rather than global averages. In contrast, this study, despite its smaller sample, controls for one commercial publisher and inflation rates, revealing regional differences in APC models that are often missed by longitudinal studies of single journals. Our findings suggest that APC business models, particularly those associated with dominant publishers, may evolve over time and exhibit regional variations, an aspect not typically captured in global trend studies. Thus, journal editors and policymakers must carefully balance economic considerations with societal impact when navigating the scholarly publishing landscape.

Nevertheless, it is clear that more robust tracking mechanisms are necessary to address the challenges of collecting reliable longitudinal data for accurately monitoring APCs over time. Moreover, replicating this study using alternative data sources, such as bibliographic databases (e.g., Scopus, Dimensions) or APC data (e.g., OpenAPC, Wayback Machine), could offer further validation of the conclusions presented. Panel data fixed effects and time effects models [77,78] are widely used in econometric studies to analyze relationships among variables over time. In the context of this study, such models could provide a more nuanced understanding of the dynamic interactions among APC, JCI, and PUB by isolating the effects of observable factors while addressing potential biases from unmeasured discipline or publisher influences. Future research could benefit from incorporating these models to explore these relationships further.

While expanding the scope to include other publishers could provide valuable insights, many of them may not be directly comparable due to differences in business models or strategic directions. For instance, Butler et al. [36] highlighted that Elsevier and Wiley derived most of their APC revenue from hybrid fees between 2015 and 2018, though their business models may have since evolved. Therefore, future research could focus on comparing different publishers, particularly those behind OA mega journals like PLOS, MDPI, and Frontiers, which are prominent players in the OA publishing landscape [57].

6. Conclusions

Cross-correlation and linear regression analyses were applied to APC-based OA journals from NP to examine the interplay between APC, PUB, and JCI. The three research questions are addressed as follows:

Interactions between APC, PUB, and JCI within the Business Model: This study reveals that APC, PUB, and JCI exhibit a dynamic relationship. Both APC and JCI tend to grow together, reflecting an interdependent connection between revenue and journal quality. However, the key difference lies in the role of PUB, particularly in the context of mega OA journals. Moreover, the impact of PUB exhibits significant regional variation, with its role in the Chinese OA publishing sector posing challenges that threaten the long-term sustainability of the sector. Specifically, the development of PUB in relation to APC has proven counterproductive, leading to structural discrepancies.

Distinct Business Models for OA Journals Inside and Outside of China: There are notable differences in how OA journal business models operate within China compared to international markets. International journals generally maintain a balanced relationship between APC, PUB, and JCI, ensuring that APCs do not negatively affect publisher revenue or journal reputation. In contrast, China-based OA journals often experience a misalignment between APC pricing and PUB strategies. This mismatch can complicate journal management and hinder the ability to remain competitive in the global OA landscape, underscoring the need for region-specific business models.

Limitations Imposed by the Business Model on Journal Development: The current business model imposes limitations, particularly within China. Unique funding policies, specific

requirements for OA APCs, and regional policy differences highlight the need for more tailored business models. The APC model used by China-based OA journals may not align with international standards or OA mandates, potentially restricting journal growth and competitiveness. This suggests that more customized models, as well as region-specific OA policies, are crucial for supporting the long-term development and sustainability of the regional APC market.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/publications12040046/s1, Table S1: Nine journals from China (excluding Hong Kong, Macao, and Taiwan); Table S2: Twenty-nine journals from outside China (excluding Hong Kong, Macao, and Taiwan).

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