Blockchain-based Academic Journals*

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Abstract

This paper investigates the economic implications of blockchain-based academic journals, proposed by the recent computer science literature, in which authors and referees are *individually incentivized*. We study models in which the journal publishes qualified papers under two types of information asymmetry: paper quality and type of referee. We characterize the conditions under which equilibrium in decentralization exists or fails and leads to a better outcome than in centralization. Our research also helps us understand how to design an incentive structure for information providers required for funding decisions, loan inspections, and credit ratings.

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Keyword: Blockchain, Decentralization, Coordination failure, Moral hazard, Negative externality, Intermediary funding problems

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1 Introduction

> ”Scientists create work under their own direction – funded largely by governments – and give it to publishers for free; the publisher pays scientific editors who judge whether the work is worth publishing and check its grammar, but the bulk of the editorial burden – checking the scientific validity and evaluating the experiments, a process known as peer review – is done by working scientists on a volunteer basis. The publishers then sell the product back to government-funded institutional and university libraries, to be read by scientists – who, in a collective sense, created the product in the first place.”
>
> *– Is the staggeringly profitable business of scientific publishing bad for science? (The Guardian 2017)*

As many media such as the Guardian have pointed out, scientists spend a huge portion of government- and public-funded research grants on publishing papers. In particular, the publication fees are fairly high for academic journals of pure science, biomedicine, life science, and so on in which research questions are generally objective.[1] More specifically, the total cost adds up much higher at the institutional level, as publishers indirectly charge research institutions and universities high fees for journal subscriptions – fees that are continuing to increase over time.[2] This phenomenon is remarkable and somewhat ironic given that in this context, scientists, who are both the producers and consumers of knowledge, also have to pay for both the production and consumption of this knowledge, while middlemen – that is, publishers – earn huge profits as monopolists and copyright holders.

This paper investigates the economic implications of blockchain-based journals (BJPs): the idea proposed by the recent computer science literature that attempts to resolve this concern (see the first paragraph in Section 1.1). While the literature mostly suggests decentralized BJPs, we elaborate economic models and argue that a BJP can take either a centralized or decentralized form. We investigate the trade-off between the two platform choices, given two types of information asymmetry: (i) paper quality and (ii) type of each referee. We find that equilibrium may or may not exist in decentralization. We also compare social welfare between the two platform choices by investigating the trade-off.

Although our model considers the problem of referees, setting aside the blockchain usage it closely resembles the incentive problem when specialists are required for quality

[1] For example, fees for Nature, Science, and the Proceedings of the National Academy of Sciences are a few thousand USD. The cost can rise to more than 20,000 USD if the authors insert several color figures in the published paper. Moreover, since research questions are objective in these fields, rapid publication is essential for a success since there is no reward for coming second. Therefore, these journals charge high fees of subscribing for recent volumes.

[2] For example, according to University Affairs (Feb 2018), Canadian university libraries pay US $350,000 to US $9 million annually in subscription fees. See also Bergstrom et al. (2014) for various payment statistics of individual publishers.

evaluation or information production, as is the case with credit-rating agencies, venture capital partners, investment banks, and accounting firms. As an illustrative example, consider the case in which there are funding applicants (entrepreneurs or borrowers) and a venture capital partner who cannot verify the quality of the projects proposed by the applicants. Decentralization in this case represents that each analyst, who verifies a project's quality and recommends whether to approve it for funding, will also obtain rights to the cash flow generated from the approved project.[3]

The centralized profit-sharing structure is optimal when the sharing of information is efficient, as has been shown in the economics literature (e.g., Ramakrishnan and Thakor (1984) and Millon and Thakor (1985)). That is perhaps the main reason why most information-production industries including the current publication industry were formed in a centralized manner. In general, the cost of production is too high for an information provider to individually bear in the case of decentralization. Those monopolists have had comparative advantages in production or management, partly thanks to the economy of scale and partly thanks to their own know-how and skills.

However, such comparative advantages would no longer exist when BJPs are a reality and available for use. A recent example is the dramatic rise of decentralized exchanges (DEXs) for cryptocurrency trading or decentralized finance (DeFi) lending/borrowing platforms.[4] Note that these platforms are built by free open software that anyone can reuse to launch a new DEX or DeFi platform with slight modifications. Likewise, once the very first blockchain code for academic journal management is effectively distributed as an open source, the cost for scientists (referees) to deal with a paper individually and to produce a journal collectively without having a publisher as a middlemen will become significantly lower. That would leave three types of available journals: (i) journals run by monopoly publishers (e.g., Elsevier, Cambridge University Press, and Oxford University Press), (ii) centralized journals on blockchain, (iii) decentralized journals on blockchain. Note that in our analysis, we only focus on the comparison between (ii) and (iii). However, once we understand our characterization of (ii), it will be easy to understand (i) as well because case (ii) is quite similar to case (i) in terms of social welfare except for the editor's expertise in management because optimal contracts are determined in a centralized way in both (i) and (ii) (see Section 6.1).

Let us more concretely summarize the advantages of using blockchain for journal plat-

[3] Comparing this case with the journal case, one might think that it is bizarre for referees to make money by reviewing a paper. Rather the idea can be better interpreted so as to create the ecosystem in which research funds are spent and circulated within academics, not paid to publishers. This will also save the government research spending. In this sense, decentralization in this paper includes the case in which the library or the university that the referee is affiliated with receives the cash flow right partially or entirely depending on the incentive structure.

[4] Examples include Uniswap, Sushiswap, Pancakeswap, Compound, Maker, Aave, and so on.

forms. First, it is not only feasible but also arguably more efficient than the current publication process in terms of system efficiency, managing costs, and encouraging the participation of reviewers and authors (see the first paragraph of our literature review section). Second, as blockchain is an immutable record-keeping device, the profit generated by the journal can be easily and separately distributed to reviewers according to the contribution of a published paper[5] accepted by each referee, without revealing the reviewer's identity.[6] It is important that anonymity will be more strongly guaranteed under the BJP system than under the current system. Thus, referees will have better incentives to objectively evaluate a paper's quality and will be much less influenced by the authors' reputations or by other potential political considerations. Third, a BJP, in addition to playing its conventional role as a journal, can serve as a market place for intellectual property and investment, creating additional value for the platform. For example, by using blockchain technology academic papers can be tokenized and traded as a form of non-fungible tokens (NFTs), which have become popular for their use in trading property rights and (digital) art works (see Section 6.1 for the related discussion). Finally, a BJP can lower the entry barrier and encourage an ordinary person to participate in the knowledge production because anyone can submit his/her papers, notes, and technical reports. Therefore, both the demand and supply of knowledge can increase by more participation.

If the switch to BJPs has the various advantages mentioned above, the following questions will arise. Which ownership structure is actually feasible? Specifically, does decentralization work as is demonstrated in the computer science literature? If so, is it economically meaningful? Under what conditions is it not economically feasible? Which structure is socially efficient? Are there any trade-offs between centralization and decentralization? We aim to address these questions, provide economic insights based on our findings, and suggest the implications for financial intermediaries.

To answer these questions, we compare two business models: (a) a journal owned by a monopoly publisher or a centralized BJP in which the journal equally distributes the profit to referees, and (b) a decentralized BJP in which referees are *individually incentivised*. Theoretically, in terms of welfare, the conventional business model in which a single monopoly publisher keeps the whole profit is equivalent to the case in which the profits are equally distributed to reviewers in a coalition, because any *fixed* distribution of profits within such a coalition is a simple cash transfer and there is no difference in the individual incentive. Therefore, we simply call both cases in (a) centralization. In

[5] In this paper we assume that there exist objective measures for the quality and the contribution of a paper, which is reasonably accepted in the field of pure science. See further discussion in Section 6.6.

[6] One might suspect that it can only implemented by permissioned blockchain. In fact, it is also possible to impliment it by public blockchain. For example, Monero (XMR) and Zcash provide a significant level of privacy and anonymity in their transactions.

contrast, in decentralization each referee directly receives cash flow generated from the corresponding paper that he/she accepts for publication netting out the production cost.[7]

In our model there are two groups of heterogeneous players: authors and reviewers. Authors write papers of varying quality. They earn a *non-transferable* reward if their papers are accepted. Thus, they are willing to submit papers by paying a fee with their own endowment (university research endowment or grant). The fee includes both the journal subscription fee and the paper submission/publication fee. In this sense, an author, being a consumer of the journal, can be considered as a representative agent of a department or an academic institution. The journal earns profit by producing the intellectual property (i.e., a function of the quality of the published papers) and by receiving the fees from authors; thus, there is a benefit of verifying paper quality. There are two types of information frictions in our model. First, the paper quality is private information and can be verified only by a referee. Second, a referee's type is also private information: each referee gets an independent and identically distributed (i.i.d., hereafter) random opportunity cost shock to become a bad or good referee each time. Good referees review the paper correctly, whereas bad referees do not because the marginal disutility of reviewing the paper is fairly high.

Considering the information structure in our model, we explain the main results by categorizing them into the three cases (see Figure 3 for the graphical summary). First, following the idea from the screening literature (Leland and Pyle (1977) and Campbell and Kracaw (1980)), we find that if the authors' endowment is sufficiently large, it is possible to charge a high fee and to attract only papers whose quality is greater than a certain threshold level to be submitted, which is called a *separating equilibrium*. While this separating equilibrium is always efficient in both centralization and decentralization, we view it as less important in our context since it is less likely to occur not only in the academic world but also in other relevant industries. For example, a venture capitalist would not want to screen entrepreneurs (funding applicants) using applicants' endowments.

Next we turn to the realistic case in which the endowment of the authors is not sufficient and thus screening is not feasible. There are two cases depending on whether the average quality of the papers (AQ, hereafter) is lower or greater than the marginal cost of publication (MC, hereafter). In the case when the AQ is greater than the MC, we find that there is a trade-off: *moral hazard* in centralization vs *negative externality* in decentralization. In centralization, a bad referee pretends to be a good referee by randomly accepting the same proportion of papers that good referees do. As a result, many high-quality papers

[7] In a decentralized BJP authors and referees can share the profits. However, again a fixed profit-sharing rule between the author and the referee of the paper does not change the incentive structure. Therefore, for the sake of simplicity, we assume that in the case decentralization, the referees hold the entire rights to the cash flow.

are rejected while many low-quality papers are accepted. However, this moral hazard problem is gradually mitigated as the AQ increases: a higher (smaller) number of high-quality (low-quality) papers are accepted as the AQ increases. In contrast, there is no moral hazard problem in decentralization. However, referees in decentralization fail to internalize the authors' reward when maximizing their profits, since each referee sets the acceptance threshold independently after the fee is paid. While the level of the negative externality does not vary with the AQ in decentralization, the degree of moral hazard decreases with the AQ in centralization. Therefore, decentralization is, in general, better off as there is no moral hazard, but centralization can be better off for a high level of the AQ. We present the precise conditions under which one is preferable to the other in the main body of the paper.

What about the case when the AQ is lower than the MC without screening? It is notable that only centralization works regardless of its high inefficiency from moral hazard, because in decentralization *no pure strategy equilibrium* is sustainable.[8] This no-equilibrium result is caused by the two types of *coordination failures*: one among bad referees and the other among authors. First, good referees set the acceptance policy at which marginal productivity is equal to the MC. In contrast, bad referees who do not verify the quality need to reject all the papers since the expected profit from accepting a paper is negative when the AQ is lower than the MC. Knowing this, authors of lower-quality papers will not submit their papers because the probability of acceptance is zero as long as bad referees reject all the papers. However, this creates an incentive for a bad referee to deviate to accept all the papers since he/she can enjoy a positive profit when only authors with high-quality papers submit their papers. Then, authors with low-quality papers will also deviate to submit a paper once bad referees follow an accept-all strategy. This deviation leads to a failure of pure strategy equilibrium.

Our model provides several implications for the incentive structure in the information-production process. First, when screening is infeasible, one might think that the decentralized market structure mostly dominates the centralized one since specialists are individually incentivized. This is, however, only partially true. From our result we predict that decentralizing markets with low average productivity or quality can fail due to the coordination failure problem. This result, in addition to the aforementioned cost efficiency in information production or management, can help us understand why many financial intermediaries requiring specialists have formed in a centralized manner (cf. Stein (2002)

[8] There is a unique mixed-strategy equilibrium in this case. We view that the mixed-strategy equilibrium is unrealistic since it requires the authors' cooperation and it fails to provide individual incentives from decentralization (see more detail in Section 4.2.2).Therefore, we do not include a discussion of it in the main body of the paper. Since it might be theoretically interesting, interested readers should refer to Appendix C for more details.

and Vayanos (2003)). Furthermore, regarding how to incentivize specialists in general, our equilibrium failure result in decentralization can also provide normative implications. Considering bank lending or credit ratings, the average default rate can be interpreted as the inverse of the AQ in our context. This implies that given that the default rate is high in recessions, loan inspectors and rating specialists should not be compensated according to their performance (although it might be the aim to avoid moral hazard).

Second, even if the average productivity is greater than the MC when screening is infeasible, it is not always that decentralization is better off. Inspectors or analysts in decentralization set the threshold for project quality without considering the applicants' non-transferable reward, which leads to a welfare loss by excessively rejecting high-quality projects (negative externality). When the average productivity becomes very high, moral hazard is significantly mitigated and thus centralization is preferable. Note that the negative externality problem can be substantial in the industries in which intellectual property rights or copyright are well established or the industries in which a good reputation can be created from a single success. There are many such examples: (i) if an entrepreneur successfully sells off his/her company, he/she is more likely to receive significant funding in the future; and (ii) if a firm receives a loan approval from a bank, it will have an easier time obtaining additional funding from other banks. In these cases, the centralized funding structure would be more efficient than the decentralized one that provides individual incentives for inspectors.

We aim to suggest a stringent model that can provide rich insights into when decentralization works and into the trade-off between centralization and decentralization. Indeed, the baseline model is fairly simple, making it easier to ask questions about the feasibility of BJPs. For example, the level of reward from publication is exogenousely given in the baseline model. However, we show that the fundamental insight into the trade-off between moral hazard from centralization and negative externality from decentralization is preserved for the case in which the reward is determined in equilibrium. The same is largely true for other extensions, such as models with heterogeneous endowments and rewards, and learning about the type of a referee over time when the shock is persistent. In addition to these extensions, we provide further discussion of important features that we omit and simplify in the baseline model and implementation challenge regarding the paper quality measure choice in Section 6.

Our study is motivated by the rapidly growing trend of decentralization in the blockchain industry and the computer science literature. We acknowledge that we had expected that decentralization would mostly be welfare-improving since it would overcome the moral hazard problem in the review process. However, we find that decentralization is not always better off due to negative externality and coordination failure. Interpreting the marginal cost of publishing a paper as referees' opportunity cost of publishing the paper, it implies that it is not possible to individually incentivize referees in top-tier journals in which the opportunity cost is very high. In contrast, our result implies that incentivizing referees in mid-tier journals is indeed welfare-improving. However, centralization in our model implies that top-tier journals can run on blockchains and distribute profits in a centralized manner, by which it essentially removes middlemen (publishers). Regarding the information-production process in general, we hope that our paper can provide guidelines for entrepreneurs or investors who aim to create decentralized platforms and for policy makers who contemplate regulations regarding decentralization.

The rest of the paper proceeds as follows. We provide a literature review in Section1.1. Section 2 describes the baseline setup of the model including the characteristics of authors and reviewers and the production technology of the journal. We characterize the centralization case in Section 3 and the decentralized case in Section 4. We compare the social welfare between the two cases in Section 5. We provide various extensions of the baseline model and further discussion in Section 6. Section 7 presents concluding remarks. The efficient allocations from the planner's problem are outlined in Appendix A.

1.1 Literature Review

Recently there has been a burst of publications in the computer science literature investigating how to design academic publication systems based on blockchain (see Coelho and Brandao (2019), Duh et al. (2019), Heaven (2019), Janowicz et al. (2018), Mackey et al. (2019), Mohan (2019), Niya (2019), Novotny et al. (2018), Schaufelbuhl et al. (2019), Tenorio-Fornes et al. (2019), Wang, Liew, and Zhang (2020), Zhou, Wan, and Guan (2020), and references therein). This literature suggests various journal management schemes for decentralized journals on blockchain. We do not attempt to (and are not able to) assess individual implementation schemes. However, there is a consensus in the literature that blockchain technology has various advantages relative to the existing publication system in terms of system efficiency and managing costs, not to mention the benefit of increasing the participation of authors and reviewers on the platform. Therefore, we deem it to be just a matter of time until we see the appearance of blockchain-based academic journals. We are motivated to better understand this trend and whether it is economically feasible in terms of equilibrium selection and social welfare, and we aim to deepen this understanding by proposing a simplified version of BJPs. Furthermore, while the existing literature mostly focuses on decentralization and its benefits, we note that decentralization can fail and BJPs can also be run in a centralized manner. Further, our paper provides guidelines by which a profit-sharing structure can be sustainable and socially desirable.

There is a rapidly growing literature on blockchain (see, for example, Biais et al. (2019), Gryglewicz, Mayer, and Morellec (2019), Leshno and Strack (2020), Huberman et al. (2021), Chod, Trichakis, and Yang (2021), Cong and He (2019), Cong, Li, and Wang (2021a,b), Prat and Walter (2021), and references therein). Our paper is in line with this literature in that the implementation method suggested in this paper uses blockchain and smart contracts. However, most of the literature is interested in explaining how these new blockchain platforms work and related problems such as risk-sharing, mining pool equilibrium, and so on. We suggest a new platform ownership structure, in particular, through the mechanism design approach.[9] We also relate it to existing information-production industry cases, and provide the welfare comparison. Our approach is more normative than most of the existing approaches. We believe that the idea of decentralization will bring a big change in many different industries. We hope that when there is a disruption in these industries, our paper can shed light on the trade-off and help to design an appropriate ownership structure.

This paper is closely related to the literature on the role of intermediaries as information providers, such as that found in studies by Leland and Pyle (1977), Campbell and Kracaw (1980), Ramakrishnan and Thakor (1984), Millon and Thakor (1985), Chemmanur and Fulghieri (1994), and Yung (2005). After the seminal contribution of Leland and Pyle (1977) on signalling, Campbell and Kracaw (1980) showed that financial intermediaries can provide signals for markets to persuade signal receivers to believe their information. Our model provides a similar result in the sense that signaling can resolve information asymmetry when endowments are sufficient. However, we further investigate in depth the cases in which signalling is not feasible. Our paper is broadly related to these papers in that they investigate the benefits of either centralization or decentralization.[10] Our paper provides comprehensive analysis for a welfare comparison between centralizing and decentralizing information-production processes and characterizes the economic conditions under which (de)centralization is preferable. This paper is also closely related to Chemmanur and Fulghieri (1994), who investigate the role of investment banks in evaluating entrepreneurs' projects and reporting to investors in return for fees. In their model, the reputation of investment banks as information providers plays a critical role in reducing information asymmetry. Our setup is different from their setup in that the anonymity

[9]See Chen, Cong and Xiao (2020) for an overview of the mechanism design aspects in blockchain economics.

[10]For example, Ramakrishnan and Thakor (1984) and Millon and Thakor (1985) focus on internal monitoring and profit distribution to prevent the free-riding of information producers, and show the benefits of centralization such as sharing information and portfolio diversification. Similarly, Mukhopadhyay (2004) shows that the incentive payments to the rating agency can eliminate the moral hazard problem. Corwin and Schultz (2005) show evidence that the IPO cost due to moral hazard can be reduced by adding more underwriting members.

of information providers (referees) in our model is important for the evaluation process. That is, we focus on how to provide incentives for information providers without revealing their identities, abstracting a reputation effect, while information providers' reputations play a key role in Chemmanur and Fulghieri (1994).[11] Therefore, our model is complementary of Chemmanur and Fulghieri (1994) in understanding the role of financial intermediaries as information providers.

Finally our paper is also related to the literature on the role of credit rating agencies as information providers, such as the work by Skreta and Veldkamp (2009), Bolton et al. (2012) and Kashyap and Kovrijnykh (2016). Skreta and Veldkamp (2009) and Bolton et al. (2012) point out that competition in the rating industry can facilitate ratings shopping, and the inflation of credit ratings appears more frequently in the expansion periods. In our model ratings shopping does not occur since the inspectors/specialists are randomly and anonymously assigned. Our paper has a similar focus as Kashyap and Kovrijnykh (2016) in that they study an optimal contracting problem in which a firm is seeking funding for a project from investors and a credit rating agency is hired to evaluate the project quality. Kashyap and Kovrijnykh (2016) show that giving the entire surplus to the rating agencies maximizes the accuracy and the total surplus. We find that in our case decentralization is not always feasible and is not always preferable.

2 Baseline Setup

Time $t = 0, 1, 2, ...$ is discrete and the horizon is infinite. There are two types of heterogeneous agents: a continuum of authors with unit mass and a continuum of referees with mass $k < 1$. All the agents are risk-neutral. Let us first introduce the basic BJP structure. Then, we explain authors and referees and the journal revenue structure.

We model the following two cases of a BJP. The first one is the centralized case in which referees collectively own the journal and share the profits equally. The second case is the decentralized journal in which referees are individually incentivized in that they divide the profits according to the contribution made by the paper that each referee accepts. It is important to note that not only the review process but also the profit distribution are designed in a way to strictly maintain the anonymity of a referee. We assume that in order to do so, no one can know who reviews which paper.[12] In this sense a blockchain mechanism is necessary for implementing our journal platform, because it can play a role

[11] In this respect, Yung (2005) also emphasizes the importance of investors' feedback for banks to screen correctly.

[12] Thus, it is infeasible to distribute the profit based on their contribution in a centralized platform without using a blockchain mechanism, because in order do so without using blockchain a middleman, who knows who has reviewed which paper, is required.

as an editor by assigning papers to the referees without revealing the identity of both authors and referees. However, the information about the referee's acceptance rate is accessible to the journal, although the journal cannot verify which papers are accepted by which referee. In the case of centralization the journal provides publication guidelines for the referees to accept or reject papers. If a referee accepts or rejects papers excessively without considering the guideline, he/she will not be paid in that period. Thus, bad referees have an incentive to mimic good referees in the centralization. On the other hand, no one pays attention to the other referees' behavior in the case of decentralization because each referee's earning rely only on his/her own decision.

To implement each case, a BJP can issue and use its own coins as a rewarding device.[13] With respect to the governance structure, the coin holders can participate in voting for major decisions such as publication policies, including the rejection rate of the journal or profit-sharing rule. Thus, it is even possible to switch between centralization and decentralization by voting. However, we do not model the voting mechanism or how the ownership dynamics change over time because it is beyond the scope of this paper.[14] Finally, academic or non-academic people can trade a certain NFT (the digital form of ownership of a paper) through the BJP that is a separate token assigned to each paper. However, we do not model how to price NFTs nor do we incorporate the value of the platform created by the NFT issuance in detail.

2.1 Authors

Each author is endowed with one paper indexed by $x \in [0, 1]$ at the beginning of each period. We assume that the paper quality is quantifiable and is denoted by $q(x)$, increasing in x. Without loss of generality, assume $q(0) = 0$. Ex ante, the probability density function of the paper quality is given by $g(x)$, which is public information. The AQ (average quality of the papers) is important in the analysis and denoted by $\bar{q} := \int_0^1 q(x)g(x)dx$.

Once a paper is endowed, the paper's quality becomes private information. After learning about the quality of the paper, the author decides whether to complete and submit the paper. In order to do so, an author is required to make a transfer to the journal. For example, an author needs to subscribe to the journal to read the literature that will help in the development of his or her paper. Also, many journals require authors to pay a fee when they submit their papers for consideration for publication.[15] In our model

[13]For example, it is implementable by using *open* blockchain: A new wallet address can be generated separately for each time of the review and the profit distribution (e.g., Monero) or zero-proof-knowledge can be used (e.g., Zcash).

[14]We assume that the journal initially starts with one form and does not change it.

[15]There are many academic journals whose final publication fees are much higher than the submission fee. For example, the publication fees for journals such as Nature, Science, and the Proceedings of the

authors pay a fee or coins to the journal. The fee payment or the coin purchase in our model refers to the sum of both the subscription and submission fees. Note that the subscription fee usually refers to the payments that universities and libraries make to the journal. Thus, in our model an author can be considered a representative agent of other authors in a department or university. In this sense, if the journal charges the university for the subscription, it is actually charged to a representative author. We will specify the incentive constraints for authors regarding the submission decision later.

Every author has the same initial endowment e, which is public information. Therefore, in the centralized case a journal can request a fee whose level depends on the amount of the authors' endowments. In a decentralized platform, e is an upper bound for the price of a coin.

Finally, if a paper is accepted (equivalently, published), the author earns a *non-transferable* reward, R, the value from publishing the paper. For example, it can include monetary compensation, the value of being tenured or promoted, research grants awarded based on the research output, and so on.

We will consider the case in which endowment and rewards are heterogeneous in Section 6.2. We will also extend the model in which the rewards are determined in equilibrium in Section 6.3. Specifically, in this case authors will obtain a greater reward as the average quality of the published papers increases.

2.2 Referees

There are referees of mass $k < 1$, which means the mass of referees is less than the mass of authors. This implies that the smaller subset of authors serves as qualified referees or a certain fraction of scholars runs the journal. In centralization if a paper is submitted to the journal, the journal contacts a referee through random selection. In decentralization, each referee, randomly matched with a submitted paper, makes his or her own decision to accept or reject the assigned paper for their own profits. In both cases, we assume a simple review process: a paper is reviewed by a single referee, and there is only a one-time acceptance or rejection decision by the referee (without having any rounds of revision). Since the measure of referees is less that that of authors, each referee will review more than one paper in each period. If every author submit their paper at time t, each referee will review $\frac{1}{k}$ measure of papers at time t.

There are two types of referees: bad referees and good referees. The type of referee is private information. Both types of referees are all capable of verifying the quality of

National Academy of Sciences can range upward of a few thousand dollars (US). When the fee per color cost is factored in, scientists could end up paying between US$10,000 to US$20,000 to publish their work in those journals.

a paper without a cost.[16] However, a bad referee does not spend time enough to review a paper correctly. In each period when a referee receives a certain mass of papers, he/she does not know his/her type. However, immediately prior to reviewing the papers, he/she receives an i.i.d. shock to be a bad referee with probability ρ and a good referee with probability with $1-\rho$. There are various reasons. As a real life example, when a scholar starts to review an assigned paper, he/she can get hit by an unexpected negative shock related to teaching or other service commitments, and when that happens, the referee's cost of reviewing the paper is much higher than in normal times. This kind of bad referee makes an accept/reject decision without reviewing the paper due to the high cost.

Note that the existence of bad referees, i.e., $\rho > 0$, which reflects the existence of *imperfect quality verification*, is critical in our model. Note also that thanks to the i.i.d. shock assumption, the mass of bad referees is always fixed as ρ in each period and there is no learning about a referee's type over time. In Section 6.4 we will consider the extension case in which the shocks are persistent over time and thus learning is feasible. We will discuss the role of editors in Section 6.4, since the role of the editor becomes clearly visible when learning is feasible.

2.3 Profit Structure

Regarding the journal's profit structure, there are two sources of revenue. First, the journal receives a fee or a coin from the authors who submit their papers. Second, the journal produces knowledge or intellectual property by publishing papers. We model a linear production function. More precisely, the value of the intellectual property is linear in the quality of the published paper: $Aq(x)$ for each published paper with quality x where $A > 0$ is the productivity coefficient. Without loss of generality we assume $A = 1$. On the other hand, there is a cost of publishing per paper, c_p. The total cost is linear in the measure of the published papers.

In sum, the total profit of the journal depends on the fee (or coin) sales and the total production revenue minus the publication cost. This total profit is equally distributed to the referees in a centralized BJP. However, in a decentralized BJP the referee gets paid the profits according to the published paper's performance net of the publication cost.

In the current practice, referees normally do not get paid for the service of reviewing papers, or they get paid only a very small amount. However, as we mentioned in our introduction, there is no difference in terms of social welfare between the case in which a single monopoly publisher takes all the profits and the case in which each referee shares

[16] We assume that the referees have already paid a fixed cost to obtain their expertise in quality verification process. However, it is excluded in our model, because it is a sunk cost.

a certain fixed proportion of the profits. In the case of general verification problems, the monopolistic firm makes a contract to hire a specialist. One can consider a simple case in which the firm is equally shared by all specialists.

2.4 Some Implementation Details

Here we provide several technological aspects of implementation. While one can reuse open sources to launch a new BJP and thus the cost can be significantly small, it is not cost-free. ICO (Initial Coin Offerings) can be useful for launching a new platform, issuing its coins efficiently, and providing the incentives to the original designer. Since there are various fields in academics and each field has a different convention or practice of running a journal, each BJP can have a different governance structure.

The original designer can launch a new platform of blockchain and earn a capital gain from his/her own coin share. The platform can have a separate native token that can be used for rewarding referees and for governance decision. On the contrary, the coin value can be pegged with a well-circulated coin such as Bitcoin and Ethereum. A consensus mechanism is chosen by the designer. This blockchain can be open to the public, that is, it can be permissionless, from the initial stage, but a permissioned one can be also implementable in such a way that only qualified reviewers are selected or added over time.[17] Finally, it requires block validators (separate entities from authors and reviewers) to maintain the system and to protect the privacy of the reviewers. They can be paid with the coins when they match an author's paper with a reviewer in the system under anonymity, and publish the accepted papers and distribute rewards to the corresponding authors and reviewers according to the review results. In the following sections we focus on the reviewer's incentives in this decentralized setting rather than on explaining the details of the platform-launching process and the validating mechanism.

We will further describe how to use blockchain and coins in detail in Section 6.1.

3 Centralized BJP

3.1 Journal's Profit Maximization Problem

Once a paper is submitted, the platform contacts a referee randomly, instructing the referee to accept the papers with $x \geq x_c$ or to reject the papers with $x < x_c$. Good referees correctly review the paper according to this policy; thus a probability that a paper is ac-

[17] See Chen, Cong and Xiao (2020) and Cao, Cong and Yang (2019) for examples of permissioned blockchain.

cepted by a good referee is $p(x_c)$, where $p(x)$ is defined by

$$p(x) := \int_x^1 g(y)dy.$$

Note that this acceptance rate can be pre-determined by voting among referees. Although the profits are equally distributed to referees, bad referees do not review the paper, but *pretend* to be good referees. If a referee does not follow the guidelines for acceptance, he/she will not be paid in that period. Thus, the bad referees have an incentive to mimic the good referees in centralization. Given that a referee receives a non-trivial measure of papers to review in each period[18], a bad referee uses a mixed strategy of accepting a paper with probability $p(x_c)$.

Knowing that bad referees mimic good referees, the journal determines the fee policy f and the publication policy x_c to maximize the profit. Given x_c, we define the average quality of the published papers as $Q(x_c)$. First, if the journal decides to publish all the papers, i.e, $x_c = 0$, the average quality of the journal is $Q(0) = \bar{q} := \int_0^1 q(x)g(x)dx$. If $x_c > 0$, the average quality of the paper accepted by bad referees is $\bar{q}$ and the average quality of the paper accepted by good referees is $\mathbf{E}[x|x \geq x_c] = \frac{\int_{x_c}^1 q(x)g(x)dx}{\int_{x_c}^1 g(x)dx}$. Therefore, the average quality of the accepted papers will be

$$Q(x_c) := \rho\bar{q} + (1-\rho)\frac{\int_{x_c}^1 q(x)g(x)dx}{\int_{x_c}^1 g(x)dx}. \tag{1}$$

Because the total measure of the accepted papers in this case is $p(x_c) = \rho p(x_c) + (1-\rho)\int_{x_c}^1 g(x)dx$, the aggregate value of the accepted papers is

$$\begin{aligned} Q(x_c)p(x_c) &= \rho p(x_c)\bar{q} + (1-\rho)\int_{x_c}^1 q(x)g(x)dx \\ &= \int_{x_c}^1 \{\rho\bar{q} + (1-\rho)q(x)\}g(x)dx. \end{aligned}$$

By the same reason, the total cost to publish the accepted papers is $c_p \int_{x_c}^1 g(x)dx$. Therefore, the net revenue from production is

$$\Pi_c := AQ(x_c)p(x_c) - c_p p(x_c) = \int_{x_c}^1 \{(\rho\bar{q} + (1-\rho)q(x)) - c_p\}g(x)dx,$$

[18]As will be shown in the following analysis, each referee will review $\frac{1}{k}$ measure of papers since every author will submit the paper in the pooling equilibrium.

where the linear (knowledge) production technology is applied with $A = 1$.

Regarding the fee collection from the authors, the journal has three constraints. The first one is the fee feasibility constraint (FC), which means that the journal cannot charge a fee that is more than the author's endowment:

$$f \leq e. \tag{2}$$

The second is the participation constraint (PC) for authors with $x \leq x_c$:

$$f \leq \rho R p(x_c) = \rho R \int_{x_c}^{1} g(x)dx. \tag{3}$$

This participation constraint is considered only when the journal decides to provide incentives for all authors to submit their papers. We call this case the *pooling* equilibrium. In the pooling equilibrium, the expected value for an author with $x < x_c$ is $\rho R p(x_c)$ since his or her paper can be accepted only if the paper is reviewed by a bad referee who uses the mixed strategy of accepting any paper with probability $p(x_c)$.

On the other hand, if the journal decides not to provide incentives for authors with $x < x_c$ and attracts only authors with $x \geq x_c$ to submit their papers, then the participation constraint (3) for authors with $x < x_c$ is violated. We call this case the *separating* equilibrium. In the separating equilibrium, the participation constraint for authors with $x \geq x_c$ is

$$\rho R p(x_c) < f \leq R, \tag{4}$$

because the authors with $x \geq x_c$ know that all their papers will be accepted in the separating equilibrium.[19]

The journal's profit maximization can differ depending on whether there is a separating or pooling equilibrium. First, in the pooling equilibrium the journal maximizes the following objective function:

$$\Pi_c^p := \max_{(x_c, f)} \int_{x_c}^{1} \left[\{\rho\bar{q} + (1-\rho)q(x)\} - c_p\right] g(x)dx + f \int_0^1 g(x)dx, \tag{5}$$

subject to (2) and (3). Second, the journal's objective function in the separating equilibrium is as follows:

$$\Pi_c^s := \max_{(x_c, f)} \int_{x_c}^{1} (q(x) - c_p) g(x)dx + f \int_{x_c}^{1} g(x)dx, \tag{6}$$

[19] Note that the inequality $\rho R p(x_c) < f$ is satisfied in equilibrium because the separating equilibrium exists only when $e > \rho R$ and FC (2), $f \leq e$ must hold in equilibrium.

subject to (2) and (4). If both pooling and separating equilibrium allocations are feasible, then the journal will compare the two cases and choose the one that provides a higher profit.

For given x_c, both the objective functions (5) and (6) increase in f. Therefore, at least one constraint, either (2) or (3) in the pooling equilibrium and either (2) or (4) in the separating equilibrium, must bind. Thus, we can derive the first-order conditions (FOCs) for x_c by plugging the binding constraint into the objective functions (5) and (6), respectively.

First Order Conditions: In the separating equilibrium we will have the following FOCs:

$$q(x_c) = c_p - R \quad \text{for} \quad e \geq R, \tag{7}$$

$$q(x_c) = c_p - e \quad \text{for} \quad e < R. \tag{8}$$

In the pooling equilibrium, we will encounter the following FOCs:

$$\{\rho\bar{q} + (1-\rho)q(x_c)\} = c_p - \rho R \quad \text{for} \quad e \geq \rho R p(x_c), \tag{9}$$

$$\{\rho\bar{q} + (1-\rho)q(x_c)\} = c_p \quad \text{for} \quad e < \rho R p(x_c). \tag{10}$$

Let us define x^*, $x^s(e)$, $\hat{x}_c^p$, and $\bar{x}_c^p$, as the solution to (7), (8), (9), and (10), respectively.[20]

Let us first consider the FOCs in the pooling equilibrium. The left-hand sides of FOCs (9) and (10) are the marginal benefit of the journal in terms of intellectual property, while the right-hand sides are the marginal cost when the journal accepts more papers by lowering the acceptance threshold policy, x_c. The marginal benefit is a weighted average of the average quality papers, $\bar{q}$, accepted by bad referees and the marginal quality papers, $q(x_c)$, accepted by good referees. That means the journal cannot accept only the marginal paper with quality, $q(x_c)$, without accepting some papers with average quality $\bar{q}$. It is important to note from (9) that the journal internalizes part of R, the benefit of an accepted paper to the author. However, the journal cannot internalize it if the endowment is significantly low.

Similarly, in the separating equilibrium the left- and right-hand sides of (7) and (8) represent the marginal benefit and the marginal cost, respectively, when the monopolistic journal accepts more papers by lowering x_c. Unlike the pooling equilibrium, the journal can raise the marginal benefit by $q(x_c)$, because only the authors with $x \geq x_c$ submit their papers in the separating equilibrium. Moreover, the journal internalizes the reward to the authors, because the fee collection is based on the number of accepted papers, $p(x_c)$.

The following assumption holds throughout the paper:

[20] In particular, we define x^* as the planner's allocation (see Appendix A) and here $x_c^s(e) = x^*$ holds when $e \geq R$.

Assumption 1. $q(1) > max\{c_p - \rho R, \frac{c_p - \rho \bar{q}}{1-\rho}\}$ *and* $q(0) < min\{c_p - R, \frac{c_p - \rho R - \rho \bar{q}}{1-\rho}\}$.

The inequalities in Assumption 1 imply that the publishing cost relative to the reward for each paper reviewed by a good referee is intermediate, so that neither rejecting nor publishing all the papers is socially efficient. Assumption 1 is required to avoid trivial cases and to guarantee the existence of the interior solution to the first-order conditions (10)-(7) that appear in each model.[21]

3.2 Equilibrium Characterization

Given (x_c, f) in the separating equilibrium, if $f > \rho R$, the authors with $x < x_c$ will not submit their papers, because the fee is higher than their maximum expected return. Therefore, bad referees will accept all the submitted papers in the separating equilibrium.

Lemma 3.1 (Centralization: Equilibrium Cases)**.** *The following hold:*

(a) Both separating and pooling equilibrium are feasible when $e > \rho R$.

(b) Only the pooling equilibrium exists when $e \leq \rho R$.

Lemma 3.1 shows that the publication and the fee policy (x_c, f) can be used for excluding a type of equilibrium by affecting the author's submission decision. Thus, we characterize the equilibrium according to the endowment of the authors to consider the possibility of enforcing one type of equilibrium.

3.2.1 Sufficient Endowment: $e > \rho R$

If $e > \rho R$, the pooling equilibrium can be excluded by setting $f > \rho R$ (Lemma 3.1). However, if $f > R$, no paper submission occurs so that the maximum possible fee is $f = R$. In order to maximize the profit, the journal will choose a fee $f = R$ when $e \geq R$, and $f = e$ if (2) binds with $e < R$.

While it is somewhat intuitive that the separating equilibrium provides higher profits, we still need to carefully compare the profits between the two cases. The following proposition shows that by comparison the separating equilibrium is achieved when $e > \rho R$.

Proposition 3.1 (Centralization: Sufficient Endowment)**.** *The following hold:*

(a) If $e \geq R$*, then the separating equilibrium is achieved with* $f = R$ *and* $x_c = x^*$*, where* x^* *is the unique solution to* (7).

[21] Note that if $c_p > R$, $\rho < \frac{1}{2}$ and $Aq(1)$ is sufficiently large, then Assumption 1 is always satisfied.

(b) If $\rho R < e < R$, then the separating equilibrium occurs with $f = e$ and $x_c = x^s(e)$, where $x^s(e)$ is the unique solution to (8).

Proposition 3.1 shows that if the authors have a sufficiently large endowment, the separating equilibrium is implementable and it provides higher profits than the pooling equilibrium. Since a higher fee level is applicable, the journal can *screen ex ante* and receive only high-quality papers. However, in order to implement a pooling equilibrium, the fee must be lowered to attract the authors of low-quality papers, so the revenue from the fee collection could decrease. Moreover, the average quality of the accepted papers will decline because bad referees use the mixed strategy.

Regarding the authors' surplus, if $e \geq R$, then $f = R$, so the journal can extract all the rents from the authors. Thus, the expected net reward of the authors will be zero. However, if $e \in (\rho R, R)$, then $f = e$, thus authors' expected surplus is $\int_{x^s(e)}^{1} (R - e)dx > 0$.

3.2.2 Insufficient Endowment: $e \leq \rho R$

When $e \leq \rho R$, the separating equilibrium is not implementable (Lemma 3.1). Knowing that bad referees accept all submitted papers in the separating equilibrium, the authors with $x < x_c$ will submit their papers because $f \leq e \leq \rho R$.

Since at least one of (2) or (3) must bind in the pooling equilibrium, Proposition 3.2 has three different cases: (a) only the PC (3) binds, (b) both (2) and (3) bind, and (c) only the FC (2) binds.

Proposition 3.2 (Centralization: Insufficient Endowment)**.** *The following are true:*

(a) If $\rho R \int_{\hat{x}_c^p}^{1} g(x)dx \leq e \leq \rho R$, the pooling equilibrium with $(x_c, f) = (\hat{x}_c^p, \rho R p(\hat{x}_c^p))$ is achieved, where $\hat{x}_c^p$ is the solution to (9).

(b) If $\rho R \int_{\bar{x}_c^p}^{1} g(x)dx \leq e < \rho R \int_{\hat{x}_c^p}^{1} g(x)dx$, the pooling equilibrium with $(x_c, f) = (x_c^p(e), e)$ is achieved, where $x_c^p(e)$ is such that $f = e = \rho R p(x_c^p(e))$.

(c) If $e < \rho R \int_{\bar{x}_c^p}^{1} g(x)dx$, the equilibrium is pooling with $(x_c, f) = (\bar{x}_c^p, e)$, where $\bar{x}_c^p$ is the solution to (10) and satisfies $f = e < \rho R p(\bar{x}_c^p)$.

If the author's endowment is relatively large, then FC (2) does not bind. Given the binding PC (3), the revenue from the fee collection can increase by raising f and reducing x_c. Therefore, the journal can choose the optimal threshold x_c by considering this trade-off between the fee collection and the average quality of the journal. If the author's endowment is intermediate, then FC (2) also begins to bind, so it is inevitable to increase x_c and reduce f to satisfy the binding PC (3). Finally, if the author's endowment is relatively small, then PC (3) can be relaxed and the journal chooses x_c without considering the revenue from the fee collection. As the endowment decreases, the profit decreases: although accepting more papers can raise the aggregate value of the journal's publication, the revenue from the fee collection decreases more than that. Figure 1 describes the publication and the fee policy (x_c, f) for each equilibrium case according to the endowment level.

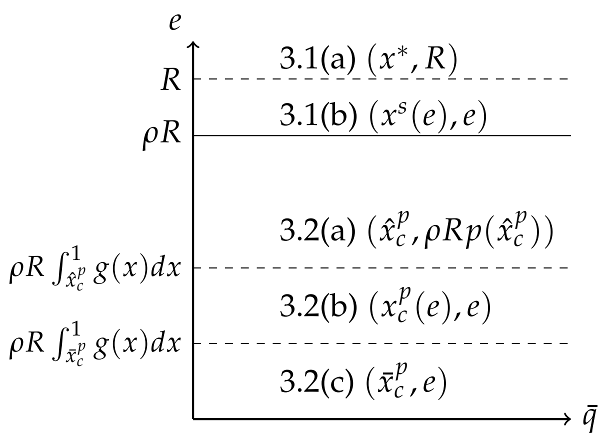

Figure 1: Summary of the centralization allocations for each region (see Propositions 3.1-3.2 for the details in each case).

4 Decentralized BJP

4.1 Referees' Profit Maximization

Now we turn to the decentralized BJP. There are also two sources of profits. First, referees receive a coin from an author at the submission stage and pay the publication cost when they accept the paper. Second, later each referee will be paid according to the contribution of the published paper. The contribution is determined by the paper quality. Since the quality of each paper is not revealed before the paper is reviewed, every referee gets paid the same share of the coin earnings at the submission stage. However, once a refereed paper is published, the profit generated by the paper can be distributed individually to the corresponding referee. For example, we can consider a compensation scheme such that if a paper obtains a higher citation number, the referee of the paper will receive a higher reward.

Note that this transfer mechanism is implemented without revealing the identity of the referee by using blockchain technology (see footnote 6). The key feature of the decentralized setting is that given the coin price, each type referee chooses the publication threshold separately, which in turn affects the incentive of the authors to submit and the equilibrium coin price.[22] We denote the thresholds set by good and bad referees as x_g and x_b, respectively.

We assume that the marginal cost of producing coins is zero, so in this economy coins can be supplied elastically to satisfy the demand. Instead, in each period t referees set the price of coin, ϕ_t, by considering the expected value of the author's submission and their endowment. For simplicity we assume that authors have no bargaining power in the decentralized system and only decide to submit their papers given the coin price and the expected reward of being accepted. Once papers are submitted and refereed, coins can be traded again in the next period, $t+1$. The timeline within each period is as follows: (i) ϕ_t is set at the beginning of each period t, (ii) each author then discovers the paper quality and decides whether to submit the paper by purchasing a coin, (iii) referees learn their types after receiving a coin and a paper to review, and (iv) the paper is published and the generated profits are distributed to the referees at the end of period t. From now on we will focus on the stationary equilibrium by defining the steady state price of the coin as $\phi := \phi_t$ for all period t.

With coin revenues, as in the case of the centralized system, referees are subject to the feasibility constraint (FC),

$$\phi \leq e, \tag{11}$$

and the participation constraint (PC) for authors with $x \leq x_g$,

$$\phi \leq \rho R \int_{x_b}^{1} g(x)dx \tag{12}$$

in a pooling equilibrium (in which every author submits a paper). However, in a separating equilibrium referees are subject to the PC for authors only with $x > x_g$,[23]

$$\rho R p(x_b) < \phi \leq \rho R p(x_b) + (1-\rho)R. \tag{13}$$

Referees' profit maximization can differ depending on whether there is a separating or pooling equilibrium. Recall that each referee learns his/her type after receiving a paper and a coin. Thus, in the pooling equilibrium, each type of referee chooses the optimal

[22] Recall that in the centralized case, bad referees have to mimic the acceptance rate of good referees. Otherwise the journal can detect them. They are not able to share the profits once they get caught cheating. In the decentralization case, referees are individually incentivized and thus bad referees will choose a pure or mixed strategy for their own profits. In fact, it turns out that bad referees will only choose a pure strategy in equilibrium.

[23] Similar to the centralization case, inequality $\rho R p(x_b) < \phi$ is satisfied in equilibrium, because the separating equilibrium exists only when $\phi > \rho R$ and the feasibility constraint (11), i.e., $\phi \leq e$, must hold in equilibrium.

thresholds (x_b, x_g) given the price ϕ,

$$\begin{aligned}\Pi_b^p &:= \max_{x_b} \int_{x_b}^1 (\bar{q} - c_p) g(x) dx + \phi, \\ \Pi_g^p &:= \max_{x_g} \int_{x_g}^1 (q(x) - c_p) g(x) dx + \phi.\end{aligned}$$

Then, ex ante, a referee's problem is to set ϕ to maximize the following objective function:

$$\begin{aligned}\Pi^p &:= \max_{\phi} \rho \Pi_b^p + (1-\rho) \Pi_g^p \\ &= \max_{\phi} \rho \int_{x_b}^1 (\bar{q} - c_p) g(x) dx + (1-\rho) \int_{x_g}^1 (q(x) - c_p) g(x) dx + \phi \int_0^1 g(x) dx,\end{aligned} \tag{14}$$

subject to (11) and (12). Note that bad referees use a simple strategy, either $x_b = 0$ or $x_b = 1$, by considering the AQ, i.e., $\bar{q}$, since they do not actually review the paper. Therefore, they accept the assigned papers when the AQ of the submitted papers is greater than the unit publication cost. We will also consider the possibility of mixed strategies in the next subsection. On the other hand, since the price ϕ is given, good referees set threshold x_g where the marginal revenue of the paper is equal to the marginal cost of production. In other words, the first-order condition for good referees in the pooling equilibrium is

$$q(x_g) = c_p, \tag{15}$$

where $\hat{x}$ is defined as the solution to (15).[24] Note that in both good referees' FOC (15) and bad referees' binary choice, authors' rewards are not incorporated because the referees maximize their profit given price ϕ. This feature in the pooling equilibrium of the decentralization case is different from that in the centralization case.

In the separating equilibrium, bad referees will accept all the papers because they know that only the authors with $x > x_g$ submit their papers, and so he/she can earn the same profit as a good referee does. Since their profits are equal, i.e., $\Pi_b^s = \Pi_g^s$, ex ante the referees choose ϕ and x_g together to maximize

$$\Pi^s = \Pi_g^s := \max_{(x_g, \phi)} \int_{x_g}^1 (q(x) - c_p) g(x) dx + \phi \int_{x_g}^1 g(x) dx, \tag{16}$$

subject to (11) and (13) in the separating equilibrium.

[24] A sufficient condition for the existence of the interior solution to (15) is $q(1) > \max\{c_p, \frac{c_p - \rho\bar{q}}{1-\rho}\}$.

4.2 Equilibrium Characterization in Decentralization

Note that similar to the centralization case, we can characterize the types of equilibria in accordance with the endowment. That is, screening is feasible (infeasible) if authors have a sufficiently high (low) endowment. More precisely, if $e > \rho R$, both the separating and pooling equilibrium are feasible. The separating equilibrium is implemented by choosing $\phi > \rho R$ because the expected reward for an author with $x < x_g$ is $\rho R p(0)$, which is less than the coin price ϕ. However, a pooling equilibrium is also feasible if the fee is set by $\phi \leq \rho R$. Therefore, referees will choose the equilibrium that provides more profit between the two cases.

When $e < \rho R$, the separating equilibrium is no longer feasible. One interesting and important feature in this case is that the equilibrium may not exist. More precisely, in the case of $\bar{q} \geq c_p$, a pooling equilibrium exists: since $x_b = 0$, the expected reward for an author with $x < x_g$ is $\rho R p(0) = \rho R$, which is greater than or equal to the coin price, ϕ, because of the feasibility constraint, $\phi \leq e$. However, in the case of $\bar{q} < c_p$, this pooling equilibrium cannot be supported in the same way: if the bad referees reject all the submitted papers then the authors with $x < x_g$ will not submit their papers, so the bad referees have no incentive to keep rejecting papers. We will explain this in more detail in Section 4.2.2.

4.2.1 Sufficient Endowment: $e > \rho R$

When $e > \rho R$, the decentralization case is similar to the centralization case. Since the coin price can be set as the fee charged in centralization, the same separating equilibrium allocations are feasible. By setting $\phi > \rho R$, only the authors with $x \geq x_g$ will submit their papers and bad referees will accept all the papers, i.e. $x_b = 0$.

However, if e is close to ρR and $\bar{q} \geq c_p$, referees may want to implement a pooling equilibrium. Unlike the centralization case, bad referees accept all the papers, $x_b = 0$, instead of a proportion of the papers. Thus, the coin price is determined to be $\phi = \rho R$ in (12) regardless of a good referee's choice. Then, the profit can be greater when the benefit of screening is low, because the fee can be collected from all the authors. Since both the pooling and separation equilibrium allocations are feasible, then ex ante the referees will compare the net expected revenues and choose the optimal coin price to maximize their aggregate profit.

The following proposition summarizes the above discussion and provides a precise condition when the separating or the pooling equilibrium is preferred.

Proposition 4.1 (Decentralization: Sufficient Endowment)**.** *When $e > \rho R$, the following hold:*

(a) *If* $\bar{q} < c_p$*, a separating equilibrium is achieved with* $(x_g, x_b, \phi) = (x^*, 0, R)$ *for* $e \geq R$ *and* $(x_g, x_b, \phi) = (x^s(e), 0, e)$ *for* $\rho R < e < R$*, respectively.*

(b) *Given* $\bar{q} \geq c_p$*, if* $\int_0^1 \{q(x) - c_p + R\} g(x) dx \leq \int_{x^s(e)}^1 \{q(x) - c_p + R\} g(x) dx$*, the same separating equilibrium in (a) is achieved. Otherwise, there is* $\tilde{e} \in (\rho R, R)$*, such that when* $\tilde{e} \leq e < R$*, the same separating equilibrium in (a) is achieved and when* $\rho R < e < \tilde{e}$*, and a pooling equilibrium is achieved with* $(x_g, x_b, \phi) = (\hat{x}, 0, \rho R)$*, where* $\hat{x}$ *is the solution to* (15)*. Note that* $\tilde{e}$ *is given in the proof.*

4.2.2 Insufficient Endowment: $e \leq \rho R$

Similar to the centralized setting, when $e \leq \rho R$, it is impossible to discourage the authors with $x < x_g$ to submit by setting the coin price at $\phi > \rho R$. If $\bar{q} \geq c_p$, i.e., the AQ is sufficiently high, then bad referees are willing to accept all the submitted papers because it provides a positive profit for them. Therefore, a pooling equilibrium occurs: all authors will submit their papers as long as $\phi \leq \rho R$. In this pooling equilibrium the thresholds (x_g, x_b) do not depend on the coin price in (14). Therefore, ex ante referees set $\phi = e$ to maximize their revenue. Given the price, bad referees accept all the papers since $\bar{q} > c_p$, while a good referee solves $\max_{x_g} \int_{x_g}^1 (q(x) - c_p) g(x) dx + e$. This pooling equilibrium is supported because every author submits as long as $\phi = e \leq \rho R$ with $x_b = 0$ and there is no reason to deviate.

On the other hand, if $\bar{q} < c_p$, bad referees first consider rejecting all the papers ($x_b = 1$) since the expected profit from accepting a paper is negative. Note that the revenue from the paper submission is not considered in this case because it will be earned regardless of the referee's decision. Given this, only the authors with $x \geq x_g = \hat{x}$ from FOC (15) will submit their papers. Knowing that there is no submission of low-quality papers, bad referees have incentives to deviate since accepting a paper is now profitable. This implies that neither $x_b = 0$ nor $x_b = 1$ is a part of equilibrium: there is no pure-strategy equilibrium. Note that the nonexistence of the pure-strategy equilibrium is caused by the coordination failure among bad referees and among the authors with $x < x_g$, respectively. Bad referees could reject all the papers ($x_b = 1$) by screening to attract only the authors with $x \geq x_g$. However, each bad referee has incentives to deviate (since accepting a screened paper is profitable) given that the other bad referees screen papers. Similarly, the authors with $x < x_g$ could earn rewards by randomizing their submission if they committed to submit only a proportion of their papers. However, as long as bad referees use a pure strategy (either accept all or reject all), the author's randomization cannot work; thus, the equilibrium does not exist.

In summary, we have shown the following proposition.

Proposition 4.2 (Decentralization: Insufficient Endowment)**.** *When $e \leq \rho R$, the following are true:*

(a) If $\bar{q} \geq c_p$, a pooling equilibrium is achieved with $(x_g, x_b, \phi) = (\hat{x}, 0, e)$, where $\hat{x}$ is the solution to (15)*.*

(b) If $\bar{q} < c_p$, no pure strategy equilibrium exists.

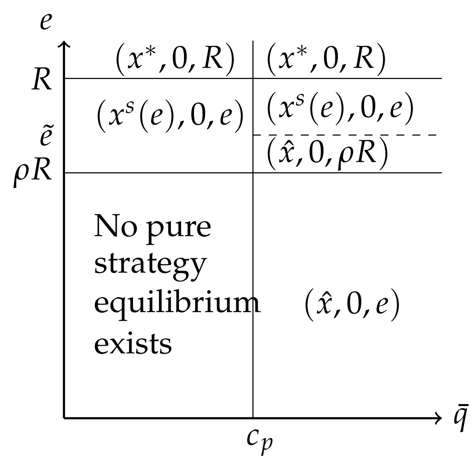

Figure 2: Summary of the decentralized allocations (x_g, x_b, ϕ) for each region in Propositions 4.1 and 4.2.

While there is no pure strategy equilibrium, there exists a mixed-strategy equilibrium. Let us first consider a mixed strategy of bad referees such that they randomly accept $p_b \in (0, 1)$ proportion of papers. Then, all the authors with $x \leq \hat{x}$ submit the paper as long as $R\rho p_b \geq \phi$, which gives a negative net profit for bad referees (excluding the revenue from the paper submission). Thus, it is not sustainable, since bad referees deviate to reject all the papers rather than accept a portion of them. If $R\rho p_b < \phi$, only authors with $x > \hat{x}$ will submit their papers. Knowing this, bad referees will have an incentive to accept all the papers since it is profitable, which leads to a failure of the equilibrium. Finally, one may consider the mixed strategies of authors with $x \leq \hat{x}$ such that they randomly submit $p_a \in (0, 1)$ proportion of papers. In this case there exists a unique mixed-strategy equilibrium in which the authors with $x \leq \hat{x}$ submit a p_a proportion of papers and the bad referees accept only a p_b proportion of the submitted papers.

However, this mixed-strategy equilibrium is unrealistic in the following senses. First, from the authors' perspective it implies that authors with $x \leq \hat{x}$ cooperate: some of them submit a paper and the others do not. This type of cooperation is fairly hard to implement without having a strong institutional action or arrangement. Second, from the referees' point of view, the mixed-strategy equilibrium means that bad referees are indifferent to accepting the papers or not in the mixed equilibrium since their profit is zero for either case. When they use a pure strategy either it provides a positive payoff or negative payoff. In this case, a clear profit-oriented motive incentivizes their acceptance or rejection decision. In contrast, the mixed strategy aims for zero profit and thus it is essentially against the individual incentive motive for decentralization. Because of these two reasons, we do not investigate the mixed-strategy equilibrium in detail in the main body of the paper. Instead we provide it with the detailed welfare analysis in Appendix C.

5 Welfare Analysis

5.1 Social Welfare Functions

The social welfare function, W, is the total surplus of all the agents, consisting of the aggregate quality of the accepted papers minus the cost of publishing the accepted papers, plus the aggregate reward for authors. In what follows let superscript p and s denote 'pooling' and 'separating,' respectively, and let subscript c and d denote 'centralization' and 'decentralization,' respectively. Let y_g and y_b be the equilibrium thresholds of good and bad referees, respectively. Then, in a pooling case the social welfare is

$$W^p(y_g, y_b) := \rho \int_{y_b}^{1} \{\bar{q} - c_p + R\} g(x) dx + (1-\rho) \int_{y_g}^{1} \{q(x) - c_p + R\} g(x) dx \tag{17}$$

without screening authors. However, if authors are screened with a sufficiently large endowment bad referees will accept all the submitted papers with $x \geq y_g$ in a separating equilibrium. Thus, the welfare function in the separating equilibrium can be written as

$$W^s(y_g, y_b) := \rho \int_{max\{y_b, y_g\}}^{1} \{q(x) - c_p + R\} g(x) dx + (1-\rho) \int_{y_g}^{1} \{q(x) - c_p + R\} g(x) dx. \tag{18}$$

Note that since the fee collection and the coin purchase are just transfers between agents, social welfare is determined by the thresholds (y_g, y_b) for each type of equilibrium. We summarize the welfare functions in each case as follows.

In centralization, the two thresholds must be equal because of bad referees mimicking good referees. Therefore, when the endowment is sufficiently large as $e \geq R$ and $\rho R < e \leq R$, welfare is $W_c^s(x^*, 0)$ and $W_c^s(x^s(e), 0)$, respectively. Similarly, if the endowment is low as $\rho R p(\hat{x}_c^p) \leq e \leq \rho R$, $\rho R p(\bar{x}_c^p) \leq e < \rho R p(\bar{x}_c^p)$ and $e \leq \rho R p(\bar{x}_c^p)$, the welfare will be $W_c^p(\hat{x}_c^p, \hat{x}_c^p)$, $W_c^p(x_c^p(e), x_c^p(e))$ and $W_c^p(\bar{x}_c^p, \bar{x}_c^p)$, respectively.

In decentralization, when the endowment is sufficiently large as $e \geq R$ and $\rho R < e \leq R$, welfare is $W_d^s(x^*, 0)$ and $W_d^s(x^s(e), 0)$, respectively, which are the same as in centralization. Exceptionally, if $\int_0^1 \{q(x) - c_p + R\}g(x)dx > \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$, then when $\rho R < e < \tilde{e}$, welfare is $W_d^p(\hat{x}, 0)$. When $e \leq \rho R$ and $\bar{q} \geq c_p$, welfare is $W_d^p(\hat{x}, 0)$. Finally, when $\bar{q} < c_p$, the welfare function for decentralization is not defined.

5.2 Comparison: Monopoly vs Decentralization

Now we are ready to compare social welfare between the two cases by using the formula for the welfare functions (17) and (18) with the allocations in Propositions 3.1, 3.2, 4.1, and 4.2. The results are summarized in Proposition 5.1. Refer to Figure 3 for the graphical description for Proposition 5.1. Note that the cases are divided according to the author's AQ, $\bar{q}$.

Proposition 5.1. *The following welfare comparison results hold with function $q(e)$:*

(a) When $e > \rho R$, $W_c^s = W_d^s$ except when $\bar{q} > c_p$ and $e \in (\rho R, \tilde{e})$, in which $W_c^s > W_d^s$.

(b) When $e \leq \rho R$ and $\bar{q} < c_p$, only centralization survives.

(c) When $e \leq \rho R$ and $\bar{q} \geq c_p$, $W_d^p < W_c^p$ if $\bar{q}$ is sufficiently high. Otherwise, $W_d^p > W_c^p$.

Note that $\tilde{e}$ is specified in the proof of Proposition 4.1.

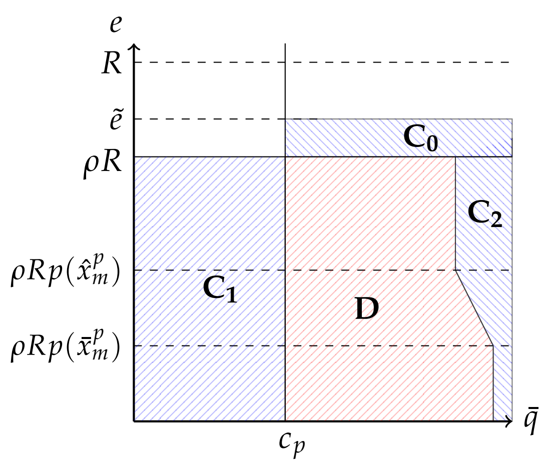

Figure 3: Welfare Comparison in Proposition 5.1. Decentralization is superior in the red region (region D) and centralization is superior in the blue region (regions C_0, C_1, and C_2). Neither decentralization nor centralization is superior in the white region (the region with no color).

5.2.1 When $e > \rho R$

First, note that both cases have the same efficient allocation if $e \geq R$. However, the efficient allocation is not achieved for any $e < R$. When the endowment is sufficiently high ($\rho R < e < R$), there is no difference between the two cases other than in the small region C_0 in Figure 3, in which $\bar{q} > c_p$ and $\rho R < e < \tilde{e}$.

Not only in C_0, but also in the entire region where $\rho R < e < R$, both the centralization and the decentralization cases choose to induce either separating or pooling by properly charging the fee/coin. The journal in centralization optimally implements 'separating' by charging $f = e$ when $\rho R < e < R$. On the contrary, in C_0, since screening (or separating) is less profitable for the decentralization case, referees attract all the authors to submit their papers by charging smaller fees ($f = \rho R < e$). In this case, all the papers are submitted and bad referees accept all the papers. Therefore, too many high-quality papers are rejected by good referees (note that $\hat{x} > x^s(e)$ for $e \in (\rho R, R)$ in Proposition 4.1), and too many low-quality paper are accepted by bad referees in this pooling equilibrium. Thus, the social welfare of the decentralized case in region C_0 is inferior to the separating equilibrium in centralization.

5.2.2 When $e \leq \rho R$

Let us turn to the realistic case when $e < \rho R$. First, if $\bar{q} < c_p$, there is no equilibrium in decentralization so that only centralization can exist. Then, we are left to consider the case when $\bar{q} > c_p$. Note that in centralization the journal's acceptance strategy always depends on the average quality of papers ($\bar{q}$) and the authors' reward (R), whereas in decentralization, good referees do not consider them at all and bad referees only consider the average quality of papers. This is clearly seen in the FOCs in each case, i.e., FOCs (9) and (10) in centralization versus FOC (15) in decentralization. More precisely, in centralization as $\bar{q}$ increases, the journal can accept more high-quality papers and reject more low-quality papers: the moral hazard problem is gradually mitigated as $\bar{q}$ increases. In decentralization, there is no change in the publication volume although the average quality increases.

Note that bad referees accept all the papers since $\bar{q}$ is sufficiently high. Therefore, in D, a higher number of high-quality papers are accepted in decentralization, while there is a significant welfare loss from moral hazard in centralization. Thus, decentralization is better off in D. However, the journal quality gradually improves as $\bar{q}$ increases in centralization. If the average quality is sufficiently high (in C_2), the measure of the accepted papers in decentralization is fixed, but the moral hazard problem is significantly mitigated in C_2 relative to D. In contrast, in C_2 too many high-quality papers are rejected in decentralization since referees in decentralization do not take the authors' reward into account. Thus, centralization is better off in C_2. Regarding the boundary between D and C_2, note that the measure of accepted papers is fixed for the decentralization case. However, the journal accepts more high-quality papers as e increases in centralization. Therefore, C_2 becomes wider as e increases.

In summary, there is a trade-off between the two cases. The welfare loss in decentralization is mainly caused by unnecessarily rejecting too many high-quality papers without considering the authors' reward. On the other hand, the welfare loss in the centralization setting mainly results from free-riding. Depending on which type of loss is smaller, decentralization can be more desirable, or vice versa.

5.3 Comparative Static Analysis

By using Figure 3, we can perform fairly intuitive comparative static analyses. First, as c_p increases (or $\bar{q}$ decreases by a relative amount), region C_1 increases. In other words, the proportion of region C_1 is larger for small $\bar{q}$. This implies that the centralized structure is more likely to be preferred as the average productivity of the industry is low.

There are two more comparative static analyses regarding ρ and R. We summarize the results in the following proposition.

Proposition 5.2. *The following comparative static analysis results hold:*

(a) If $\int_0^1 \{q(x) - c_p + R\} g(x)dx > \int_{\hat{x}}^1 \{q(x) - c_p\} g(x)dx$, then $\tilde{e}$ increases in ρ. Otherwise, $\tilde{e}$ decreases in ρ.

(b) Let $\tilde{q}(e)$ be the cutoff between D and M_2. Then, $\tilde{q}(e)$ decreases in R.

Note that $\tilde{e}$ and $\tilde{q}(e))$ are specified in the proofs of Propositions 4.1 and 5.1, respectively.

Regarding Proposition 5.2 (a), if the average revenue of bad referees is larger than that of good referees, there is not much benefit of screening. In this case, the relative size of region M_0 increases with $\tilde{e}$. On the other hand, if the average revenue of bad referees is smaller than that of good referees, it is better to screen as ρ increases. Therefore, the relative size of region M_0 shrinks as ρ increases.

Regarding Proposition 5.2 (b), region D becomes wider and the boundary moves to the right as R decreases. We can view that it is closer to a copyleft type of world or industry as R becomes smaller. Therefore, this result implies that decentralization is more desirable in such an industry for the welfare reason, while the centralized profit-sharing or monopoly structure is preferred in an industry in which there are large rewards for the inventor, the holder of the copyright, and the entrepreneur.

6 Extension and Further Discussion

This section considers various extensions of the baseline model. We also provide further discussion of important features that we omit and simply in the baseline model. Each subsection is independent of the others, and as such, readers can read these subsections in whatever order they choose.

6.1 Monopoly versus Centralized BJPs

Our baseline model abstracts from including the efficiency and new benefits created by using blockchain, and it focuses on highlighting the theoretical differences between centralization and decentralization in terms of a BJP's ownership and profit distribution. Here we compare the difference between journals run by monopoly publishers and centralized journals on blockchain, while previously we treated them equivalently since there is no difference in terms of social welfare.

The cost of information production and journal management for monopoly publishers might be smaller thanks to their know-how and skills than for a centralized BJP. However, there are benefits of using a BJP. For example, a new market for trading property rights or artwork by using blockchain tokenization is growing rapidly. For instance, issuing NFTs (non-fungible tokens) is getting more and more popular for the sale of digital assets.[25] Likewise, once a BJP is introduced, papers in the DJP can easily be tokenized and their ownership can be traded in the form of NFTs. The NFTs for a paper may or may not reflect the cash flow rights of a published paper, and it will depend on the design choice among the BJP participants or coin holders through voting. Moreover, general investors, though not necessarily academic scholars, who believe that a new finding in a scientific paper will change the world may want buy its NFTs, much like they would collect art pieces, paintings, or other collectibles. In this sense, a BJP will serve as a market place for trading property rights in addition to its conventional role as a journal, which creates additional value for the platform.

In addition, we did not elaborate on the mechanism of using coins in the baseline model. We simply described it as if the fee is paid with coins. Note that the role of coins is different from the fee in the case of the journal run by a monopoly publisher. Coins are not only used for a transfer from authors to referees, but also for distributing the profits to the authors and the assigned referees. Therefore, coins have equity-like

[25] For example, the first tweet by Jack Dorsey (Twitter's CEO) sold for about 1630 ETH (about USD$6 million) in March 22, 2021 (see https://v.cent.co/tweet/20). A piece of art (not a physical piece of art, but a form of JPG file) by artist Beeple (Mike Winkelmann) sold for USD$69 million in March 11, 2021 (see https://onlineonly.christies.com/s/firstopenbeeple/beepleb19811/112924).

properties in our proposed system. Moreover, coins can be traded in a secondary market, so it will make the journal a platform for direct investment and trading knowledge. In addition, we suggest that the institutions and libraries of the authors and the referees of a published paper should deserve a certain fraction of the ownership and thus they should receive coins. This is, however, a design choice. All these design choices are made through voting among the platfrom participants. These features also create additional benefits from using a BJP.

In summary, depending on whether the benefit from using blockchain is greater or smaller than the cost-efficiency when a journal is run by a monopoly publisher, either form of centralization would be preferred.

6.2 Heterogeneous Endowments and Rewards

In reality authors (or universities) have different levels of research funds and face different types of rewards. In our model, however, we assume that authors are all ex ante homogeneous in their endowments and rewards from publication. The purpose is to isolate authors' reputation effect in understanding the optimal conditions for our verification system, although we admit that the homogeneity assumption may simplify other interesting aspects in the publication world. In what follows we discuss which results would change or not by introducing heterogeneity in the baseline model.

Regarding endowment, it is important to note that in our model authors start with an equal endowment *before* they produce papers. It is possible to distribute the endowments after the papers are produced. However, the equal distribution of endowments is natural as long as the authors' paper quality is private information. There could arise a coalition of authors in which the authors with low-quality papers yield their endowments to the authors with high-quality papers. This can be feasible if it is possible to form a contract with full commitment such that the rewards can be shared among authors after publication. However, we do not pursue this extension since it could only create a secondary issue in our comparative analysis between centralization and decentralization.

The heterogeneity in rewards will be more meaningful to consider. In the case of heterogeneous rewards, screening would not be feasible because the authors with low-quality papers will submit their papers if the publication reward is substantially high. For example, consider the following case in which authors with a low quality paper will get a higher reward than authors with a high quality paper when the paper is accepted. More specifically, let $x_c \in (0,1)$ be given. Suppose R_1 is the reward for the authors with quality $x < x_c$ and R_2 is the reward for the authors with $x \geq x_c$. Assume that $R_1 > R_2$ and $\rho R_1 P(x_c) \geq R_2$. If the fee is larger than $\rho R_1 P(x_c)$, the authors with high quality papers are discouraged to submit because the fee cost is greater than their expected rewards, R_2. If the fee is smaller than $\rho R_1 P(x_c)$, the authors with low quality papers would also submit and a pooling equilibrium arises. This example shows that screening can be infeasible when the rewards are negatively related to the quality of the papers. Moreover, the coordination failure in decentralization would disappear due to the existence of such high-reward authors. However, as long as the pooling equilibrium exists, the argument for dividing the area between D and C_2 is still valid. More precisely, the trade-off between moral hazard in centralization and negative externality in decentralization still remains for the case of heterogeneous rewards. Consequently, in the case of heterogeneous rewards there might remain only two regions: D (when the AQ is low) versus C_1 (when the AQ is high).

6.3 Equilibrium Reward

As a realistic extension, we consider the case in which the reward depends on the quality or reputation of the journal. Specifically, the reward increases with the average quality of the published paper in the journal. In this case, the reward will be determined along with the optimal threshold, which is chosen in equilibrium.

First note that the main result will not change in decentralization. Each referee chooses the threshold only by considering their cost of publication, c_p, as shown in (15). Therefore, the average quality of the journal remains the same as in the baseline model and the referees ask the same price in coins for submission ex ante. In other words, in decentralization the negative externality problem does not disappear, nor is it mitigated even if authors are given better incentives.

In contrast in centralization the journal can internalize the authors' reward. This mechanism leads to an increase in the journal quality and thus an increase in welfare. To verify this intuition, let us assume $R = R(Q(x_c))$, where $Q(x_c)$ is the average quality of accepted papers defined by (1) and the reward is an increasing function of $Q(x)$. The journal chooses the threshold by considering not only the average quality of the journal, but also its effect on the rewards for the authors. More precisely, the first-order condition in the pooling equilibrium (9) is rewritten as

$$\{\rho \bar{q} + (1-\rho) q(x_c^e)\} = c_p - \rho R(Q(x_c^e)) \quad \text{for} \quad e \geq \rho R(Q(x_c^e)) p(x_c^e). \tag{19}$$

The threshold is chosen by reflecting the effect on the rewards $R(Q(x))$. Thus, welfare in the pooling equilibrium improves in centralization by internalizing the authors' reward more than in the case in which R is exogenously given, while the negative externality remains the same in decentralization. As a result, the region for C_2 will expand to the left, while the region for D will shrink, as described in Figure 4.

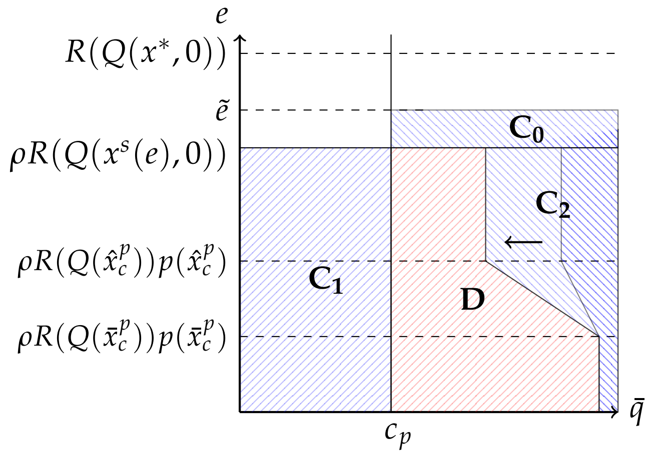

Figure 4: Welfare comparison when authors' reward is determined in equilibrium.

6.4 Learning about Referees' Type and the Role of Editors

In our baseline model referees receive i.i.d. shocks of being good types or bad types in each period. Due to the assumption, the previous history of decisions to accept or reject a paper over time is useless for inferring the type of a referee in subsequent periods. Therefore, learning is impossible under this assumption, which greatly simplifies our analysis and means that the baseline model is essentially the same as a one-period model. On the other hand, we assume that neither referees nor editors comment on a paper to improve its quality. Referees just make a one-time accept/rejection decision and thus the role of an editor, if there is such a role, is limited to assigning a referee to a paper. Therefore, if the shock on a referee's type is random and thus learning is not available, then in our model there is still no role for editors.

What if the shock on a referee's type is persistent? The extension in this direction will be fairly interesting, but we find the analysis highly complicated, so we leave this for future research. Instead, we provide an intuitive discussion of the persistent case as follows.

Consider an extreme case in which the type of a referee is determined in the initial period and the types are fixed afterwards. Since learning is feasible by analyzing the outcomes over time, the optimal mechanism would be set up in a way that the probability of getting bad referees to review the paper becomes lower over time. It can be implementable regardless of centralization or decentralization, as long as the history of the referee's decision can be used to exclude bad referees. For example, in the case of a monopoly publisher, the editor must rely on his or her own memory, while in either a centralized or decentralized BJP, the information is stored using blockchain technology. Therefore, the editor may play a unique role only if the editor receives noisy signals about the quality of a submitted paper. If the editor can sort out some high-quality papers and match them with good referees (with a higher probability than in the case without the editor), it will improve welfare. Again, even if the editor receives the noisy signals about the paper quality, this kind of matching may not be effective when the shock on a referee's type is independently distributed over time.

6.5 Effort Cost for Verification

We can consider the case in which the cost of reviewing a paper increases with the effort rather than the case with heterogeneous referee types. However, the main intuition of this model will be robust in the case of the effort cost: there exists the trade-off between moral hazard and negative externality. Referees are still subject to moral hazard in centralization because their payoff is based on the average quality of the accepted papers. Decentralization can improve the welfare by aligning the incentives of referees. However, there still exists a problem of the negative externality in decentralization because the individual referees cannot internalize the author's reward and thus they will accept or reject the papers excessively.

6.6 Implementation Challenge: Measurement of Quality

There arises a question of how to measure the quality of a paper and/or the contribution of a paper (in terms of the profit distribution). From our interviews with researchers from various academic fields, we find that the number of citations as the measure of paper quality seems broadly accepted in general sciences such as mathematics, life sciences and biomedicine, and physical sciences. Researchers in these areas tend to have a general consensus in assessing the difficulty of a research question. However, researchers in other areas such as arts and humanities and social sciences are less likely to agree on this point. Nevertheless, in reality we often see many cases such as art awards or film festivals in which selected arts or films are scored and ranked by judges from each field. That means, even though there is no universal measure that everyone agrees on about the quality of art, they keep trying to quantify the values and to decide which one is better. Similarly the quality verification process is also conducted in other information industry. Credit rating agencies estimate the credit risk of a firm by using measures in financial statements and evaluate the quality by discretized rating such as AAA, AA, A, etc. Loan officers investigate observable indicators from the loan documents of an applicant and suggest a binomial decision whether to provide a loan or not. Therefore, even if it is difficult to find an objective measure for the paper quality, the logic in this paper can still apply as long as a group of experts can participate in the quality verification process.

In addition, if the contribution were solely measured by the number of citations, it would have the effect of encouraging only research with wide application rather than research which attempts to address more fundamental questions. Therefore, to find (more) objective measures of a paper's quality will be important for implementing in journals in those areas. In addition, it would be interesting to consider the case in which there is uncertainty (or ambiguity) in the future contribution of a published paper. We hope that further research will focus on these aspects.

7 Concluding Remarks

Following the recent computer science literature, we have constructed a model to study optimal profit-sharing among information producers by comparing the centralized structure with the decentralized one. Our first finding is the importance of the applicant's endowment (own equity). If the endowment is sufficiently large, screening is feasible, so the ownership structure of the inspectors may not matter while there is a specific case in which decentralization is not preferable. However, such screening is rarely feasible in reality. When the endowment is not large, a pure strategy equilibrium does not exist in decentralization if the average productivity is lower than the marginal cost because of the coordination failure: decentralization is hard to implement and there only exists a centralized profit-sharing structure allowing free riding. On the other hand, if the average productivity is higher than the marginal cost, there arises a trade-off between the two cases: the source of the welfare loss is moral hazard in centralization and negative externality in decentralization. Using blockchain technology, we can incentivize information providers under anonymity in decentralization. Therefore, the inefficiency associated with free riding can be mitigated. However, if the non-transferable reward that authors (funding applicants) obtain from the acceptance (approval) is sufficiently high, it is more likely that centralization could be preferable. This is because the coalition of referees (inspectors) can internalize the authors' (applicants') rewards by adjusting the fee collection.

This paper takes just one step toward understanding the implementation of blockchain-based journal platforms with application in the information industry such as intermediary (e.g., venture capital) funding decision problems, credit ratings, lending practices, and so on. However, there could be many limitations in our model. While our paper can provide insights into how to decentralize a certain business platform, there also could be practical issues in the real world. We hope that future research will be able to generalize the current model and address its limitations.

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Appendix

A Efficient Allocations

In order to understand the optimal allocation in our environment, we introduce a planner who maximizes the social welfare function by choosing each publication policy x_g and x_b for good and bad referees, respectively. Moreover, we assume that the planner can collect taxes, T, from the authors to screen the quality of their papers as long as the authors' endowment is available.

It is important to note that there is a critical difference between the efficient allocation presented here and the centralization-versus-decentralization allocations investigated in the main body of the paper. Screening is infeasible when $e < \rho R$ in the latter case. However, screening is largely feasible in the planner's problem since the planner can not only choose the publication policy x_g and x_b separately, but can also impose a partial acceptance policy for bad referees.

The social welfare function, W, represents the total surplus of all the agents, which consists of the aggregate quality of the accepted papers minus the cost of publishing the accepted papers, plus the aggregate reward for the authors. Therefore, it is written as

$$W^p := \rho \int_{x_b}^{1} \{\bar{q} - c_p + R\} g(x) dx + (1-\rho) \int_{x_g}^{1} \{q(x) - c_p + R\} g(x) dx \tag{A.1}$$

in a pooling equilibrium without screening the authors by collecting taxes. However, in the separating equilibrium in which the authors are screened, the welfare function is reduced to

$$W^s := \int_{x_g}^{1} \{q(x) - c_p + R\} g(x) dx, \tag{A.2}$$

because bad referees will accept all the submitted papers with $x \geq x_g$.

Since tax T is just a transfer between the agents, T is not included in the welfare function. However, the tax is used for screening the quality of the paper given the author's endowment, so it is considered in the feasibility constraint,

$$T \leq e, \tag{A.3}$$

and the participation constraint for authors with $x \leq x_g$,

$$T \leq \rho R \int_{x_b}^{1} g(x) dx, \tag{A.4}$$

and the participation constraint for authors with $x > x_g$,

$$\rho R p(x_b) < T \leq \rho R p(x_b) + (1-\rho)R. \tag{A.5}$$

Thus, the planner maximizes (A.1) subject to (A.3) and (A.4) in the pooling equilibrium, while he or she maximizes (A.2) subject to (A.3) and (A.5) in the separating equilibrium. If both types of equilibrium are feasible, then the planner will choose one type of equilibrium to maximize the social welfare.

If $e > \rho R$, then the planner can use T for screening the papers. The papers with quality $x < x^*$ are not submitted. Therefore, a separating equilibrium is achieved by $T \in (\rho R, e]$, with $x_b = 0$ and $x_g = x^*$ where x^* is the solution to $q(x^*) = c_p - R$.

When $e \leq \rho R$, the planner can still use the endowment e for screening papers, but it is only available with the partial acceptance of bad referees. In this case, to prevent the authors with $x < x^*$ from submitting their papers, $T = e > \rho R p(x_b)$ needs to be satisfied. Therefore, it is required for bad referees to accept only $p(x_b)$ proportion of the submitted papers, even though the submitted papers are all qualified, $x \geq x^*$. The welfare with screening can be addressed as $W^s(e) = \frac{e}{R}\int_{x^*}^{1}\{q(x) - c_p + R\}g(x)dx + (1-\rho)\int_{x^*}^{1}\{q(x) - c_p + R\}g(x)dx$, because $\rho p(x_b) = \frac{e}{R}$. Since $p(x_b)$ must be reduced as e decreases, the welfare also falls as e decreases.

Without screening, the planner can choose two different thresholds (x_g, x_b) to verify the submitted papers. Since all the papers are submitted in this case, there are two equilibrium cases by the decision of bad referees, because good referees can always verify the quality of the papers, and they choose $x_g = x^*$. If $\bar{q} - c_p + R > 0$, the bad referees accept all the papers, $x_b = 0$, so it is a pooling equilibrium. However, in the case of $\bar{q} - c_p + R < 0$, the bad referees reject all the papers, $x_b = 1$, so only the authors with $x \geq x^*$ submit their papers in a separating equilibrium. Note that $T \in [0, e]$ is available but not necessary because it is just a transfer between agents when it is not used for screening. Thus, the welfare in these pooling and separating equilibria can be written by the following cases: if $\bar{q} - c_p + R \geq 0$, $W^p = \rho\{\bar{q} - c_p + R\} + (1-\rho)\int_{x^*}^{1}\{q(x) - c_p + R\}g(x)dx$, and if $\bar{q} - c_p + R < 0$, $W^s = (1-\rho)\int_{x^*}^{1}\{q(x) - c_p + R\}g(x)dx$.

When $e \leq \rho R$, since screening is not perfect with partial acceptance, we can compare the welfare between the equilibrium with screening and the one without screening. If $\bar{q} - c_p + R < 0$, $W^s(e) \geq W^s$ for all $e \leq \rho R$, because it is always better to verify and accept the qualified papers rather than rejecting all of them. On the other hand, if $\bar{q} - c_p + R \geq 0$, there is a threshold of endowment, $\hat{e} \in (0, \rho R)$, at which $\rho\{\bar{q} - c_p + R\} = \frac{\hat{e}}{R}\int_{x^*}^{1}\{q(x) - c_p + R\}$ holds. It is because $W^s(e)$ decreases as e declines, but W^p remains regardless of e. Thus, if $\hat{e} \leq e \leq \rho R$ then the planner will use the endowment for screening the papers, while if $e < \hat{e}$, then the planner will implement a pooling equilibrium. We summarize the strategy and the welfare in each region as follows (see also Figure 5).

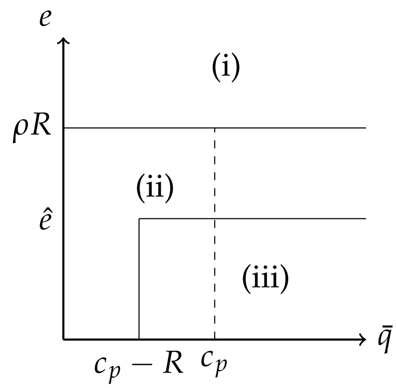

Figure 5: Efficient allocations by regions

(i) If $e > \rho R$, the planner chooses $x_g = x^*$, $x_b = 0$ and $T = (\rho, e]$. The welfare is $W^s = \int_{x^*}^1 \{q(x) - c_p + R\} g(x) dx$.

(ii) If $e \le \rho R$ and $\bar{q} - c_p + R < 0$, or $\hat{e} \le e \le \rho R$ and $\bar{q} - c_p + R \ge 0$, then the planner implements $x_g = x^*$, $T = e$ and lets bad referees accept $p(x_b) = \frac{e}{\rho R}$ proportion of papers. The welfare is $W^s(e) = (\frac{e}{R} + 1 - \rho) \int_{x^*}^1 \{q(x) - c_p + R\} g(x) dx$.

(iii) If $e < \hat{e}$ and $\bar{q} - c_p + R \ge 0$, the planner chooses $x_g = x^*$, $x_b = 0$ and $T = (\rho, e]$. The welfare is $W^p = \rho\{\bar{q} - c_p + R\} + (1 - \rho) \int_{x^*}^1 \{q(x) - c_p + R\} g(x) dx$.

B Proofs

Proof of Lemma 3.1:

Proof. (a) When $e > \rho R$, a separating equilibrium is feasible by choosing $f > \rho R$ because the expected reward for an author with $x < x_c$ is $\rho R p(0)$, which is less than the cost f. Therefore, a pooling equilibrium is also feasible if the fee is set by $f \le \rho R$.

(b) When $e \le \rho R$, a separating equilibrium cannot be supported: the expected reward for an author with $x < x_c$ is $\rho R p(0) = \rho R$ in a separating equilibrium, and it is greater than or equal to the cost, f, because of the fee feasibility, $f \le e$. □

Proof of Proposition 3.1:

Proof. If the journal wants to implement the separating equilibrium, the journal charges a fee $f = R$ when $e \ge R$ and a fee $f = e$ when $\rho R < e < R$ because the fee feasibility constraint (2) binds when $e < R$. Therefore, the journal's objective function (6) is rewritten as

$$\int_{x_c}^{1} \{q(x) - c_p + min\{e, R\}\} g(x) dx. \tag{B.1}$$

By taking the derivative of (B.1), the maximum profit in the separating equilibrium is obtained from FOC (8) when $e < R$ and (7) when $e \geq R$.

If the journal wants to induce the pooling equilibrium, then (3), the PC for the authors with $x < x_c$, should be satisfied. In this case, the PC must bind for maximizing the profit and thus $f = \rho R \int_{x_c}^{1} g(x)dx < e$. Therefore, the journal's objective function (5) is reduced as

$$\int_{x_c}^{1} \left[\{\rho\bar{q} + (1-\rho)q(x)\} - c_p + \rho R\right] g(x)dx.$$

Taking the derivative in the above equation, we obtain FOC (9). Then, $(x_c, f) = (\hat{x}_c^p, \rho R p(\hat{x}_c^p))$ is the optimal policy in the pooling equilibrium.

Now we will show that Π_c^s, the profit of the separating equilibrium with $(x_c, f) = (x^s(e), e)$, is greater than Π_c^p, that of the pooling equilibrium with $(x_c, f) = (\hat{x}_c^p, \rho R p(\hat{x}_c^p))$, when $\rho R < e < R$. Note that $\Pi_c^s = \int_{x^s(e)}^{1} \{q(x) - c_p + min\{e, R\}\} g(x)dx$ increases in e, because $x^s(e)$ decreases in e. Therefore, if $\Pi_c^s > \Pi_c^p$ when $e = \rho R$, then the separating equilibrium occurs for $\rho R < e < R$. When $e = \rho R$,

$$\begin{aligned}
\Pi_c^p &= \int_{\hat{x}_c^p}^{1} \left[\{\rho\bar{q} + (1-\rho)q(\hat{x}_c^p)\} - c_p + e\right] g(x)dx \\
&= \rho \int_{\hat{x}_c^p}^{1} \{\bar{q} - c_p + e\} g(x)dx + (1-\rho) \int_{\hat{x}_c^p}^{1} \{q(x) - c_p + e\} g(x)dx \\
&< \rho \int_{x^s(e)}^{1} \{q(x) - c_p + e\} g(x)dx + (1-\rho) \int_{x^s(e)}^{1} \{q(x) - c_p + e\} g(x)dx = \Pi_c^s.
\end{aligned}$$

In the above inequality, $\int_{x^s(e)}^{1} \{q(x) - c_p + e\} g(x)dx > \int_{\hat{x}_c^p}^{1} \{q(x) - c_p + e\} g(x)dx$ because $x^s(e)$ maximizes $\int_{x_c}^{1} \{q(x) - c_p + e\} g(x)dx$ by definition. Moreover, if $\bar{q} - c_p + e \geq 0$,

$$\begin{aligned}
\int_{x^s(e)}^{1} \{q(x) - c_p + e\} g(x)dx &> \int_{0}^{1} \{q(x) - c_p + e\} g(x)dx \\
&= \int_{0}^{1} \{\bar{q} - c_p + e\} g(x)dx > \int_{\hat{x}_c^p}^{1} \{\bar{q} - c_p + e\} g(x)dx.
\end{aligned}$$

Otherwise, if $\bar{q} - c_p + e < 0$, $\int_{x^s(e)}^{1} \{q(x) - c_p + e\} g(x)dx > 0 > \int_{\hat{x}_c^p}^{1} \{\bar{q} - c_p + e\} g(x)dx$. Finally, the separating equilibrium also occurs for $e \geq R$ because the profit of the separating equilibrium with $(x_c, f) = (x^s(e), e)$ is equal to that of the separating equilibrium with $(x_c, f) = (x^*, R)$ when $e = R$, whereas the profit of the pooling equilibrium remains.

□

Proof of Proposition 3.2:

Proof. For case (a), suppose that (2) does not bind. In this case, (5) is reduced to

$$\max_{x_c} \int_{x_c}^{1} \left[\{\rho\bar{q} + (1-\rho)q(x)\} - c_p + \rho R \right] g(x)dx$$

with $f = \rho R \int_{x_c}^{1} g(x)dx$, because (3), the PC for the authors with $x \le x_c$, only binds. Then, the optimal threshold is $x_c = \hat{x}_c^p$ in (9), and this allocation is supported when $e \ge \rho R \int_{\hat{x}_c^p}^{1} g(x)dx$.

Similarly, for case (c), suppose that (3) does not bind. In this case, (5) is reduced to

$$\max_{x_c} \int_{x_c}^{1} \left[\{\rho\bar{q} + (1-\rho)q(x)\} - c_p \right] g(x)dx + e,$$

because only (2) binds, i.e., $f = e$. Therefore, the optimal threshold, $x_c = \bar{x}_c^p$, is determined by (10), and this allocation is supported when $e < \rho R \int_{\bar{x}_c^p}^{1} g(x)dx$.

When $\rho R \int_{\bar{x}_c^p}^{1} g(x)dx \le e < \rho R \int_{\hat{x}_c^p}^{1} g(x)dx$ in case (b), (5) can be rewritten as

$$\max_{x_c} \int_{x_c}^{1} \left[\{\rho\bar{q} + (1-\rho)q(x)\} - c_p \right] g(x)dx + f,$$

subject to $f \le e$ and $f \le \rho R \int_{x_c}^{1} g(x)dx$. In this case both constraints (2) and (3) bind: If (4) only binds, then $e < \rho R \int_{\hat{x}_c^p}^{1} g(x)dx = f$ violates (3). If only (3) binds, then $\rho R \int_{\bar{x}_c^p}^{1} g(x)dx \le e = f$ contradicts (4) being relaxed. Therefore, $x_c(e)$ is determined by binding (2) and (3), i.e. $f = e = \rho R \int_{x_c(e)}^{1} g(x)dx$, not by a FOC. For example, suppose that the journal chooses $x_c = \bar{x}_c^p$ and $f = \bar{e}$, where $\bar{e} := \rho R \int_{\bar{x}_c^p}^{1} g(x)dx$. Then, the profit will be $\Pi_c(e) = \int_{\bar{x}_c^p}^{1} \left[\{\rho\bar{q} + (1-\rho)q(\bar{x}_c^p)\} - c_p \right] g(x)dx + \bar{e}$, which is the same as the profit in case (c) when $e = \bar{e}$. Since $e \ge \bar{e}$ in this case, the profit can increase by reducing x_c and raising f. In this way the profit can be maximized when $f = e = \rho R \int_{x_c(e)}^{1} g(x)dx$ holds. Finally, since threshold $x_c(e)$ decreases in e, it moves down from $\bar{x}_c^p$ to $\hat{x}_c^p$ when e increases from $\rho R \int_{\bar{x}_c^p}^{1} g(x)dx$ to $\rho R \int_{\hat{x}_c^p}^{1} g(x)dx$. □

Proof of Proposition 4.1:

Proof. If the referees want to implement a separating equilibrium, the coin price will be set at $\phi = R$ when $e \ge R$ and at $\phi = e$ when $\rho R < e < R$, because FC (11) binds when $e < R$. Therefore, a good referee's objective function (16) is rewritten as $\int_{x_g}^{1} \{q(x) - c_p + min\{e, R\}\}g(x)dx$, so $x_g = x^*$ when $e \ge R$ and $x_g = x^s(e)$ when $e < R$. Since the authors with $x \leq x_g$ will not submit their papers, bad referees will accept all the papers to earn the same profit as the good referees. Thus, the aggregate revenue of the entire referees will be

$$\Pi_d^s := \rho \Pi_b^s + (1-\rho)\Pi_g^s = \int_{x_g}^1 \{q(x) - c_p + min\{e, R\}\} g(x)dx,$$

where $x_g = x^*$ when $e \geq R$ and $x_g = x^s(e)$ when $e < R$.

If the referees want to induce a pooling equilibrium, then (12), the PC for the authors with $x \leq x_g$, should be satisfied. Note that in the pooling equilibrium, $x_b = 1$ if $\bar{q} - c_p < 0$, and $x_b = 0$, otherwise. Therefore, if $\bar{q} - c_p < 0$, $\phi = 0$ is required in (12), so a pooling equilibrium cannot be supported. However, if $\bar{q} - c_p \geq 0$, the PC (12) binds with $\phi = \rho R$ for maximizing the profit and $(x_g, x_b, \phi) = (\hat{x}, 0, \rho R)$ is implemented to support a pooling equilibrium. Hence, the aggregate revenue of the entire referees in the pooling equilibrium is

$$\Pi_d^p := \rho \Pi_b^p + (1-\rho)\Pi_g^p = \rho \int_0^1 \{\bar{q} - c_p\} g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p\} g(x)dx + \rho R,$$

when $\bar{q} - c_p \geq 0$.

Now we can show that $\Pi_d^p < \Pi_d^s$ when $e \geq R$ and $\bar{q} - c_p \geq 0$ as

$$\begin{aligned} \Pi_d^p =& \rho \int_0^1 \{q(x) - c_p + R\} g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p\} g(x)dx \\ &< \rho \int_{x^*}^1 \{q(x) - c_p + R\} g(x)dx + (1-\rho) \int_{x^*}^1 \{q(x) - c_p + R\} g(x)dx = \Pi_d^s. \end{aligned}$$

When $\rho R \leq e < R$ and $\bar{q} - c_p \geq 0$, $\Pi_d^p < \Pi_d^s$ holds if e is sufficiently large and close to R:

$$\begin{aligned} \Pi_d^p =& \rho \int_0^1 \{q(x) - c_p + e\} g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p + e\} g(x)dx + \rho R - e(\rho + (1-\rho)p(\hat{x})) \\ &< \rho \int_{x^s(e)}^1 \{q(x) - c_p + e\} g(x)dx + (1-\rho) \int_{x^s(e)}^1 \{q(x) - c_p + e\} g(x)dx = \Pi_d^s, \end{aligned}$$

because $x^s(e) = \arg\max_x \int_x^1 \{q(z) - c_p + e\} g(z)dz$ and $\rho R < e(\rho + (1-\rho)p(\hat{x}))$.

On the other hand, if e is close to ρR, $\Pi_d^p > \Pi_d^s$ is possible as

$$\begin{aligned} \Pi_d^p =& \rho \int_0^1 \{q(x) - c_p + R\} g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p\} g(x)dx \\ &> \rho \int_{x^s(e)}^1 \{q(x) - c_p + \frac{e}{\rho}\} g(x)dx + (1-\rho) \int_{x^s(e)}^1 \{q(x) - c_p\} g(x)dx = \Pi_d^s, \end{aligned} \tag{B.2}$$

when $\int_0^1 \{q(x) - c_p + R\}g(x)dx > \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$, because $\hat{x} = \arg\max_x \int_x^1 \{q(z) - c_p\}g(z)dz$ and $x^s(e) > x^* > 0$. Otherwise, if $\int_0^1 \{q(x) - c_p + R\}g(x)dx \leq \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$, then $\rho < \tilde{\rho}$ is additionally required for $\Pi_d^p > \Pi_d^s$. Note that $\tilde{\rho}$ can be defined by the threshold of ρ where $\Pi_d^p = \Pi_d^s$ holds at $\rho = \tilde{\rho}$ when e is close to ρR. Therefore, except for the case when $\int_0^1 \{q(x) - c_p + R\}g(x)dx \leq \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$ and $\rho \geq \tilde{\rho}$, there exists a threshold $\tilde{e} \in [\rho R, R)$ and $\Pi_d^p > \Pi_d^s$ when $e < \tilde{e}$. □

Proof of Proposition 4.2:

Proof. (a) In the pooling equilibrium the thresholds (x_g, x_b) do not depend on the coin price in (14). Therefore, the referees set $\phi = e$ to maximize their revenue. Given the price, bad referees accept all the papers since $\bar{q} > c_p$, while a good referee solves $\max_{x_g} \int_{x_g}^1 (q(x) - c_p)g(x)dx + e$. This pooling equilibrium is supported because every author submits as long as $\phi = e \leq \rho R$ with $x_b = 0$.

(b) In the case of $\bar{q} - c_p < 0$ the strategy of authors with $x \geq x_g$ is to submit their papers. Also, the strategy of the good referees is to accept the papers which are greater than x_g and reject them otherwise. Given that, we describe the strategies of authors with $x < x_g$ and the bad referees in Table 1 in Appendix C. Given $e < \rho R$, $\phi < \rho R$ always holds because $\phi \leq e$ in (11) must satisfy all the authors. When all the papers are submitted, the bad referee will reject the papers because $\bar{q} - c_p < 0$ in the "submit" column in Table 1. Then, given that the bad referees reject papers, the authors with $x < x_g$ would not submit their papers because $-\phi < 0$ in the "reject" row. Given that the authors with $x < x_g$ would not submit, the bad referees would accept the papers since $\int_{x_g}^1 \{q(x) - c_p\}g(x)dx > 0$ in the "Do not submit" column. Finally, given that the bad referees accept, the authors with $x < x_g$ would submit papers because $-\phi + \rho R > 0$ in the "accept" row. There are no pure-strategy best responses matched for the two parties, thus there is no pure strategy equilibrium. □

Proof of Proposition 5.1:

Proof. (a) When $e > \rho R$, $W_c^s = W_d^s$ because the allocations are equal according to Propositions 3.1 and 4.1, except for the case when $\bar{q} \geq c_p$, $\rho R < e < \tilde{e}$, and either $\int_0^1 \{q(x) - c_p + R\}g(x)dx > \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$ or $\rho < \tilde{\rho}$. In this case a pooling equilibrium with $(\tilde{x}, 0, \rho R)$ is chosen in decentralization. Then,

$$W_d^p = \rho \int_0^1 \{q(x) - c_p + R\}g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p + R\}g(x)dx,$$

$$W_c^s = \rho \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx + (1-\rho) \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx.$$

If $\int_0^1 \{q(x) - c_p + R\}g(x)dx > \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$, then since $\hat{x} > x^s(e) > x^*$, there is a threshold $\hat{\rho} \in (0,1)$, where $W_d^p < W_c^s$ if $\rho < \hat{\rho}$. Otherwise, $\int_0^1 \{q(x) - c_p + R\}g(x)dx \leq \int_{x^s(e)}^1 \{q(x) - c_p + R\}g(x)dx$ and $\rho < \tilde{\rho}$, $W_d^p < W_c^s$ always holds. Hence, along with the proof of Proposition 4.1, if $\rho < min\{\tilde{\rho}, \hat{\rho}\}$, then $\Pi_d^p > \Pi_d^s$ and $W_d^p < W_c^s$.

(b) It is straightforward from Proposition 4.2.

(c) When $e \leq \rho R$ and $\bar{q} \geq c_p$, $x_b = 0$ and $x_g = \hat{x}$ in decentralization, whereas $x_c \in [\hat{x}_c^p, \bar{x}_c^p]$ in centralization. Since $\bar{q} \geq c_p$, $\hat{x} \leq \bar{x}_c^p$ in (10). Given that

$$W_d = \rho \int_0^1 \{\bar{q} - c_p + R\}g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p + R\}g(x)dx, \tag{B.3}$$

if $\bar{q} = c_p$ and $e < \rho R p(\bar{x}_c^p)$, $W_d > W_c$ because $x_g = \hat{x} = \bar{x}_c^p = x_c$ and $\bar{q} - c_p + R > 0$. When $\bar{q} = c_p$ and $e \geq \rho R p(\bar{x}_c^p)$, $W_d > W_c$ holds if

$$\rho \int_0^{x_c} \{\bar{q} - c_p + R\}g(x)dx > (1-\rho) \int_{x_c}^{\hat{x}} \{q(x) - c_p + R\}g(x)dx, \tag{B.4}$$

where $x_c \in [\hat{x}_c^p, \bar{x}_c^p)$, and otherwise, $W_d \leq W_c$ holds. Given e, if $\bar{q}$ increases, then x_c decreases in (10)-(9), thus there exists a threshold, $\tilde{q}(e)$, where (B.4) holds with equality. Note that $\tilde{q}(e)$ will be greater when x_c at $\bar{q} = c_p$ is larger, given e. □

Proof of Proposition 5.2:

Proof. (a) In the proof for Proposition 4.1, $\tilde{e}$ is defined as a threshold at which (B.2) holds with equality, as shown below.

$$\begin{aligned} \Pi_d^p &= \rho \int_0^1 \{q(x) - c_p + R\}g(x)dx + (1-\rho) \int_{\hat{x}}^1 \{q(x) - c_p\}g(x)dx \\ &= \int_{x^s(\tilde{e})}^1 \{q(x) - c_p + \tilde{e}\}g(x)dx = \Pi_d^s. \end{aligned}$$

Note that Π_d^s is independent with ρ, while Π_d^p increases in ρ when $\int_0^1 \{q(x) - c_p + R\}g(x)dx > \int_{\hat{x}}^1 \{q(x) - c_p\}g(x)dx$. Therefore, in this case if ρ is relatively high, then Π_d^p is larger, so the threshold $\tilde{e}$ increases. On the other hand, if $\int_0^1 \{q(x) - c_p + R\}g(x)dx < \int_{\hat{x}}^1 \{q(x) - c_p\}g(x)dx$, then $\tilde{e}$ decreases in ρ.

(b) When R increases, the threshold $\tilde{q}(e)$ in (B.4) decreases because the right-hand side of (B.4) increases further as x_c declines. □

C Mixed-Strategy Equilibrium in Decentralization

C.1 Analysis

In the case of $\bar{q} - c_p < 0$ and $e < \rho R$, the strategy of authors with $x \geq x_g$ is to submit their papers. Also, the strategy of the good referees is to accept the papers which are greater than x_g and reject them otherwise. Given that, we can describe the strategies of authors with $x < x_g$ and the bad referees as in Table 1.

Bad Referees \ Authors	submit	mixed (p_a)	do not submit
accept	$(\bar{q} - c_p, -\phi + \rho R)$	N/A	$\left(\int_{x_g}^{1}\{q(x) - c_p\}g(x)dx, 0\right)$
mixed (p_b)	N/A	(MP_B, MP_A)	N/A
reject	$(0, -\phi)$	N/A	(0,0)

Table 1: Payoff table of the game between bad referees and authors with $x < x_g$.

Note: The first column is a bad referee's strategy set: (i) accept, (ii) mixed strategy with the acceptance probability $p_b \in (0,1)$, and (iii) reject. The first row is an author's strategy set: (i) submit, (ii) mixed strategy with the submission probability $p_a \in (0,1)$, and (iii) do not submit. The first argument of the parentheses in each cell is the bad referee's payoff and the second argument is the author's payoff. In the middle cell, the mixed-strategy payoff of an author is $MP_A := -\phi + \rho R p_b$ and the mixed-strategy payoff of a referee is $MP_B := p_b\{(1 - p_a)\int_{x_g}^{1}\{q(x) - c_p\}g(x)dx + p_a(\bar{q} - c_p)\}$.

There is no mixed-strategy equilibrium in which one group of agents chooses a pure strategy, since the best response to the opponent's pure strategy is a pure strategy, as we proved in Proposition 4.2. However, there is a mixed equilibrium in which both agents choose mixed strategies. In order to make bad referees indifferent, authors with $x < x_g$ submit only p_a proportion of their papers. Similarly, bad referees only accept p_b proportion of submitted papers to make authors with $x < x_g$ earn zero, on average. Thus, we can find out p_a and p_b such that the following two equations are satisfied:

$$(1 - p_a)\int_{x_g}^{1}\{q(x) - c_p\}g(x)dx + p_a(\bar{q} - c_p) = 0 \quad \text{and} \quad -\phi + \rho R p_b = 0.$$

Therefore, when $c_p < \bar{q}$ and $e < \rho R$, only a mixed-strategy equilibrium with $(x_g, \phi) = (\hat{x}, \rho R p_b)$ exists, where authors with $x < x_g$ submit p_a proportion of papers and bad referees accept a paper with probability p_b. This implies that there is no way for bad referees and low-quality authors to earn strictly positive profits, because their expected payoff must be zero according to the property of the mixed-strategy equilibrium.

C.2 Welfare Comparison

As mentioned in the main body of the paper, the mixed-strategy equilibrium is unrealistic in that authors must cooperate, which does not fit with the idea of decentralization in that referees use the mixed strategy to obtain zero profit. However, for interested readers in this subsection we describe the welfare in the decentralized case and compare it with the centralized case.

Before we provide a detailed comparative analysis, here is a brief summary. On one hand, note that some authors in the mixed-strategy equilibrium will receive the rewards because a proportion of papers are accepted, unlike in the other decentralization allocations. This increases welfare for decentralization. On the other hand, the moral hazard in centralization increases as the average quality of the papers decreases. From these two observations, one can see that decentralization is superior to centralization when $\bar{q}$ is sufficiently low. This can be seen in Figure 6 and we explain the details in what follows.

When good referees accept papers with $x \geq z_g$ and bad referees accept z_b proportion of papers, regardless of the quality, x and authors with $x < z_g$ submit z_a proportion of papers. The social welfare function of this mixed-strategy equilibrium is defined as

$$\begin{aligned} W^M(z_g, z_b, z_a) &= z_b\rho \int_0^1 \{\tilde{q} - c_p + R\} g(x)dx + (1-\rho) \int_{z_g}^1 \{q(x) - c_p + R\} g(x)dx \\ &= z_b\rho R + (1-\rho) \int_{z_g}^1 \{q(x) - c_p + R\} g(x)dx, \end{aligned} \tag{C.1}$$

where $\tilde{q} := (1 - z_a) \int_{z_g}^1 q(x)g(x)dx + z_a\bar{q}$. Note that $\tilde{q} = c_p$ always holds in this mixed-strategy equilibrium by definition, because z_a is chosen to make the bad referees indifferent between accepting and rejecting papers. Therefore, the first row of the social welfare function (C.1) can be reduced into the second row of (C.1).

We can show that this mixed-strategy equilibrium in decentralization dominates the pooling equilibrium in centralization when $\bar{q} \leq c_p - R$ and $e < \rho R$. First, welfare for bad referees in centralization is negative in (17) due to $\bar{q} - c_p + R \leq 0$, while welfare for bad referees in decentralization is strictly positive as $z_b\rho R > 0$. Second, as shown in Proposition 3.2, in the centralized case a good referee chooses thresholds $\hat{x}_c^p, x_c^p(e)$ and $\bar{x}_c^p$ according to the level of e, which satisfies (9), $e = \rho R p(x_c^p(e))$ and (10), respectively. On the other hand, in the decentralized case a good referee chooses the threshold regardless of e as $z_g = \hat{x}$, where $\hat{x}$ is defined as the solution to $q(x) = c_p$ in (15). Since $x^* < \hat{x} \leq \hat{x}_c^p < x_c^p(e) < \bar{x}_c^p$ holds when $\bar{q} \leq c_p - R$, welfare for good referees in centralization is lower or at least the same as welfare for good referees in decentralization. In sum, given $\bar{q} \leq c_p - R$, welfare is improved by decentralizing the journal system with the mixed strategy.

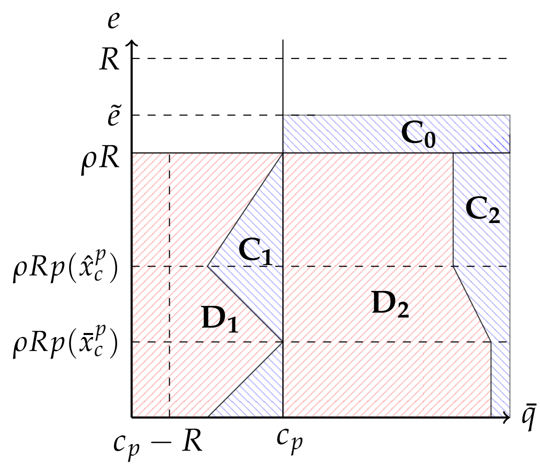

Figure 6: Welfare comparison with the mixed-strategy equilibrium in decentralization. Decentralization is superior in the red region (regions D_1 and D_2) and centralization is superior in the blue region (regions C_0, C_1, and C_2). Neither case is superior in the white region (the region with no color).

This result is somewhat intuitive. Since the average quality of the papers is lower than the social net cost, $c_p - R$, referees should not accept any papers without verifying the quality. In case of a mixed-strategy equilibrium, the quality of the submitted papers is raised as authors with $x < \hat{x}$ submit a p_a-proportion of the papers. However, in centralization bad referees keep accepting papers to mimic good referees. Moreover, centralization turns out to be inefficient in this case because the journal chooses the higher threshold for good referees to make up for the negative profit generated by bad referees.

On the other hand, when $c_p - R < \bar{q} \leq c_p$ and $e < \rho R$, there arise several areas where the pooling equilibrium in centralization is better off. Remember that p_b is chosen to satisfy $\phi = \rho R p_b$ in the mixed-strategy equilibrium. Since the participation constraint (12) is always satisfied with $\phi = \rho R p_b$ in the mixed-strategy equilibrium, ϕ is determined as $\phi = e$ to maximize the revenue. Therefore, the welfare for bad referees in the mixed-strategy equilibrium is $\rho R p_b = \phi = e$. Note that when $\bar{q} = c_p$ and $\rho R p(\bar{x}_c^p) \leq e \leq \rho R p(\hat{x}_c^p)$, it is equal to welfare for bad referees in centralization, that is, $\rho R p(x_c) = e$. Moreover, the thresholds of good referees in the two systems are equal when $\bar{q} = c_p$ and $e \leq \rho R p(\bar{x}_c^p)$ according to (10). Therefore, welfare in the two systems will be the same when $\bar{q} = c_p$ and $e = \rho R p(\bar{x}_c^p)$.

Then, as e decreases, the thresholds for good referees do not change, but welfare for bad referees in decentralization becomes smaller than in centralization because $e < \rho R p(\hat{x})$. Since the threshold for good referees in centralization goes up as $\bar{q}$ decreases, welfare can be maintained when both e and $\bar{q}$ decline from the point at which $\bar{q} = c_p$ and $e = \rho R p(\bar{x}_c^p)$.

Similarly, as e decreases in $[\rho R p(\bar{x}_c^p), \rho R p(\hat{x}_c^p)]$, welfare for bad referees is equal to e in the two systems. However, the threshold for good referees in centralization decreases from $\bar{x}_c^p$ towards $\hat{x}_c^p$, which improves welfare. Thus, welfare can be maintained when e rises and $\bar{q}$ falls from the point at which $\bar{q} = c_p$ and $e = \rho R p(\bar{x}_c^p)$.

Finally, if e increases in $[\rho R p(\hat{x}_c^p), \rho R)$, welfare from bad referees in decentralization, e, is always greater than in centralization, $\rho R p(\hat{x}_c^p)$, because $e > \rho R p(\hat{x}_c^p)$, and the gap becomes wider as e increases. On the other hand, the threshold of good referees in centralization is equal to that in decentralization when $\bar{q} = c_p - R$ according to (9), and becomes greater as $\bar{q}$ increases. Therefore, welfare can be maintained as both e and $\bar{q}$ increase.

There is a trade-off between centralization and decentralization in the region of $c_p - R < \bar{q} \leq c_p$ and $e < \rho R$. There are several main reasons: First, when $e > \rho R p(x_c)$, bad referees in the mixed-strategy equilibrium can freely raise p_a for $\rho R p_a = e$ to collect the whole endowment from authors, but in the centralized case given the threshold x_c, the fee is lower than e, as the participation constraint binds. That means a mixed-strategy equilibrium has an advantage of maximizing the fee collection. Second, the threshold of good referees in the centralized case moves away from the optimal point, x^*, as $\bar{q}$ decreases, whereas that in the decentralized case is fixed. Thus, centralization can be preferable only when $\bar{q}$ is sufficiently high. Finally, there is also an effect of negative externality being considered in the centralized case as R increases, given $e \geq \rho R p(\hat{x}_c^p)$.