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Economic Analysis of Blockchain Technology on Digital Platform Market

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***Abstract*—Blockchain technology on the platform business becomes a new paradigm which gets security, irreversibility, and trustfulness closer to both of clients and service providers (SPs) for providing a better quality of service. To provide an economic analysis of such blockchain-based platform business, a game theoretic approach is used to model a competitive market against the incumbent platform operated by a centralizer as a trusted third party. In this market, the platforms behave as a mediator to deliver the services provided by SPs to clients. The crucial factors for the success of blockchain-based platform business are (i) how SPs' participation is reflected on its quality of service (QoS) and (ii) how to incentivize SPs to contribute their resources such as computing/storage infrastructure. In our game formulation, a non-cooperative two-stage dynamic game is used, where the first stage models how to incentivize SPs in a blockchain-based platform and the second stage models the competition between platforms to attract clients. As a result, we provide an equilibrium analysis, which gives a useful insight into how much the service quality of blockchain-based platform affects the competition between platforms and the equilibrium incentive strategy for SPs. Moreover, our numerical analysis shows that the equilibrium incentive increases with proportional to the QoS of a blockchain-based platform whereas the incentive becomes negative if it provides a non-increasing QoS with the number of participated SPs.**

***Index Terms*—Blockchain, Platform market, Incentive mechanism, Network economics, Game theory.**

I. Introduction

Today we are witnessing a significant growth of blockchain technology, which originates from the nucleus of Bitcoin's architecture [1]. With the widespread adoption of blockchain technology, a number of projects that require real-time co-operation between mutually-suspicious contributors over the internet have arisen. The growth of blockchain technology includes a horizontal expansion led by startups mainly using the public blockchain, e.g., Bitcoin [1], Ethereum [2], and a vertical development driven by consortiums and industry partnerships mostly based on the permissioned blockchain, e.g., Hyperledger [3] and Corda [4].

Blockchain technology has enabled the emergence of a new type of platform structure by which a group of collaborative and equally privileged providers is able to jointly maintain a substantial amount of data storage and computational power in a decentralized manner, without any unilateral centralizer. For example, Samsung SDS [5] releases a digital blockchain-based platform for supply chain management which can replace a conventional electronic data interchange (EDI) system. R3 [6] provides a blockchain consortium to create open-account trade finance network among banks. As described in Fig. 1, unlike a platform intermediated by a trusted centralizer, the quality of service of blockchain-based platform highly depends on its intrinsic cryptographic structure that brings an increase of QoS in terms of security, irreversibility, and trustfulness. Moreover, the QoS of blockchain-based platform relies on decentralized data storage and computational power at a large scale, thus the blockchain based platform needs to have an incentivizing mechanism to encourage participants to join the platform.

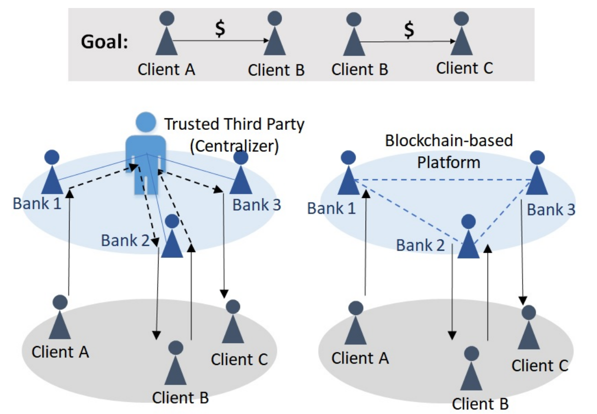

Fig. 1. Example showing a difference between centralizer-based platform (left) and blockchain-based platform (right). The arrows represent the certification flow for transactions between clients (e.g., A →B and B → C). If the banks form a financial platform based on permissioned blockchain such as R3 in [6], then its QoS would depend on the participated Banks' decentralized resource contribution on the blockchain-based platform.

The main interest of this paper lies in the viability of such blockchain-based platform who mediates SPs and clients by delivering services, where SPs participate as nodes of blockchain and their services would be consumed by clients. Successfully operating blockchain-based platform against the competition with the centralizer-based platform requires the incentive mechanism for SPs and the pricing strategy for clients where the service quality of blockchain-based platform varies with a participation of SPs. However, it has been

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underexplored how to incentivize SPs who spend costs for maintaining decentralized storage and computational power, which has a high dependence on how the blockchain-based platform and the centralized platform compete for pricing strategies for clients.

To model a platform market, we consider the centralizer-based platform, the blockchain-based platform, SPs, and clients, where we formulate a platform-based two-stage dynamic game. In the first stage, platforms and SPs play a dynamic sequential game, where the SPs decide which platform to join and the blockchain-based platform determines the incentives for SPs. Under the blockchain-based platform, SPs should spend a cost for investment while they should pay a commission to centralizer under the centralizer-based platform. In the second stage, platforms and clients play a dynamic sequential game, where the clients choose where to subscribe and each platform decides its pricing strategy for clients. Besides, towards more practicability, we model various heterogeneities in (i) willingness to pay of clients, (ii) willingness to invest of SPs, and (iii) QoS function of each platform.

Analyzing our two-stage dynamic platform game, we aim at answering the following questions: (i) How much the QoS depending on the participation of SPs in blockchain-based platform impacts on the incentive to joined SPs and (ii) under what conditions, the blockchain-based platform would be viable against the incumbent centralizer-based platform. We quantify each platform's economic impact as a form of the net-revenue depending on platform selections of SPs and clients. As a result, we provide an equilibrium analysis, which gives us a useful insight into how much the service quality of blockchain-based platform affects on the competition between platforms and the equilibrium incentive strategy for SPs. Moreover, our numerical analysis shows that the equilibrium incentive increases as the QoS of a blockchain-based platform whereas the incentive becomes negative if it provides a non-increasing QoS with the number of participated SPs thus the blockchain-based platform is paid by SPs.

We summarize our main contributions as follows:

- ○ Our economic analysis provides an insight into the viability of blockchain-based platform whose QoS, reflecting security, irreversibility, and trustfulness of services, highly depends on the participation of SPs.
- ○ We provide a game-theoretic model for a competitive platform market between an emerging blockchain-based platform and an incumbent centralizer-based platform, which captures how three players (i.e., platforms, SPs, clients) interplay in the market.
- ○ From the equilibrium of analysis, we first show that a platform offers a higher QoS can set a higher equilibrium price and get a larger revenue. Moreover, the incentive for SPs participated in blockchain-based platform highly relies on the QoS function, thus we show when and how the QoS impacts on the incentive.

II. Related Work

The platform business based on blockchain technology has proliferated over the past few years. Bitcoin [1], the first blockchain-based cryptocurrency, acts as a financial platform in which transactions can be validated between nodes without a trusted third party. Moreover, the concept of smart contracts suggested by Ethereum [2] has enabled execution of trusted distributed applications on the blockchain-based platform. Furthermore, the emergence of permissioned blockchain technology such as Nexledger [7], Hyperledger [3], and Corda [4] has accelerated the platform business for companies who want to make a connection with permissioned nodes rather than with permissionless (or public) ones. Moreover, each of cloud service providers [8]–[11] operates an infrastructure to facilitate forming a blockchain-based platform.

Examples of a blockchain-based platform include the Internet of Things (IoT) platform and the supply chain platform. The papers in [12], [13] study the adoption of blockchain technology on IoT platform and the white paper in [14] addressed the possibility of IoT-blockchain combination in supply chain management. Moreover, the papers in [15], [16] investigate the economic impact of a blockchain-based platform. The authors in [15] discuss how the costs affected by blockchain platform, the verification cost and the networking cost, impact on the digital marketplaces and the paper in [16] inductively studies the implications of blockchain technology on the platform economy and how to create multi-sided markets.

In perspective of modeling and analysis, the literatures [17], [18] are close to our work that analyzed the economic impact of a platform market with non-cooperative game theory. In [17], the authors have an interest in the investment incentive of Internet service providers and the paper in [18] studies the incentive mechanism for edge resource owners contributing on fog computing platform. However, our interest is mainly at understanding the economic impacts of the emergence of a blockchain-based platform thus we precisely model the characteristics of blockchain technology such as the QoS function depending on participated SPs and the investment cost for decentralized resources. To the best of our knowledge, this paper is the first game-theoretic approach that studies the impact of the emergence of blockchain-based platform on the incumbent platform market.

The rest of the paper is organized as follows. In Section III, we introduce our model and two-stage dynamic game formulation. In Section IV and Section V, we describe the equilibrium analysis and show the numerical examples in Stage II and Stage I, respectively. In Section VI, we finally conclude the paper.

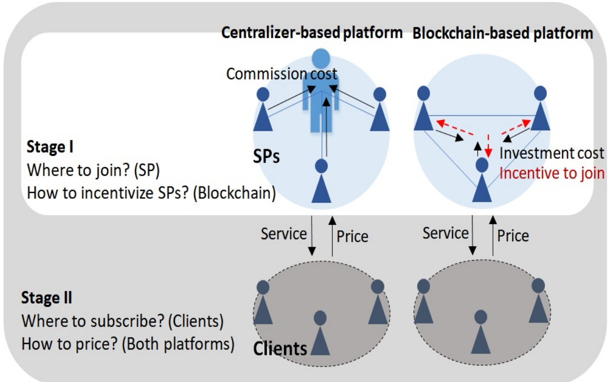


Fig. 2. Game structure among centralizer-based platform, blockchain-based platform, SPs, and clients.

III. Model and Game Formulation

A. System Model

Clients and service providers (SPs). We consider N number of clients who can subscribe to multiple services provided by SPs through a platform. There is a set $\mathcal{S} = \{1, 2, \ldots, S\}$ of S services where each service $s \in \mathcal{S}$ can be provided by $\rho_s N$ number of SPs. We assume that each SP serves a single service and the total number of SPs is less than or equal to that of clients, i.e., $\sum_{s\in\mathcal{S}} \rho_s \leq 1$. Then, each SP chooses a platform to deliver its service to clients and each client also decides to subscribe services and corresponding platforms.

Platforms. We consider two types of service platforms which are (i) a centralizer-based platform and (ii) a blockchain-based platform. Both types of platforms provide software/hardware infrastructure to guarantee service performance, security, irreversibility, and trustfulness under which SPs deliver their services to clients. For a service s, a platform in $\mathcal{A} = \{n, c, b\}$ sets a service price p_s^α, $\alpha \in \mathcal{A}$ to clients, where we use 'n','c' and 'b' to refer a selection of no-service, centralizer-based platform, and blockchain-based platform, respectively. Thus, a client pays zero price if it chooses no-service. In the centralizer-based platform, a centralizer owns the infrastructure and thus is paid commissions τ_s^c to SPs. The blockchain-based platform supports a decentralized infrastructure among SPs in which SPs spend the investment cost τ_s^b and get the participation incentive e_s.

Quality of service depending on platforms. Let $\lambda_s^b(\rho_s^b)$ be the quality of service $s \in \mathcal{S}$ of the blockchain-based platform, where ρ_s^b implies the level of SPs' participation for service s through the blockchain-based platform. We denote by $\lambda_s^c(\rho_s^c)$ the centralizer-based platform's quality of service s, which is proportional to the level of SPs' participation on the centralizer-based platform, ρ_s^c.

B. Two-stage Dynamic Platform Game

In this section, we introduce our game model for understanding how SPs and clients interplay for providing and consuming service through two types of platforms not only under the competitive relationship between SPs and clients but also under that between centralizer-based platform and blockchain-based platform. To this end, we present a two-stage dynamic platform game in which three types of players (i.e., platforms, SPs, and clients) interplay sequentially.

Utility of clients. We first introduce a utility function of client subscribing service $s \in \mathcal{S}$, $u_s : \mathcal{A} \times \mathbb{R}^2 \mapsto \mathbb{R}$ is defined by:

$$u_s(\alpha, \boldsymbol{p}_s; \theta) = \begin{cases} 0, & \text{if } \alpha = \text{`}n\text{'}, \\ \theta\lambda_s^c(\rho_s^c) - p_s^c, & \text{if } \alpha = \text{`}c\text{'}, \\ \theta\lambda_s^b(\rho_s^b) - p_s^b, & \text{if } \alpha = \text{`}b\text{'}, \end{cases} \tag{1}$$

where the price vector for service s is $\boldsymbol{p}_s = \{p_s^c, p_s^b\}$. To model heterogeneity of clients, we assume that the clients have different willingness to pay θ, where θ is a uniformly random value over the interval $[0, 1]$ as popularly modeled in e.g., [19]. It means that a client with a smaller θ prefers a lower QoS than the one with a higher θ. We assume that the QoS of blockchain-based platform λ_s^b increases with proportional to the level of SPs' participation ρ_s^b, where the QoS depends on security, irreversibility, and trustfulness. One may think that this assumption is controversial since the public blockchain sometimes has a performance limitation in terms of scalability and transaction per second (TPS). However, our focus is on a blockchain-based platform among companies, e.g., consortiums, which can guarantee a non-decreasing performance in terms of scalability and TPS by adopting a permissioned blockchain. Furthermore, the centralizer is assumed to provide a consistent QoS to their subscribers, thus we model the centralizer-based platform's QoS λ_s^c is not proportional to the level of SPs' participation ρ_s^c but a constant.

Utility of SPs. An SP's utility function for platform selection $v_s : \mathcal{A}\backslash\{n\} \times \mathbb{R} \mapsto \mathbb{R}$ with service $s \in \mathcal{S}$ is written by:

$$v_s(\beta, e_s; \gamma) = \begin{cases} 0, & \text{if } \beta = \text{`}c\text{'}, \\ e_s - \gamma\tau_s^b + \tau_s^c, & \text{if } \beta = \text{`}b\text{'}, \end{cases} \tag{2}$$

where SPs' heterogeneous willingness to invest on blockchain-based platform is modeled by γ, which is assumed to be a uniformly random value over interval $[0, 1]$. It means that an SP with smaller γ prefers a lower investment cost than the one with a larger γ. An SP serving $s \in \mathcal{S}$ with willingness to pay γ decides a platform in $\beta \in \mathcal{A}\backslash\{n\}$ to deliver its service to clients. We assume that the SPs' utility under the centralizer-based platform is zero as a baseline, and an SP gains the participation incentive e_s and saves the commission cost τ_s^c under the blockchain-based platform. Moreover, the investment cost τ_s^b is assumed to be larger than the commission cost τ_s^c.

Revenue based on platforms. For a service $s \in \mathcal{S}$, each platform earns its net-revenue $\pi_s(\cdot)$ depending on the strategies of three types of players (i.e., platforms, SPs and clients), thus the net-revenue is expressed as:

$$\pi_s(\alpha, \beta, \boldsymbol{p}_s, e_s) : \mathcal{A} \times \mathcal{A}\backslash\{n\} \times \mathbb{R}^2 \times \mathbb{R} \mapsto \mathbb{R}.$$

Due to clients' heterogeneous willingness to pay, given $\boldsymbol{p}_s$, three different continuous intervals $\Theta_s^\alpha(\boldsymbol{p}_s) \subseteq [0,1]$, for all $\alpha \in \mathcal{A}$, are defined where each interval Θ_s^α corresponds to the market share of a platform α for service $s \in \mathcal{S}$. In similar, because of SPs' difference in willingness to invest, given e_s, two different continuous interval $\Gamma_s^\beta(e_s) \subseteq [0,1]$, for all $\beta \in \mathcal{A}\backslash\{n\}$, are defined where interval Γ_s^β corresponds to the SPs' participation degree of a platform β for service $s \in \mathcal{S}$. Then, the revenue based a platform β of the service $s \in \mathcal{S}$ is given by:

$$\pi_s(\beta,\cdot) = \begin{cases} p_s^c N \int_0^1 \mathbf{1}_{\{\theta \in \Theta_s^c(\boldsymbol{p}_s)\}} d\theta, & \text{if } \beta = \text{`}c\text{'}, \\ p_s^b N \int_0^1 \mathbf{1}_{\{\theta \in \Theta_s^b(\boldsymbol{p}_s)\}} d\theta - e_s \rho_s^b N, & \text{if } \beta = \text{`}b\text{'}, \end{cases} \tag{3}$$

where we denote by $\rho_s^\beta \triangleq \rho_s \cdot \int_0^1 \mathbf{1}_{\{\gamma \in \Gamma_s^\beta(e_s)\}} d\gamma$ for all $\beta \in \mathcal{A}\backslash\{n\}$ the level of SPs' participation for service s through the platform $\beta \in \mathcal{A}\backslash\{n\}$. Then, the net-revenue of platform β over the services in $\mathcal{S}$ is given by $\pi(\beta,\cdot) = \sum_{s\in\mathcal{S}} \pi_s(\beta,\cdot)$, for all $\beta \in \mathcal{A}\backslash\{n\}$. We now introduce a more detailed description of our two-stage dynamic platform game, which is described in Fig. 2.

Two-stage Dynamic Platform Game

Stage I: Incentivizing SPs and platform selection of SPs. Blockchain-based platform, as a leader, sets a participation incentive vector $\boldsymbol{e} = [e_s]_{s\in\mathcal{S}}$ for incentivizing SPs, then each SP serving a service $s \in \mathcal{S}$ with the willingness to invest γ chooses a platform between 'b' and 'c' as follows.

- `Step 1.` Blockchain-based platform sets an incentive vector $\boldsymbol{e}^\star$ maximizing the net-revenue under his platform, i.e.,

$$\boldsymbol{e}^\star = \arg\max_{\boldsymbol{e}} \pi(b,\cdot).$$

- `Step 2.` Each SP providing a service s chooses a platform β maximizing its utility function, i.e.,

$$\beta_s^\star(\gamma) = \arg\max_{\beta\in\mathcal{A}\backslash\{n\}} v_s(\beta, e_s; \gamma),\ \forall s \in \mathcal{S}.$$

Stage II: Pricing for clients and platform selection of clients. Platforms decide their prices $\boldsymbol{p}^c = [p_s^c]_{s\in\mathcal{S}}$ and $\boldsymbol{p}^b = [p_s^b]_{s\in\mathcal{S}}$ for selection of clients over all services $s \in \mathcal{S}$. Then, each client with the willingness to pay θ selects a platform or no-service for each service in $\mathcal{S}$.

- `Step 1.` Each platform β sets price vector $\boldsymbol{p}^\beta$ maximizing the net-revenue under his platform, i.e.,

$$(i) \quad \boldsymbol{p}^{c,\star} = \arg\max_{\boldsymbol{p}^c} \pi(c,\cdot), \quad \text{if } \beta = \text{`}c\text{'},$$

$$(ii) \quad \boldsymbol{p}^{b,\star} = \arg\max_{\boldsymbol{p}^b} \pi(b,\cdot), \quad \text{if } \beta = \text{`}b\text{'}.$$

- `Step 2.` Each client subscribing service s selects a platform β or no-service maximizing its utility functions, i.e.,

$$\alpha_s^\star(\theta) = \arg\max_{\alpha\in\mathcal{A}} u_s(\alpha, \boldsymbol{p}_s; \theta),\ \forall s \in \mathcal{S}.$$

In the following section, we present the equilibrium analysis conducted by the backward induction, which is a standard tool for computing the equilibrium of sequential game. Therefore, our analysis starts from Step 2 in Stage II, in which we describe how each client selects a platform for given price vectors $\boldsymbol{p}^c$ and $\boldsymbol{p}^b$, followed by the price selection of platforms at Step 1 in Stage II.

IV. Interaction between Platforms and Clients: Pricing and Platform Selection

In this section, we first focus on the interaction between platforms and clients in Stage II. Each platform delivers the platform-based services provided by SPs to clients with corresponding QoS, which depends on the participation level of SPs. Assuming that the participation level of SPs is given from Stage I, then the QoS of platforms for a service $s \in \mathcal{S}$ can be divided into two regimes under the following condition `C0`:

$$\texttt{C0:} \quad \lambda_s^b(\rho_s^b) \geq \lambda_s^c(\rho_s^c). \tag{4}$$

`R1` corresponds to *blockchain-preferred regime*, under which the condition `C0` holds and the blockchain-based platform provides more qualitative service than the centralizer-based platform. In similar, `R2` refers *centralizer-preferred regime*, under which the condition `C0` does not hold.

A. Equilibrium Analysis of Stage II

The following Proposition IV.1 states when each client selects which platforms under what conditions.

Proposition IV.1 (*Step 2 in Stage II*)**.** *Consider a service $s \in \mathcal{S}$, then the platform selection of a client with the willingness to pay θ at the equilibrium is given by:*

`R1.` *Blockchain-preferred regime.*

$$\alpha_s^\star(\theta) = \begin{cases} c, & \text{if } \frac{p_s^c}{\lambda_s^c(\rho_s^c)} < \theta \leq \frac{p_s^b - p_s^c}{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}, \\ b, & \text{if } \theta > \frac{p_s^b - p_s^c}{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}, \\ n, & \text{otherwise.} \end{cases} \tag{5}$$

`R2.` *Centralizer-preferred regime.*

$$\alpha_s^\star(\theta) = \begin{cases} c, & \text{if } \theta > \frac{p_s^c - p_s^b}{\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)}, \\ b, & \text{if } \frac{p_s^b}{\lambda_s^b(\rho_s^b)} < \theta \leq \frac{p_s^c - p_s^b}{\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)}, \\ n, & \text{otherwise.} \end{cases} \tag{6}$$

Proof. Consider a service $s \in \mathcal{S}$ under blockchain-preferred regime satisfying the condition `C0`, i.e.,

$$\lambda_s^b(\rho_s^b) \geq \lambda_s^c(\rho_s^c).$$

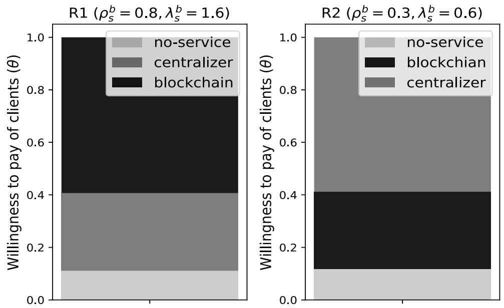


Fig. 3. Clients' platform selection at the equilibrium in each regime.

From the definition of clients' utility (1), a client with willingness to pay θ will choose the blockchain-based platform, i.e., $\alpha_s^\star(\theta) = b$, if the following holds:

$$\theta\lambda_s^b(\rho_s^b) - p_s^b > \theta\lambda_s^c(\rho_s^c) - p_s^c,$$

or

$$\theta > \frac{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}{p_s^b - p_s^c}.$$

Otherwise, a client with θ will utilize the centralizer-based platform, i.e., $\alpha_s^\star(\theta) = c$, if it brings her a positive utility, i.e.,

$$\theta\lambda_s^c(\rho_s^c) - p_s^c > 0, \text{ or } \theta > \frac{p_s^c}{\lambda_s^c(\rho_s^c)}.$$

Therefore, the platform selection of a client with the willingness to pay θ at the equilibrium under blockchain-preferred regime is obtained as (5). Similarly, we can get the equilibrium behavior of a client under the centralizer-based platform as (6). □

Note that the result in (5) and (6) leads to the market share of each platform. Thus, it is easy to see the market shares of platforms for each service $s \in \mathcal{S}$ as follows:

R1. $\Theta_s^c = \big(\frac{p_s^c}{\lambda_s^c(\rho_s^c)}, \frac{p_s^b - p_s^c}{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}\big]$, $\Theta_s^b = \big(\frac{p_s^b - p_s^c}{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}, 1\big]$,
R2. $\Theta_s^c = \big(\frac{p_s^c - p_s^b}{\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)}, 1\big]$, $\Theta_s^b = \big(\frac{p_s^b}{\lambda_s^b(\rho_s^b)}, \frac{p_s^c - p_s^b}{\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)}\big]$.

This implies that the platform providing a higher QoS can attract the clients who have a larger willingness to pay θ. The following Proposition IV.2 states the equilibrium price vectors setting by platforms over all services in $\mathcal{S}$.

Proposition IV.2 (*Step 1 in Stage II*)**.** *Platforms set the equilibrium price vectors as follows:*

R1. *Blockchain-preferred regime.*

$$\boldsymbol{p}^{c,\star} = \Big[\frac{\lambda_s^c(\rho_s^c)\big\{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)\big\}}{4\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}\Big]_{s\in\mathcal{S}},$$
$$\boldsymbol{p}^{b,\star} = \Big[\frac{2\lambda_s^b(\rho_s^b)\big\{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)\big\}}{4\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}\Big]_{s\in\mathcal{S}}. \tag{7}$$

R2. *Centralizer-preferred regime.*

$$\boldsymbol{p}^{c,\star} = \Big[\frac{2\lambda_s^c(\rho_s^c)\big\{\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)\big\}}{4\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)}\Big]_{s\in\mathcal{S}},$$
$$\boldsymbol{p}^{b,\star} = \Big[\frac{\lambda_s^b(\rho_s^b)\big\{\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)\big\}}{4\lambda_s^c(\rho_s^c) - \lambda_s^b(\rho_s^b)}\Big]_{s\in\mathcal{S}}. \tag{8}$$

Proof. By backward induction, we first derive the equilibrium of clients' platform selection at the Step 2 of the Stage II in Proposition IV.1. Here, we provide the equilibrium analysis at the Step 1 of the Stage II. Consider a service $s \in \mathcal{S}$ under blockchain-preferred regime. The blockchain-based platform decides the price vector $\boldsymbol{p}^b$ to maximize the net-revenue, i.e.,

$$\boldsymbol{p}^{b,\star} = \arg\max_{\boldsymbol{p}^b} \pi(b,\cdot).$$

The blockchain-based platform's revenue of service $s \in \mathcal{S}$ defined by (3) can be rewritten by:

$$\begin{aligned}\pi_s(b,\cdot) &= p_s^b N \int_0^1 \mathbf{1}_{\{\theta\in\Theta_s^b(\boldsymbol{p}_s)\}} d\theta - e_s\rho_s^b N,\\ &= N\Big\{p_s^b\big(1 - \frac{p_s^b - p_s^c}{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}\big) - e_s\rho_s^b\Big\},\end{aligned}$$

where we assume that the participation level of SPs ρ_s^β for each platform $\beta \in \{b, c\}$ is given from Stage I. Then, the net-revenue $\pi(b,\cdot) = \sum_s \pi_s(b,\cdot)$ is strictly concave function with respect to the positive pricing strategy $\boldsymbol{p}^b > \mathbf{0}$, since the Hessian of $\pi(b,\cdot)$ is negative definite, which is given by the negative diagonal matrix, i.e.,

$$\frac{\partial^2\pi(b,\cdot)}{\partial {p_s^b}^2} < 0 \text{ and } \frac{\partial^2\pi(b,\cdot)}{\partial p_s^b \partial p_t^b} = 0, \quad \forall s,t\in\mathcal{S}, s\neq t.$$

Similarly, the centralizer-based platform's net-revenue is also strictly concave function with respect to the positive pricing policy $\boldsymbol{p}^c > \mathbf{0}$, since the Hessian of $\pi(c,\dot)$ is negative definite, which is given by the negative diagonal matrix, i.e.,

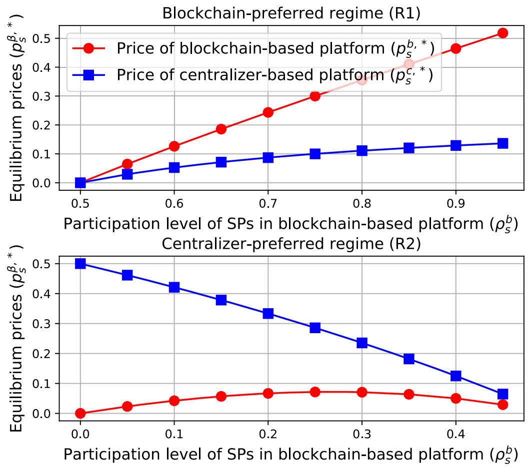
$$\frac{\partial^2\pi(c,\cdot)}{\partial {p_s^c}^2} < 0 \text{ and } \frac{\partial^2\pi(c,\cdot)}{\partial p_s^c \partial p_t^c} = 0, \quad \forall s,t\in\mathcal{S}, s\neq t.$$

Therefore, we can find a unique equilibrium $\boldsymbol{p}^\star = (\boldsymbol{p}^{b,\star}, \boldsymbol{p}^{c,\star})$ in (7) satisfying:

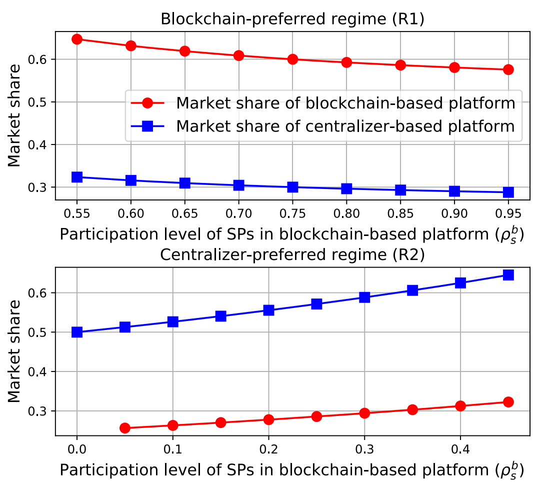
$$\frac{\partial\pi(b,\cdot)}{\partial p_s^b}(\boldsymbol{p}^\star) = 0 \text{ and } \frac{\partial\pi(c,\cdot)}{\partial p_s^c}(\boldsymbol{p}^\star) = 0,$$

for all $s \in \mathcal{S}$. Similarly, we can get the equilibrium price vectors under centralizer-preferred regime, thus we omit it. □

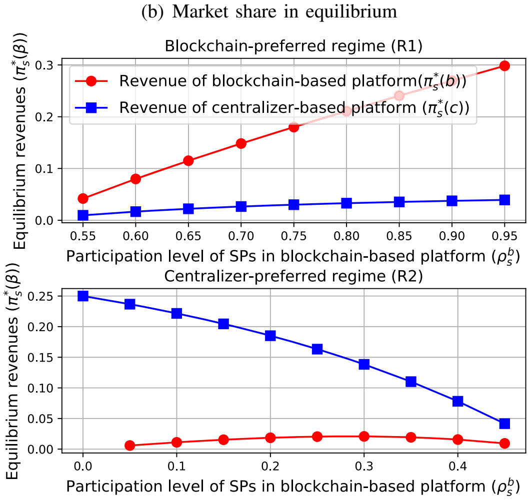
Proposition IV.2 implies that the platform who offers a higher QoS can set a higher equilibrium price, which is more than or equal to twice of the other's one. We note that the equilibrium prices highly depend on the QoS of platforms, which is a function of the participation level of SPs on each platform.



(a) Price in equilibrium



(b) Market share in equilibrium



(c) Revenue in equilibrium

Fig. 4. Impact of participation level of SPs in blockchain-based platform. We choose $|\mathcal{S}| = 1$, $\lambda_s^b(\rho_s^b) = 2\rho_s^b$, $\lambda_s^c(\rho_s^c) = 1$.

B. Numerical Analysis: Impact of Platform's QoS

We now illustrate numerical analysis that highlights the impact of the platform's QoS function with respect to the SPs' participation level on the equilibrium behavior of clients and platforms. To this end, we further assume that the incentive $\boldsymbol{e} = \mathbf{0}$ to focus on the analysis in Stage II of our two-stage dynamic platform game. We consider a single service $|\mathcal{S}| = 1$, where the centralizer-based platform provides a constant QoS with respect to the SPs' participation level and the blockchain-based platform's QoS linearly increases with the SPs' participation level, thus we respectively assume that $\lambda_s^c(\rho_s^c) = 1$ and $\lambda_s^b(\rho_s^b) = 2\rho_s^b$. Therefore, the platform market will be under blockchain-preferred regime if $\rho_s^b > 0.5$ and under centralizer-preferred regime if $\rho_s^b < 0.5$.

Impact on clients' platform selection. Fig. 3 describes that clients' platform selection at the equilibrium under each regime. Under `R1`, the blockchain-based platform providing a higher QoS is chosen from clients with high willingness to pay for a service. Meanwhile, clients with low willingness to pay select the centralizer-based platform that delivers a service with a lower quality. Similarly, under `R2`, the high-end clients subscribe to the centralizer-based platform that serves a higher QoS whereas the low-end clients choose the blockchain-based platform. Moreover, under both regime, the clients with extremely low willingness to pay do not use the service.

Impact on pricing policy for clients. Fig. 4(a) shows that each platform's equilibrium pricing policy $p_s^{\beta,\star}$ with respect to the participation level of SPs in blockchain-based platform ρ_s^b. Under `R1`, the blockchain-based platform can set a higher price than the other's pricing policy. This implies that the blockchain-based platform has a larger market power than the centralizer-based platform and a higher QoS results in a higher equilibrium price. Similarly, under `R2`, a higher QoS also brings about a higher equilibrium price of the centralizer-based platform. However, under both regime, the equilibrium prices of both platforms become zero at the point where the platforms provide homogeneous QoS, i.e., $\lambda_s^b = \lambda_s^c = 1$, due to the perfect competition.

Impact on market share and revenue. Fig. 4(b) and 4(c) depict market shares and revenues at the equilibrium, respectively. Under `R1`, the market share tends to decrease as the level of SPs' participation in blockchain-based platform because the increase of SPs' participation level causes the increase of blockchain-based platform's QoS and of the equilibrium price. Similarly, the market share grows as the level of SPs' participation under `R2`, since the equilibrium price declines. Moreover, under both regime, a higher QoS platform has a larger market power thus gets more market share in the platform market. Consequently, the equilibrium revenue with respect to the participation level of SPs as shown in Fig. 4(c) has a similar tendency to the equilibrium price depicted in Fig. 4(a), since the increase (or decrease) slope of price is steeper than the decrease (or increase) slope of market share as the increase of SPs' participation level.

V. Interaction between Platforms and SPs: Incentivizing and Platform Selection

We now aim at understanding how the blockchain-based platform's incentive vector $\boldsymbol{e}$ globally affects on the equilibrium behavior of three players (i.e., platforms, SPs, and clients). According to the backward induction, we first explain how each SP chooses a platform to deliver its service with a given incentive vector $\boldsymbol{e}$ in Step 2 analysis, where the incentive is determined by the blockchain-based platform in Step 1.

A. Equilibrium Analysis of Stage I

Proposition V.1 states that the platform selection of each SP with the preference on investment cost γ at the equilibrium.

Proposition V.1 (*Step 2 in Stage I*)**.** *Consider a service $s \in \mathcal{S}$, then the platform selection of a SP with the willingness to invest for the blockchain γ at the equilibrium is given as follows:*

$$\beta_s^\star(\gamma) = \begin{cases} c, & \text{if } \gamma \geq \frac{e_s+\tau_s^c}{\tau_s^b}, \\ b, & \text{otherwise,} \end{cases} \tag{9}$$

where $-\tau_s^c < e_s \leq \tau_s^b - \tau_s^c$.

Proof. Consider a SP providing a service $s \in \mathcal{S}$ with willingness to invest on blockchain-based platform γ. The SP will choose a platform to maximize her utility defined in (2), thus she will select the blockchain-based platform, i.e., $\beta_s^\star(\gamma) = b$, if the following holds:

$$e_s - \gamma\tau_s^b + \tau_s^c > 0 \text{ or } \gamma < \frac{e_s + \tau_s^c}{\tau_s^b}.$$

Otherwise, a SP with γ will use the centralizer-based platform to provide a service $s \in \mathcal{S}$ to clients. □

The level of SPs' participation on each platform for a service $s \in \mathcal{S}$, the important factor that determines the platform's QoS function, is induced by the result in (9):

$$\begin{aligned} \rho_s^b &= \rho_s \cdot \int_0^1 \mathbf{1}_{\{\gamma < \frac{e_s+\tau_s^c}{\tau_s^b}\}} d\gamma = \frac{\rho_s(e_s+\tau_s^c)}{\tau_s^b}, \\ \rho_s^c &= \rho_s \cdot \int_0^1 \mathbf{1}_{\{\gamma \geq \frac{e_s+\tau_s^c}{\tau_s^b}\}} d\gamma = \frac{\rho_s(\tau_s^b - e_s - \tau_s^c)}{\tau_s^b}, \end{aligned} \tag{10}$$

where the SPs' participation degree of each platform is given by: $\Gamma_s^b = \big[0, \frac{e_s+\tau_s^c}{\tau_s^b}\big)$ and $\Gamma_s^c = \big[\frac{e_s+\tau_s^c}{\tau_s^b}, 1\big]$, for all service $s \in \mathcal{S}$. Moreover, we have the range of incentive as $e_s < \tau_s^b - \tau_s^c$ and $e_s > -\tau_s^c$, which makes a larger utility of SP under the blockchain-based platform than the one under the centralizer-based platform. Then, we finally find the overall equilibrium of our two-stage dynamic platform game by analyzing the Step 1 in Stage I, which is on the procedure of the backward induction.

Theorem V.1. *The unique equilibrium incentive vector $\boldsymbol{e}^\star$ under each regime is given as follows:*

`R1`. *Under blockchain-preferred regime, for each $s \in \mathcal{S}$, $e_s^\star$ is a unique real solution of following equation:*

$$\frac{4\lambda_s^b(4(\lambda_s^b)^2 - 3\lambda_s^b\lambda_s^c + 2(\lambda_s^c)^2)}{(4\lambda_s^b - \lambda_s^c)^3} \cdot \frac{\partial \lambda_s^b}{\partial e_s} = \frac{\rho_s(2e_s + \tau_s^c)}{\tau_s^b},$$

if the following condition `C1` holds:

$$\texttt{C1:} \quad \frac{4\lambda_s^b\big(4(\lambda_s^b)^2 - 3\lambda_s^b\lambda_s^c + 2(\lambda_s^c)^2\big)}{(4\lambda_s^b - \lambda_s^c)^3} \cdot \frac{\partial^2 \lambda_s^b(e_s)}{\partial e_s^2} - \frac{8\lambda_s^c(5\lambda_s^b + \lambda_s^c)}{(4\lambda_s^b - \lambda_s^c)^4} \cdot \frac{\partial \lambda_s^b}{\partial e_s} - 2\frac{\rho_s}{\tau_s^b} \leq 0,$$

where $-\tau_s^c < e_s < \tau_s^b - \tau_s^c$.

`R2`. *Under centralizer-preferred regime, for each $s \in \mathcal{S}$, $e_s^\star$ is a unique real solution of following equation:*

$$\frac{\lambda_s^c(4(\lambda_s^c)^2 - 8\lambda_s^c\lambda_s^b + (\lambda_s^b)^2)}{(4\lambda_s^c - \lambda_s^b)^2} \cdot \frac{\partial \lambda_s^b}{\partial e_s} = \frac{\rho_s(2e_s + \tau_s^c)}{\tau_s^b},$$

if the following condition `C2` holds:

$$\texttt{C2:} \quad \frac{\lambda_s^c(4(\lambda_s^c)^2 - 8\lambda_s^c\lambda_s^b + (\lambda_s^b)^2)}{(4\lambda_s^c - \lambda_s^b)^2} \cdot \frac{\partial^2 \lambda_s^b}{\partial e_s^2} - \frac{24\lambda_s^c}{(4\lambda_s^c - \lambda_s^b)^3} \cdot \frac{\partial \lambda_s^b}{\partial e_s} - \frac{2\rho_s}{\tau_s^b} \leq 0,$$

where $-\tau_s^c < e_s < \tau_s^b - \tau_s^c$.

Note that the QoS of the blockchain-based platform is a function of incentive, i.e., $\lambda_s^b(\rho_s^b) = \lambda_s^b(\frac{\rho_s(e_s+\tau_s^c)}{\tau_s^b})$ and $\lambda_s^c(\rho_s^c)$ is assumed to be a constant, i.e., $\frac{\partial \lambda_s^c}{\partial e_s} = 0, \forall s \in \mathcal{S}$. Then, we provide the general form of the unique equilibrium price vector $\boldsymbol{p}^{\beta,\star}$ and the corresponding net-revenue $\pi^\star(\beta,\cdot)$ for all $\beta \in \mathcal{A}\backslash\{n\}$ in Table I.

Proof. By backward induction, we have shown the equilibrium analysis of the Stage II and that of the Step 2 of the Stage I, sequentially. Now, we provide the equilibrium analysis at the Step 1 of the Stage I for blockchain-preferred regime. The blockchain-based platform sets the incentive vector $\boldsymbol{e}$ to maximize the net-revenue, i.e.,

$$\boldsymbol{e}^\star = \arg\max_{\boldsymbol{e}} \pi(b,\cdot).$$

The blockchain-based platform's revenue of service $s \in \mathcal{S}$ defined by (3) can be rewritten by:

$$\begin{aligned} \pi_s(b,\cdot) &= p_s^b N \int_0^1 \mathbf{1}_{\{\theta \in \Theta_s^b(\boldsymbol{p}_s)\}} d\theta - e_s\rho_s^b N, \\ &= N\Big\{p_s^b\big(1 - \frac{p_s^b - p_s^c}{\lambda_s^b(\rho_s^b) - \lambda_s^c(\rho_s^c)}\big) - e_s\rho_s^b\Big\}, \\ &= N\Big\{\frac{2\lambda_s^b(\lambda_s^b - \lambda_s^c)}{4\lambda_s^b - \lambda_s^c}\Big(1 - \frac{(2\lambda_s^b - \lambda_s^c)(\lambda_s^b - \lambda_s^c)}{(4\lambda_s^b - \lambda_s^c)^2}\Big) \\ &\quad - \frac{e_s\rho_s(e_s + \tau_s^c)}{\tau_s^b}\Big\}, \end{aligned}$$

TABLE I

THEOREM V.1. EQUILIBRIUM PRICE VECTORS AND CORRESPONDING NET-REVENUES UNDER EACH REGIME

R1. *Blockchain-preferred regime.*

$$p_s^{c,\star} = \frac{\lambda_s^c\big(\lambda_s^b(e_s^\star) - \lambda_s^c\big)}{4\lambda_s^b(e_s^\star) - \lambda_s^c},\ p_s^{b,\star} = \frac{2\lambda_s^b\big(\lambda_s^b(e_s^\star) - \lambda_s^c\big)}{4\lambda_s^b(e_s^\star) - \lambda_s^c},$$

$$\pi^\star(c,\cdot) = \sum_{s\in\mathcal{S}} \pi_s^\star(c,\cdot) = N\sum_{s\in\mathcal{S}}\left[\frac{\lambda_s^b(e_s^\star)\lambda_s^c\big(\lambda_s^b(e_s^\star)-\lambda_s^c\big)}{\big(4\lambda_s^b(e_s^\star)-\lambda_s^c\big)^2}\right],$$

$$\pi^\star(b,\cdot) = \sum_{s\in\mathcal{S}} \pi_s^\star(b,\cdot) = N\sum_{s\in\mathcal{S}}\left[\frac{4(\lambda_s^b(e_s^\star))^2\big(\lambda_s^b(e_s^\star)-\lambda_s^c\big)}{\big(4\lambda_s^b(e_s^\star)-\lambda_s^c\big)^2} - e_s^\star\rho_s\frac{e_s^\star+\tau_s^c}{\tau_s^b}\right].$$

R2. *Centralizer-preferred regime.*

$$p_s^{c,\star} = \frac{2\lambda_s^c\big(\lambda_s^c - \lambda_s^b(e_s^\star)\big)}{4\lambda_s^c - \lambda_s^b(e_s^\star)},\ p_s^{b,\star} = \frac{\lambda_s^b(e_s^\star)\big(\lambda_s^c - \lambda_s^b(e_s^\star)\big)}{4\lambda_s^c - \lambda_s^b(e_s^\star)},$$

$$\pi^\star(c,\cdot) = \sum_{s\in\mathcal{S}} \pi_s^\star(c,\cdot) = \sum_{s\in\mathcal{S}}\left[\frac{4(\lambda_s^c)^2\big(\lambda_s^c-\lambda_s^b(e_s^\star)\big)}{\big(4\lambda_s^c-\lambda_s^b(e_s^\star)\big)^2}\right],$$

$$\pi^\star(b,\cdot) = \sum_{s\in\mathcal{S}} \pi_s^\star(b,\cdot) = \sum_{s\in\mathcal{S}}\left[\frac{\lambda_s^b(e_s^\star)\lambda_s^c\big(\lambda_s^c-\lambda_s^b(e_s^\star)\big)}{\big(4\lambda_s^c-\lambda_s^b(e_s^\star)\big)^2} - e_s^\star\rho_s\frac{e_s^\star+\tau_s^c}{\tau_s^b}\right].$$

$$= N\left\{\frac{4(\lambda_s^b)^2(\lambda_s^b-\lambda_s^c)}{(4\lambda_s^b-\lambda_s^c)^2} - \frac{e_s\rho_s(e_s+\tau_s^c)}{\tau_s^b}\right\}.$$

Note that the QoS of each platform of a service s is a function of incentive e_s, for all $s \in \mathcal{S}$, but we omit e_s from the third line for simplicity. If the net-revenue of blockchain-based platform $\pi(b,\cdot) = \sum_s \pi(b,\cdot)$ is a strictly concave function with respect to the incentive mechanism $\boldsymbol{e}$, then we can get a unique equilibrium incentive $\boldsymbol{e}^\star$ satisfying:

$$\frac{\partial\pi(b,\cdot)}{\partial e_s} = 0, \quad \forall s \in \mathcal{S},$$

where $e_s < \tau_s^b - \tau_s^c$. The Hessian of $\pi(b,\cdot)$ is negative definite if the following holds:

$$\frac{\partial^2\pi(b,\cdot)}{\partial e_s^2} < 0, \text{ and } \frac{\partial^2\pi(b,\cdot)}{\partial e_s\partial e_t} = 0, \quad \forall s,t \in \mathcal{S}, s \neq t,$$

where $-\tau_s^c < e_s < \tau_s^b - \tau_s^c$ and $-\tau_t^c < e_t < \tau_t^b - \tau_t^c$. Therefore, under the condition C1, the above condition is met thus a unique equilibrium incentive $\boldsymbol{e}^\star$ can be obtained as Theorem V.1. Sequentially, we can readily drive the general form of the unique equilibrium price vector $\boldsymbol{p}^{\beta,\star}$ and the corresponding net-revenue $\pi^\star(\beta,\cdot)$, for all $\beta \in \mathcal{A} \setminus \{n\}$. Similarly, we can get the equilibrium incentive, price and corresponding revenue under centralizer-preferred regime, thus we omit it. □

Theorem V.1 provides the equilibrium of our two-stage dynamic platform game. It reveals how much the incentive policy $\boldsymbol{e}^\star$ sequentially impacts on the pricing strategies and the net-revenue at the equilibrium. We note that the equilibrium incentive is affected how the QoS function is designed, which captures the intrinsic structure of blockchain. Thus, we now explore the impacts of different cases of blockchain-based platform's QoS on the equilibrium state of the platform market.

B. Impact of Blockchain-based Platform's QoS on equilibrium

As shown in Proposition V.1, the blockchain-based platform's QoS depends on its incentive strategy, i.e., $\lambda_s^b(\rho_s^b) = \lambda_s^b(\frac{\rho_s(e_s+\tau_s^c)}{\tau_s^b})$, since the SPs' platform selection relies on the incentive strategy. Therefore, the equilibrium behavior of platform market can be interpreted from the function $\lambda_s^b(e_s)$.

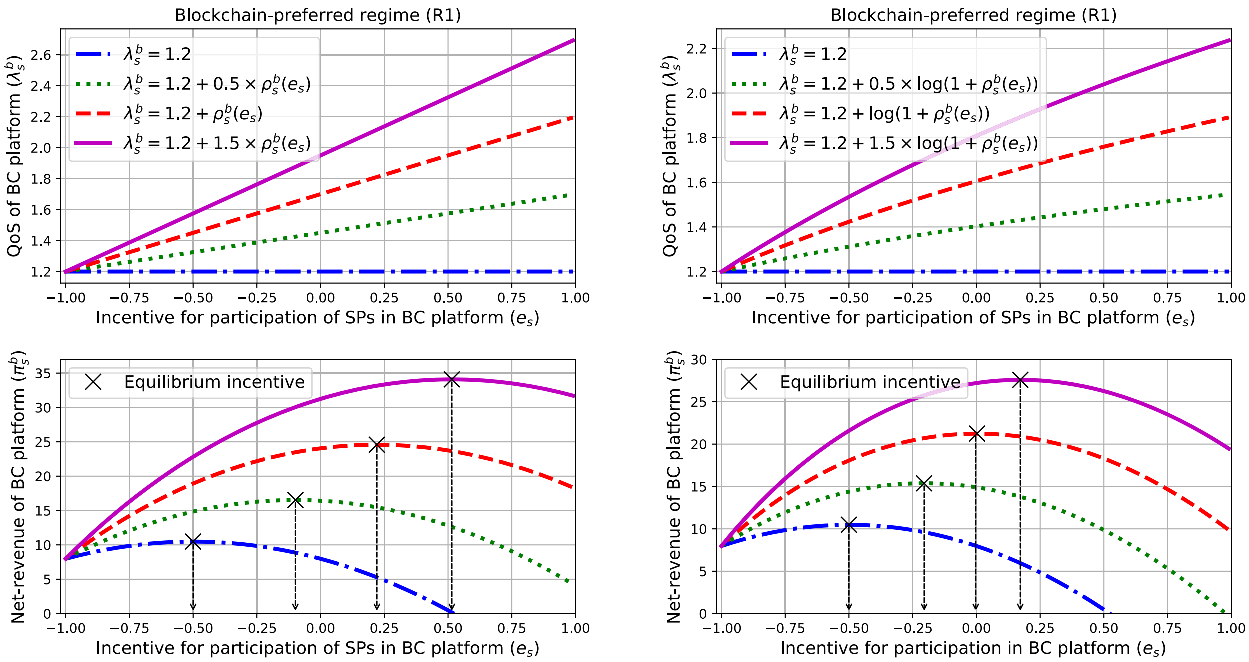
Corollary V.1. *A unique incentive $e_s^\star$ always exists for a service $s \in \mathcal{S}$, if the following condition* C3 *is met:*

$$\texttt{C3:} \quad \frac{\partial^2\lambda_s^b}{\partial e_s^2} \le 0 \quad \textit{and} \quad \frac{\partial\lambda_s^c}{\partial e_s} = 0,$$

where $-\tau_s^c < e_s < \tau_s^b - \tau_s^c$.

Proof. Recall the conditions C1 and C2. The first terms of the left-hand side of C1 and C2 become less than or equal to zero under the condition C3. Thus, the conditions C1 and C2 hold thus a unique incentive $\boldsymbol{e}^\star$ exists under both regimes. □

Corollary V.1 implies that under blockchain-preferred regime R1 with condition C3, the unique $e_s^\star$ exists and the corresponding price $p_s^{\beta,\star}$, the net-revenue $\pi_s^\star(\beta)$ for all $\beta \in \mathcal{A} \setminus \{n\}$ are also uniquely determined. The example satisfying C3 includes the case that the blockchain-based platform's QoS proportionally increases with e_s and the centralizer-based platform's QoS is a constant. We note that the equilibrium incentive $e_s^\star$ can be negative under some cases, which implies that SPs have the willingness to pay the



(a) Impact of linear QoS of blockchain-based platform. (b) Impact of logarithmic QoS of blockchain-based platform.

Fig. 5. Impact of blockchain-based platform's QoS on net-revenue and incentive at the equilibrium. We choose $|\mathcal{S}| = 1$, $\rho_s = 0.2$, $N = 100$, $\tau_s^b = 2$, $\tau_s^c = 1$, $\lambda_s^c = 1$.

incentive to the blockchain-based platform. This can be possible where the commission cost subscribing the centralizer-based platform is sufficiently higher than the investment cost using the blockchain-based platform as well as the SPs have enough willingness to pay the investment cost. The following Corollary V.2 states more extreme case in which $e_s^\star$ is always negative.

Corollary V.2. *The unique incentive is given as:*

$$e_s^\star = -\frac{\tau_s^c}{2}, \quad \forall s \in \mathcal{S},$$

if the following condition C4 *is met:*

$$\texttt{C4}: \quad \frac{\partial \lambda_s^b}{\partial e_s} = 0 \quad \textit{and} \quad \frac{\partial \lambda_s^c}{\partial e_s} = 0,$$

where $-\tau_s^c < e_s < \tau_s^b - \tau_s^c$.

Proof. Recall the condition C3. If the condition C4 holds, then the condition C3 is also met. From Theorem V.1, the unique incentive for a service $s \in \mathcal{S}$ is derived as:

$$\frac{\rho_s(2e_s^\star + \tau_s^c)}{\tau_s^b} = 0,$$

if the condition C4 holds. Then, we have $e_s^\star = -\frac{\tau_s^c}{2}$. □

The condition C4 describes the case that not only the centralizer-based platform but also the blockchain-based platform's QoS is a constant thus does not depend on how much the incentive is. In this case, the platform selection of SPs which is based on the amount of incentive does not affect the QoS of blockchain-based platform, thus it causes a negative equilibrium incentive, i.e., $e_s^\star < 0$.

C. Numerical Analysis: Impact of QoS on Incentive for SPs

In this subsection, we show numerical analysis that captures the impact of blockchain-based platform's QoS on the equilibrium incentive for SPs. We consider two types of QoS functions, one is a linear QoS function and another is a logarithmic QoS function with respect to the SPs' participation level on blockchain-based platform. We assume that a single service $|\mathcal{S}| = 1$, where the centralizer-based platform provides a constant QoS thus $\lambda_s^c = 1$.

Fig. 5(a) shows the QoS function and the corresponding net-revenue of blockchain-based platform with respect to the incentive for SPs under R1. We assume that the QoS function is linear thus given by:

$$\lambda_s^b(\rho_s^b(e_s)) = B + A \times \rho_s^b(e_s) = B + A \times \frac{\rho_s(e_s + \tau_s^c)}{\tau_s^b},$$

where $\rho_s^b(e_s)$ is induced from Proposition V.1 and we choose $B = 1.2$ and $A \in \{0, 0.5, 1, 1.5\}$. We observe that the equilibrium incentive increases with the slope of blockchain-based platform's QoS. Moreover, interestingly, the equilibrium incentive is negative if the SPs' participation in blockchain-based platform has a weak impact on the platform's quality

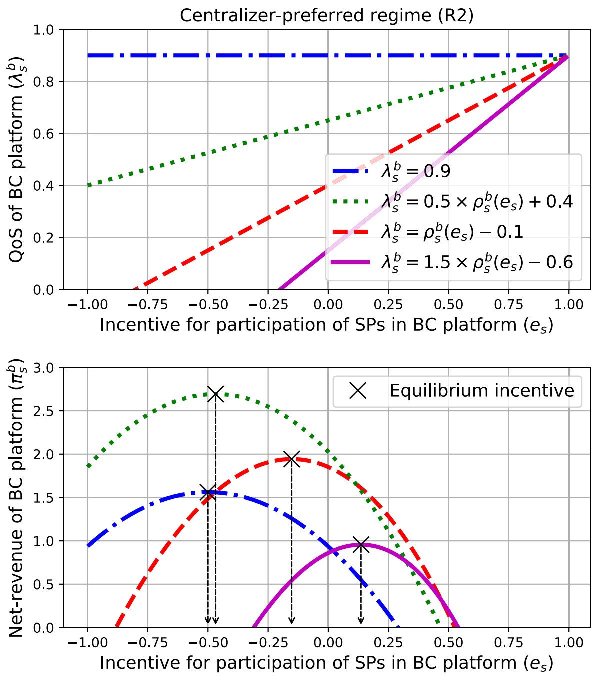


Fig. 6. Impact of blockchain-based platform's linear QoS on net-revenue and incentive at the equilibrium. We choose $|\mathcal{S}| = 1$, $\rho_s = 0.05$, $N = 100$, $\tau_s^b = 2$, $\tau_s^c = 1$, $\lambda_s^c = 1$.

of service, for example, $A = 0$ and $A = 0.5$. This implies that the equilibrium incentive is affected how much the SPs' participation contributes on the blockchain-based platform's QoS. Therefore, if the QoS logarithmically increases, then the impact of SPs' participation becomes weaker thus the incentive will decrease as shown in Fig. 5(b). In this case, the QoS is assumed to be: $\lambda_s^b(\rho_s^b) = B + A \times \log(1 + \rho_s^b(e_s))$, then the negative equilibrium incentive occurs if $A = 0, A = 0.5$, and $A = 1$. Fig. 6 captures the impact of linearly increasing QoS function of blockchain-based platform on the equilibrium incentive under R2. In this regime, the blockchain-based platform's market power is insignificant, thus the equilibrium incentive is formed at the very low value.

VI. Conclusion

We investigated a digital platform market among a blockchain-based platform, a centralizer-based platform, SPs and clients via a two-stage dynamic game. We model various features of blockchain technology such as the QoS function depending on the participated SPs and the investment cost for decentralized storage/computation. Moreover, our model captures the heterogeneities on the willingness to pay of clients and willingness to invest, which highly affect on their platform selection strategies. Our analysis includes the answers of the following key questions: (i) how SPs' participation is reflected on its QoS and (ii) how to incentivize SPs to contribute on computing/storage infrastructure. Consequently, our economic analysis provides a useful insight into the viability of blockchain-based platform against the competition with the centralizer-based platform. From the equilibrium analysis, we first show that a platform offers a higher QoS can set a higher equilibrium price and get a larger revenue. Moreover, the incentive for SPs participated in blockchain-based platform highly relies on the QoS function, thus we show when and how the QoS impacts on the incentive.

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