Platform Pricing and Blockchain Adoption for Capacity Sharing with Cross-Network Externality and Supply Risk*

Longfei He[a], Xiao Zhang[a], Baofeng Huo[a], Yang Zhang[b]

[a]*College of Management and Economics, Tianjin University, Tianjin 300072, China*

[b]*Kent Business School, University of Kent, Canterbury, Kent CT2 7NZ, UK.*

Abstract: Platform-based capacity sharing is a new business format of sharing economy to reallocate spare production resources via industrial internet, generating collaborative manufacturing related platform operations issues. This paper examines the impact of cross-network externality and supply risk of the two-sided market on the pricing and blockchain adopting decisions of capacity sharing platforms. The mean-variance model is employed to depict the impact of purchasers' or suppliers' risk-sensitive types on platform pricing, where purchasers' or suppliers' risk-sensitive types can be identified by blockchain technology and be intertwined by the cross-network externality. The obtained platform's optimal pricing under two scenarios with risk-sensitive capacity purchasers (D) and risk-sensitive suppliers (S) shows that the platform charges risk-seeking, risk-neutral and risk-averse users in descending order for the platform side containing risk-sensitive users, regardless of the comparison of bilateral cross-network externalities. However, for risk-neutral side users, the price ranking under three risk-sensitive types depends on the relative size of bilateral cross-network externalities. In addition, blockchain technology always decreases the surplus of risk-sensitive side users, whereas it increases the surplus of risk-insensitive side users. Further, we find that platform prefers to introduce blockchain technology when the fixed cost of introducing it is less than the profit increment it brings. In addition, by comparing platform profits and blockchain value in the two scenarios, we argue that platforms need to comprehensively balance the comparison of fixed costs of introducing blockchain on both sides and the importance of risk-preferring and risk-averse users to improve their profitability. Introducing blockchain technology to the side where the cost of blockchain technology is higher may result in higher blockchain value for the platform. Finally, we examine the platform with two-sided risk-sensitive users and the results are robust. This study proposes theoretical explanation for platform pricing considering the cross-network externality and risk-sensitive users, as well as some management insights for the application of blockchain technology in platform operations.

Keywords: Capacity sharing; Cross-network externality; Platform bilateral pricing; Risk sensitivity; Blockchain

---

*Contact: mspapsub@gmail.com

1 Introduction

Capacity sharing refers to an emerging format of sharing economy, promoting the development of the manufacturing industry and injecting new vitality into economic growth. Capacity sharing refers to a new economic form characterized by the access-right sharing of equipment based on the Internet platform to maximize the production efficiency of the manufacturing industry (Zhao et al., 2019). China's sharing economy market transaction scale is estimated to be around 3688.1 billion yuan in 2021, with the market scale in the field of production capacity ranking second at 1236.8 billion yuan. The vigorous development of capacity sharing is inseparable from the support of the platform. For example, the industrial Internet platform CASICloud, which provides firms with manufacturing resource matching for various production processes and products, has had over 600,000 members since 2015. Therefore, the operation and governance of capacity sharing platforms have become inescapable and important research issues.

However, platform-based capacity sharing faces many challenges, such as unreliable capacity supply exactly what we focused on. Intelligent Cloud Technology (isesol.com) informed us that capacity suppliers usually fail to deliver the contracted capacity to purchasers because of supply risks like machine breakdown and labor strike. Similarly, the key issue facing platform 1688.com currently is service stability including reliable product quality and delivery time rather than technical issues (Zhao et al., 2020). capacity supply and demand enterprises on the platform show heterogeneous sensitivity and tendency to capacity supply risks. In this context, the core issue facing the platform is how to price according to the user's risk attitude. In addition, the cross-network externalities characteristic of two-sided platforms will further complicate the above pricing issues.

Blockchain technology adopts a distributed storage architecture that preserves data completely on all nodes of the blockchain network. It has the functions of cultivating trust, establishing security systems, and achieving high system traceability and data quality. For example, FedEx uses blockchain to track high-value goods and solve payment issues, and Huawei Technologies hopes to use blockchain technology to protect privacy and security (Akter et al 2020). The blockchain technology plays a key role in platform operations, which supports Everledger's diamond authentication platform (Choi 2019), retail platform operation (Xu and He 2021) and rental service platform management by revealing product information (Choi et al., 2020a). Similarly, a blockchain-based capacity sharing platform can record, store, analyze the data of users' real transaction, identify risk attitudes and provide pricing-decision support. As a result, whether or not to adopt blockchain technology has become a critical topic for the platform to decide.

Inspired by above observations, this paper considers the capacity supply risk and cross-network externalities, and discusses the key decision-making issue of platform pricing and blockchain adoption. Therefore, this paper focuses on the following research questions: (1) How does users risk attitude affect the pricing of capacity sharing platform, supply-side and demand-side surplus, and platform owner profits? (2) How does the risk attitude of users on one side of the platform affect the pricing of users on the other side through cross-network externalities? How does the relative size of cross-network externality parameters of the supply and demand sides affect platform pricing? (3) What is the impact of blockchain investment decisions on platform profits and bilateral user surplus, considering the identification of users' risk-sensitive types and the interaction between platform pricing and the introduction of this technology?

The results suggest that when users are risk-seeking, the platform will charge the highest membership fee, followed by the risk-neutral case, and finally the risk-averse case, regardless of the relative size of bilateral cross-network externalities. However, the relative size of the usage fee for the risk-insensitive side users under the three risk-sensitive types depends on the relative size of bilateral cross-network externalities. In addition, blockchain technology benefits the surplus of risk-insensitive side users while it hurts the surplus of risk-sensitive side users. Intuitively, the platform is willing to introduce blockchain technology only when this action generates profit no less than its cost. Further, platforms should weigh the relative size of the fixed costs introduced by bilateral blockchains and the importance of risk-seeking and risk-averse users in the market to maximize benefits. In addition, the platform may obtain higher blockchain value by introducing blockchain technology to the side where the cost of blockchain technology is higher.

Our study contributes in several aspects. First, compared with the fact that few of existing literature pays attention to the capacity supply risk of the platform, this paper focuses on how the user's sensitive attitude to the capacity supply risk affects the platform pricing. Second, this paper reveals how one side's users' risk-sensitive attitudes affect the other side's pricing through cross-network externality. This paper discusses and compares the decision and value of introducing blockchain technology in diverse situations, and provides theoretical support for the application of blockchain technology in platform operation.

The remainder of this paper is organized as follows. We present the literature review in Section 2. Sections 3 states that the optimal pricing strategies of the platform under Scenario D with partial risk-sensitive purchasers and Scenario S with partial risk-sensitive suppliers, respectively. We compare the optimal decisions under the two scenarios in Section 5. The scenario having risk-sensitive users in two sides of the platform is discussed in Section 6. Concluding remarks come in Section 7.

2 Literature Review

The literature related to our study contains four research streams, i.e., capacity sharing, supply reliability, platform pricing, and blockchain-driven platform operations.

Our study is related to the literature of capacity sharing. The initial research on capacity sharing mainly focuses on capacity sharing within the enterprise alliance (Renna and Argoneto

2011, Yoon and Nof 2011, Seok and Nof 2014a, Seok and Nof 2014b and Moghaddam and Nof 2016). Later, researchers began to focus on capacity sharing with competition. Clark and Vincent (2012) explore the reason why airlines adopt dynamic pricing strategies. Similarly, Ma et al. (2019) analyze the prices of Australia's two major rival airlines and show that the increase in capacity mainly causes the price war. Considering Ex ante and Ex post contracts, Guo and Wu (2018) discuss the optimal decisions and profits of the two competitive firms with capacity sharing, which can alleviate price competition. Qin et al. (2018) disclose that capacity sharing achieves a win-win with the appropriate revenue-sharing ratio. The development of the Industrial Internet drives platform-based capacity sharing attracts extensive concern of both academia and industry. Zhao et al. (2015) investigate the manufacturing capacity sharing decisions of the firms on the Internet of Things platform. Zhao and Li (2018) show capacity sharing benefits to supplier. Zhao and Han (2020) analyze the firms' capacity sharing decision with production cost misreporting. Further, Zhao et al. (2020) give the platform-based firms' capacity sharing decisions considering random supply and demand and design the coordination contract for the firms. However, the existing literature rarely addresses the important and practical issue of how capacity supply risks affect the pricing of capacity sharing platforms. Although Zhao et al. (2020) focus on capacity supply unreliability, they assume all firms are risk-neutral. In addition, the cross-network externality of the feature of the two-sided platform has never been considered in existing researches. However, this paper investigates how capacity supply risks and cross-network externality affect capacity sharing platform pricing.

The existing researches on supply reliability is relevant to the present study. Ciarallo et al. (1994) pioneer to consider supplier reliability in operation. The research on the management of supply reliability is relatively mature. (Güllü et al., 1999; Chen and Xia 2010; Çınar and Güllü 2012; Wu et al., 2013). Guo et al. (2013) analyze the influence of supply reliability on the company's optimal purchasing decision. Hwang et al. (2018) prove that wholesale price contract can deal with supply risk well. Tang et al. (2014) discuss how to motivate sellers to improve supply reliability. Considering multiple unreliable and reliable suppliers, Merzifonluoglu (2015) derives the optimal conditions for the suppliers with the maximum expected profit or minimize risk. Kazaz and Webster (2015) investigate how risk aversion and the sources of unreliability (demand or supply) affect the optimal decision. Ma et al. (2017) explore the ordering decision of loss-averse newsboys with the reliability of supply and demand. Kouvelis et al. (2021) show the impact of price delay and risk aversion on decision-making in the case of random yield. Dong et al. (2022) discuss the issue of a single monopoly firm purchasing from multiple unreliable and related suppliers. With the rise and prosperity of the platform economy, supply reliability becomes increasingly critical in platform operation. However, few literature focus on the question. Wen and Siqin (2020) derive the optimal quality effort level and pricing strategy of the platform with risk-averse consumers. Zhang et al. (2020) explore the product pricing, optimal incentive, business model, and efficiency loss of the platform with the reliability of both supply and demand. Different from the literature above, this paper discusses capacity sharing platform pricing with risk-sensitive purchasers or suppliers considering capacity supply risk. The present study also investigates the blockchain adoption strategy of the platform based on users' risk-sensitive types, which can be identified by blockchain technology.

Our study is also closely related to platform pricing literature. Since this paper focuses on the pricing of two-sided platforms, we will only review the literature on the pricing of two-sided platform with cross-network externality. Rochet and Tirole (2006) define the two-sided market as where the transaction volume between end users not only depends on the bilateral price structure but also lies on the overall level of fees charged by the platform. Armstrong (2006) explores how the platform charges membership fees from its users with cross-network externality. Based on Armstrong (2006), Belleflamme and Peitz (2019) discuss which side of the platform can benefit from users' multi-homing behavior. Kung and Zhong (2017) compare three pricing schemes of the two-sided platform with cross-network externality. Wang et al. (2019) analyze the influence of government regulation on two-sided market competition characterized by cross-network externality in the O2O era. More research on the cross-network externality of two-sided platform can be found in King (2013). Although we focus on cross-network externality in this paper, we investigate the capacity sharing platform pricing with supply risk. Some new factors are taken into account in the platform pricing. Lin et al. (2020) analyze the two-sided pricing of the monopoly platform considering the potential production cost reduction, quality improvement of hardware products, and strategic behavior of consumers. Feng et al. (2020) study the impact of the relative size of bilateral cross-network externalities on platform pricing and product mix strategy. Zennyo (2016) explores the competition between quality differentiation platforms in the two-sided market. Closer to our study is Zhao et al. (2020), which discuss capacity sharing platform pricing schemes with capacity supply loss. However, they assume firms are risk-neutral, which fails to depict the real situation with firms' risk sensitivity to supply risk. Furthermore, they neglect the cross-network externality as well as the potential impact of the cross-network externality on the optimal decision.

More relevant to our work is the literature of blockchain-driven platform operations. Blockchain is originally proposed by Nakamoto (2009), which is established for Bitcoin. Blockchain is subsequently applied to financial management (Wang et al., 2023), information management (Choi et al., 2020a), supply chain management (Yavaprabhas et al., 2022; Fan et al., 2022; Charles et al., 2023), and other fields. Choi et al. (2020a) discuss the application of blockchain technology to product information disclosure strategy between two rental service platforms. Similarly, Cai et al. (2020) reveal how blockchain can overcome the moral hazard with the markdown sponsor contract under the rental service platform. Different from the above studies, Xu and He (2021) illustrate retail platform pricing and consumer decision-making based on product information disclosed by blockchain technology. Wu and Yu (2022) discuss the blockchain adoption strategy of the platform with different sales modes according to whether the platform shares blockchain technology based demand information with suppliers. Song et al. (2022) analyze the blockchain adoption strategies of two online retailers competing in information disclosure and further illustrate how the risk aversion attitudes of the two retailers affected their production decisions. Choi and Ouyang (2021) focus on the product certification (BPPA) platform based on blockchain technology and discuss the optimal pricing and effort decision-making of firms with or without blockchain technology support. Wu and Wang (2023) discuss the blockchain adoption decision of retail platform with agency contract, reselling contract or hybrid contracts. Similarly, Xu et al. (2023a) investigate the coordination of platform-based supply chain under different sales modes by considering manufacturer can adopt blockchain technology to improve demand forecasting. Xu et al. (2023b) derive the conditions for manufacturers to use blockchain technology for cost reduction. In addition, blockchain-based crowdfunding platforms enhance donors' trust in donations and improve the overall performance of crowdfunding platforms (Behl et al., 2023). More information on the application of blockchain technology in risk analysis and operational optimization can refer to Choi (2022). However, this paper explores the application of blockchain technology in capacity sharing platform which differ from leasing, retail, and crowdfunding platforms in terms of capacity supply risk. The closest to our work is Choi et al. (2020b), which discusses how platform charges waiting time sensitive consumers in the blockchain era. They fail to consider the pricing scheme of platforms charging both supply and demand users as well as the potential impact of cross-network externality on the optimal pricing. However, the present study fills this gap by exploring how the risk-sensitive attitudes of users on one side of the platform affect the pricing on the other side and the adoption of blockchain technology through cross-network externality. Table 1 below summarizes the differences between the present study and closely related literature.

Table 1 Comparison of closely related literature and the present study

Paper	Platform	Cross-network externality	Supply risk	Risk sensitive	Blockchain technology
Guo et al. (2013), Hwang et al. (2018), Tang et al. (2014), Merzifonluoglu (2015)	/	/	√	/	/
Ma et al. (2017),Kazaz and Webster (2015), Kouvelis et al. (2021)	/	/	√	Risk aversion	/
Wen and Siqin (2020), Zhang et al. (2020)	Sharing/service platform	/	√	Risk aversion	/
Rochet and Tirole (2006), Kung and Zhong (2017), Wang et al. (2019), Armstrong (2006), Belleflamme and Peitz (2019), Feng et al. (2020)	Two-side platform	√	/	/	/
Zhao et al. (2020)	Capacity sharing platform	/	√	/	/
Choi et al. (2020a), Cai et al. (2020)	Rental service platform	/	/	/	√
Xu and He (2021), Wu and Yu (2022), Wu and Wang (2023), Xu et al. (2023a), Xu et al.	Retail platform	/	/	/	√

(2023b)					
Song et al. (2022)	Retail platform	/	√	Risk aversion	√
Choi and Ouyang (2021)	Product provenance authentication platform	/	/	/	√
Choi et al. (2020b)	On-demand-service-platform	/	√	Risk aversion, neutral, seeking	√
Present study	Capacity sharing platform	√	√	Risk aversion, neutral, seeking	√

Note that for ease of exposition we will use capacity supplier (resp. purchaser) with provider (resp. demander) interchangeably.

3 The scenario with partial risk-sensitive purchasers (D)

In this section we consider a monopoly capacity sharing platform (hereinafter abbreviated as "the platform") connecting capacity suppliers and purchasers belonged to two separate sides, such as CASICloud.com. Platform users need to pay platform usage fees for getting the right of releasing their capacity supply and demand information. Capacity suppliers can increase revenue by selling spare capacity, while capacity purchasers can obtain extra income incurred by production and sales through capacity purchased under the platform.

Consider operational capacity risks faced by platforms (e.g. Intelligent Cloud Technology and Tao Factory), risk sources like random idle capacity (e.g. fluctuating spare capacity due to random demand), random capacity (e.g. machine breakdown or labore strike) and random yield (e.g. product quality defects) (Hwang et al., 2018). Denote the reliability of capacity supply as a random variable ξ. That is, a capacity supplier can only effectively provide capacity purchasers ξ $(0 < \xi \le 1)$ level of his capacity with $(1-\xi)$ level lost. Here we assume the sequence of random variables ξ follows independent and identically distributed with normal distribution $\xi \sim N(\mu, \sigma^2)$. The results remain when the capacity supply reliability follows other distributions, such as uniform distribution or exponential distribution. Specifically, although we assume the reliability of capacity supply is a random variable with normal distribution $N \sim (\mu, \sigma^2)$, we can calculate the expectation and variance of other distributions and bring the results into μ and σ of corresponding models when the capacity supply reliability is another distribution (such as uniform or exponential distribution). Therefore, this shows that the distribution does not affect the existing research results. A single purchaser's utility is $u_d(\xi) = v + R_d \xi + b_d n_s - F_d$, where the purchaser's type v is uniformly distributed in [0,1], representing his own initial utility obtained from using the platform, R_d the purchaser's sensitivity to capacity supply reliability, b_d the cross-network externality from the supply side, n_s the number of suppliers and F_d the usage fee charged by the platform. In this section, we consider some of capacity purchasers sensitive to capacity supply risk. A purchaser's expected and variance utility is $E[u_d(\xi)] = v + R_d \mu + b_d n_s - F_d$ and $Var[u_d(\xi)] = R_d^2 \sigma^2$, respectively. The mean-variance approach indicates individual capacity purchaser's utility function expressed as follows:

$$U_d = v + R_d \mu + \beta_d n_s - F_d - A_d R_d \sigma \qquad (1)$$

The first term of the above formula represents the basic utility when purchaser accesses the platform, the second one the average utility of a purchaser obtained when suffering the supply unreliability, the third one the cross-network utility, the fourth one purchaser's platform usage fee and the fifth one the risk sensitivity utility with A_d positive (resp. negative) for risk-averse (resp. risk seeking) reflecting the sensitivity level of the purchaser to capacity supply risk. The purchaser's participation precondition $U_d \geq 0$ implies $[v^*, 1]$ where $v^* = A_d R_d \sigma - R_d \mu - \beta_d n_s + F_d$ represents his indifferent point of joining the platform, thus giving the associated attendance probability $1 + R_d \mu + \beta_d n_s - F_d - A_d R_d \sigma$.

A capacity supplier's utility is $u_s(x) = R_s x + \beta_s n_d - F_s - k$, where R_s characterizes his sensitivity to capacity supply reliability, β_s the cross-network externality from the demand side, n_d the number of purchasers, F_s the supplier's platform usage fee, k an uniformly distributed random variable reflecting the supplier's operations cost on the platform, such as search cost. Actually, capacity supplier has the incentive to improve the capacity supply reliability to obtain more utility, e.g. proactively improving labor relations to avoid strikes or undertake projects to ensure yield (Hwang et al., 2018). Howbeit, we focus on the impact of users' risk-sensitive attitudes on platform pricing by assuming supplier's supply effort away in the paper. The expected utility is $E[u_s(x)] = R_s \mu + \beta_s n_d - F_s - k$. Suppose each capacity supplier is risk neutral with the following utility function:

$$U_s = R_s \mu + \beta_s n_d - F_s - k \qquad (2)$$

In formula (2), the first term represents supplier's average utility due to capacity supply reliability, the second term cross-network utility, the third term usage fee paid by capacity supplier to the platform. Figure 1 shows a schematic description of the focal capacity sharing platform with risk-sensitive purchasers on the demand side. Similarly, the supplier's platform-using premise $U_s \geq 0$ indicates $[k^*, 1]$ with $k^* = R_s \mu + \beta_s n_d - F_s$ representing his critical status of entering the platform given the associated participation probability $R_s \mu + \beta_s n_d - F_s$.

3.1 Homogenous risk-sensitive purchasers

In this subsection, we assume that the risk-sensitive types of all purchasers on the platform are homogeneous, that is, all purchasers hold risk-averse (RA), risk-neutral (RN), or risk-seeking (RS) attitudes toward the supply risks of capacity suppliers.

Scaling the potential number of the platform's two-sided users is 1, the previous analysis on users' probability and critical status of joining the platform implies the number of two-sided firms on the platform as follows:

$$n_s = \frac{R_s m + b_s(1 + R_d m - F_d - A_d R_d s) - F_s}{1 - b_d b_s}$$

$$n_d = \frac{1 + R_d m - F_d - A_d R_d s + b_d(R_s m - F_s)}{1 - b_d b_s}$$

As an intermediary, the platform charges its two-sided users platform-usage fees. Hence, the platform's problem is as follows:

$$\max_{F_d, F_s} p_p = F_d n_d + F_s n_s \tag{3}$$

By solving the above optimization problems, we can obtain LEMMA 1 below.

LEMMA 1. When purchasers exhibit homogeneous risk-sensitive types, the platform pricing decision is:

$$F_s^{D,o*} = \frac{[2 - b_d(b_d + b_s)]R_s m + (b_s - b_d)[1 + R_d(m - A_d s)]}{4 - (b_d + b_s)^2} \tag{4}$$

$$F_d^{D,o*} = \frac{(b_d - b_s)R_s m + [2 - b_s(b_d + b_s)][1 + R_d(m - A_d s)]}{4 - (b_d + b_s)^2} \tag{5}$$

LEMMA 1 gives platform's optimal pricing decision when purchasers are homogeneously risk-sensitive. From LEMMA 1, we can observe that the platform pricing is linearly related to the purchaser's risk sensitivity level. When purchasers are risk-seeking, the pricing of capacity demand side increases in purchasers' risk-seeking level, whereas it decreases in purchasers' risk-averse level when purchasers are risk-averse. Different from capacity demand side pricing, the relationship between capacity supply side pricing and the risk sensitivity level of purchasers is also affected by the relative size of bilateral cross-network externalities. When purchasers are risk-seeking and cross-network externality of capacity demand side is greater than that of the capacity supply side ($b_d > b_s$), the pricing of capacity supply side will decrease in purchasers' risk-seeking levels; Otherwise, the result is the opposite, while under the same situation the result exhibits the opposite when considering purchasers' risk-averse level.

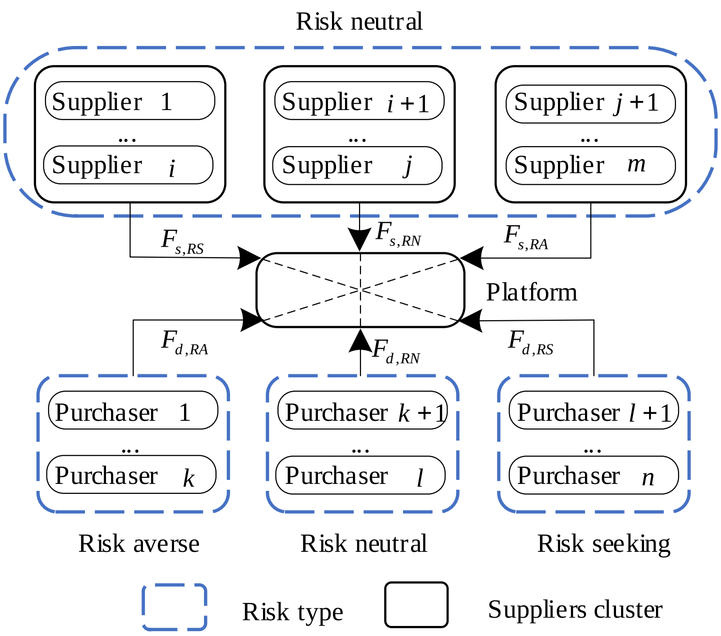


Fig. 1 Capacity sharing platform with partial risk-sensitive purchasers

According to the relationship between the number of bilateral users and platform pricing, we can get the number of bilateral users as follows:

$$n_d^{D,o*} = \frac{(b_d + b_s)R_s m + 2[1 - R_d(m - A_d)]}{4-(b_d+b_s)^2} \tag{6}$$

$$n_s^{D,o*} = \frac{2R_s m + (b_d + b_s)[1 - R_d(m - A_d)]}{4-(b_d+b_s)^2} \tag{7}$$

The number of bilateral users of the platform increases with the sensitivity of suppliers' capacity supply reliability. Meanwhile, the number of bilateral users is closely related to the sum of bilateral cross-network externalities but is independent of the relative size of bilateral cross-network externalities. In addition, higher capacity supply reliability (m) promotes an increase in the number of bilateral users of the platform. The risk-sensitive level of purchasers has a greater impact on the number of firms on the home side than on the number of firms on the opposite side ($b_d + b_s < 2$).

The surplus of capacity purchasers is:

$$\begin{aligned} CS^{D,o*} &= \int_{F_d - R_d m - b_d n_s + A_d R_d}^{1} [v + R_d m + b_d n_s - F_d - A_d R_d]\, s f(v)dv \\ &= \frac{1}{2}[1 + R_d m + b_d n_s - F_d - A_d R_d]^2 s = \frac{\{(b_d + b_s)R_s m + 2[1 - R_d(m - A_d)]\}^2 s}{2[4-(b_d+b_s)^2]^2} \end{aligned} \tag{8}$$

From equation (8) above, we can see that the purchasers' surplus is irrelevant to the relative size of bilateral cross-network externalities. While it increases in the sum of bilateral cross-network externalities.

The surplus of capacity suppliers is:

$$PS^{D,o*} = \int_0^{R_s m + b_s n_d - F_s} [R_s m + b_s n_d - F_s - k] f(k)dk$$
$$= \frac{1}{2}[R_s m + b_s n_d - F_s]^2 = \frac{\{(b_d + b_s) + 2R_s m + (b_d + b_s) R_d (m - A_d m)]\}^2}{2[4-(b_d + b_s)^2]^2} \tag{9}$$

Similarly, although suppliers' surplus is entirely unrelated to the relative size of bilateral cross-network externalities, but it increases in the sum of bilateral cross-network externalities.

Consider platform profit

$$p_p^{D,o*} = \frac{1 + R_s m (b_d + b_s R_s) m + R_d (m - A_d m)[2 s(b_d + b_s) R_s + b R_d (m - A_d)]}{4 - (b_d + b_s)^2} \tag{10}$$

It remains closely linked to the sum of bilateral cross-network externalities. In summary, the platform profit and its bilateral user surplus are independent of the relative size of bilateral cross-network externalities, but the sum of bilateral cross-network externalities has an impact on them.

PROPOSITION 1. (1)When $b_d > b_s$, $F_d^{D,o*} > 0$ holds while the sign of $F_s^{D,o*}$ depends on purchasers' sensitivity to capacity supply risk; Further, $F_s^{D,o*} > 0$ when $A_d > A_{d_1}$, otherwise $F_s^{D,o*} < 0$. (2)When $b_d < b_s$, $F_s^{D,o*} > 0$ while the sign of $F_d^{D,o*}$ depends on purchasers' sensitivity to capacity supply risk; Moreover, $F_d^{D,o*} > 0$ when $A_d < A_{d_2}$, otherwise $F_d^{D,o*} < 0$, where $A_{d_1} = \frac{[2 - b_d(b_d + b_s)]R_s m - (b_s - b_d)(1 + b R_d)}{(b_s - b_d) s}$ and $A_{d_2} = \frac{(b_d - b_s)R_s m - [2 - b_s(b_d + b_s)](1 + b R_d)}{[2 - b_s(b_d + b_s)] s}$.

PROPOSITION 1 illustrates the relationship of platform's pricing policy, bilateral cross-network externalities and purchasers' risk-sensitive level. The platform charges the users on the side, the cross-network externality of which is larger than that on the other side. While whether to charge or subsidize the other side also depends on purchasers' risk-sensitive level. Specifically, for capacity supply-side pricing, the platform charges capacity suppliers when purchasers' risk-sensitive level is greater than the threshold; otherwise platform subsidizes them. In addition, for capacity demand-side pricing, platform charges purchasers when their risk-sensitive level is less than the threshold, otherwise subsidizes them. In conclusion, PROPOSITION 1 shows that platform charges users who obtain higher cross-network externality.

PROPOSITION 2. (1) $F_{d,RA}^{D,o*} < F_{d,RN}^{D,o*} < F_{d,RS}^{D,o*}$; when $b_d > b_s$, $F_{s,RA}^{D,o*} > F_{s,RN}^{D,o*} > F_{s,RS}^{D,o*}$; when $b_d < b_s$, $F_{s,RA}^{D,o*} < F_{s,RN}^{D,o*} < F_{s,RS}^{D,o*}$; (2) $n_{s,RA}^{D,o*} < n_{s,RN}^{D,o*} < n_{s,RS}^{D,o*}, n_{d,RA}^{D,o*} < n_{d,RN}^{D,o*} < n_{d,RS}^{D,o*}$; (3) $PS_{RA}^{D,o*} < PS_{s,RN}^{D,o*} < PS_{RS}^{D,o*}$, $p_{p,RA}^{D,o*} < p_{p,RN}^{D,o*} < p_{p,RS}^{D,o*}$ and $CS_{RA}^{D,o*} < CS_{RN}^{D,o*} < CS_{RS}^{D,o*}$.

PROPOSITION 2 discloses how purchasers' risk-sensitive types affect platform pricing, profits, and bilateral user surplus. We find that purchasers' platform usage fee charged decreases from the risk-seeking over the risk-neutral to the risk-averse irrespective of relative size of bilateral cross-network externalities. However, suppliers' platform usage fee charged increases in the same sequence of risk attitudes when the demand-side cross-network externality is larger than the supply-side one. However, the opposite result can be obtained when the demand side cross-network externality is smaller than the supply side. Comparing platform profit and bilateral user surplus under triple risk attitudes gives that the situation with risk-seeking purchasers obtains the greatest platform profit and surplus of two-sided users. The result demonstrates that the platform-based supply chain benefits from purchasers' risk-seeking while suffers from their risk averseness.

3.2 Heterogeneous risk-sensitive purchasers

Different from assuming suppliers of homogeneous risk-sensitive types previously, this section turns to consider purchasers with heterogeneous types for treating capacity supply risk, i.e. risk-averse, risk-neutral and risk-seeking, the number of which, without loss of generality, is sequentially denoted as a, b and c with $a+b+c=1$. The corresponding utilities for these three kinds of risk-sensitive purchasers are u, 0 and $-l$, respectively.

Unlike hype technologies such as AI and the Internet of Things, blockchain is a distributed infrastructure and computing approach to solving trust and security issues in transactions. The key difference between blockchain and the above technologies is that blockchain technology can decentralize data, making data cannot be tampered and forged. The blockchain-based platform records users' real transaction information, which help platform evaluate users' risk-sensitive types and implement differentiated pricing contingent on the recognized risk attitudes. Thus, this kind of blockchain-driven price discrimination allows users' risk attitudes of on one side affect the pricing of users on the other side through cross-network externalities, thus reshaping the pricing problem in two-sided markets. However, the platform excluding blockchain implements uniform pricing irrespective of the users' risk-sensitive types due to lack of users' risk information. Denote the fixed cost of introducing blockchain technology on the platform as H_d. Therefore, blockchain-enabled platforms can make more accurate operational decisions through ensuring the authenticity of stored data. Furthermore, the effect of blockchain technology application is evaluated by comparing the change of platform profits and bilateral users' surplus before and after adopting blockchain. To explore the threshold condition of implementing blockchain technology and its resulting effect, we are exploring two kinds of platform pricing mechanisms, i.e. uniform pricing and differentiated pricing, respectively as follows.

3.2.1 Uniform pricing

In uniform pricing scheme, supplier's utility remains unchanged and is still represented by formula (2), while purchaser's utility is transformed as follows:

$$U_d = v + R_d m + b_d n_s - F_d - (cl + au)R_d \tag{11}$$

According to previous assumptions, the number of bilateral users in uniform pricing scheme can be derived as:

$$n_s = \frac{R_s m + b_s[1 + R_d m - F_d - (cl + au)R_d] - sF_s}{1 - b_d b_s}$$

$$n_d = \frac{1 + R_d m - F_d + (cl - au) R_d s + b_d (R_s m - F_s)}{1 - b_d b_s}$$

Platform's objective function remains unchanged and can still be expressed by formula (3). Solving platform's optimization problem derives LEMMA 2.

LEMMA 2. Considering heterogeneous risk-sensitive types of purchasers, the platform pricing decision in the uniform pricing scheme is:

$$F_s^{D,COM*} = \frac{[2 - b_d(b_d + b_s)]R_s m + (b_s - b_d)[1 + R_d m + (cl - au) R_d s]}{4 - (b_d + b_s)^2} \quad (12)$$

$$F_d^{D,COM*} = \frac{(b_d - b_s)R_s m + [2 - b_s(b_d + b_s)][1 + R_d m + (cl - au) R_d s]}{4 - (b_d + b_s)^2} \quad (13)$$

LEMMA 2 discloses platform's optimal pricing decision considering the heterogeneous risk-sensitive types of purchasers in uniform pricing scheme. We find that the demand-side pricing increases in the number and utility of risk-seeking purchasers, while it decreases in that of risk-averse purchasers. When the cross-network externality of capacity demanding side is greater than that of capacity supplying side (i.e. $b_d > b_s$), the price of capacity supplying side decreases in the number and utility of risk-seeking purchasers, while it increases in that of risk-averse purchasers; otherwise, the opposite result can be obtained.

The relationship between the number of bilateral users and the platform pricing gives the users number on the platform as follows:

$$n_d^{D,COM*} = \frac{(b_d + b_s)R_s m + 2[1 + R_d(m + (cl - au)s)]}{4 - (b_d + b_s)^2} \quad (14)$$

$$n_s^{D,COM*} = \frac{2R_s m + (b_d + b_s)[1 + R_d(m + (cl - au)s)]}{4 - (b_d + b_s)^2} \quad (15)$$

Similarly, platform users number under uniform pricing scheme is closely related to the sum of bilateral cross-network externalities while independent of the relative size of these externalities. According to Choi et al. (2020b), cl is defined as risk-seeking indicator and au risk-averse indicator. We find that the number of platform users increases in capacity supply variation when the former is greater than the latter, otherwise it decreases. Subsequently, we obtain the surplus of purchasers as follows

$$CS^{D,COM*} = \frac{1}{2[4 - (b_d + b_s)^2]^2} \left\{ \begin{aligned} & a \left[\begin{aligned} & 2 + 2R_d m + (b_d + b_s) R_s m \\ & + R_d s \left[[2 - (b_d + b_s)^2](cl - au) + [4 - (b_d + b_s)^2] au \right] \end{aligned} \right]^2 \\ & + b \left[2 + 2R_d m + (b_d + b_s) R_s m + [2 - (b_d + b_s)^2](cl - au) R_d s \right]^2 \\ & + c \left[\begin{aligned} & 2 + 2R_d m + (b_d + b_s) R_s m \\ & + R_d s \left[[2 - (b_d + b_s)^2](cl - au) - l[4 - (b_d + b_s)^2] \right] \end{aligned} \right]^2 \end{aligned} \right\} \quad (16)$$

The surplus of suppliers is

$$PS^{D,COM*} = \int_0^{R_s \mu + \beta_s n_d - F_s} [R_s \mu + \beta_s n_d - F_s - k] f(k)dk$$
$$= \frac{1}{2}[R_s \mu + \beta_s n_d - F_s]^2 = \frac{[\beta_d + \beta_s + 2R_s \mu(1 + \beta_d \beta_s) + R_d \beta_s (\mu - (c\lambda + au) -)]^2}{2[4-(\beta_d + \beta_s)^2]^2} \quad (17)$$

From equation (17), suppliers' surplus increases in the capacity supply variation when the risk-seeking indicator is greater than the risk-averse one. Correspondingly, the platform profit is

$$\pi_p^{D,COM*} = \frac{1 + R_s \mu(\beta_d + \beta_s) + \beta_s R_d(\mu - (c\lambda + au) -)[2 + \beta_s(\beta_d + \beta_s)R_s + \beta_d R_d(\mu - c\lambda - au)]}{4-(\beta_d + \beta_s)^2} \quad (18)$$

3.2.2 Differentiated Pricing

In this section, we assume that the platform introduces blockchain technology to identify the risk-sensitive types of purchasers, upon which the platform can perform differentiated pricing. Considering heterogeneity of risk-sensitive purchasers gives LEMMA 3 as follows.

LEMMA 3. For heterogeneous risk-sensitive purchasers, the platform's optimal pricing decision in the case of differentiated pricing is:

$$F_{s,RA}^{D,CUS*} = \frac{[2 - \beta_d(\beta_d + \beta_s)]R_s \mu + (\beta_s - \beta_d)[1 + \beta_d R_d(\mu - u)]}{4-(\beta_d + \beta_s)^2} \quad (19)$$

$$F_{s,RN}^{D,CUS*} = \frac{[2 - \beta_d(\beta_d + \beta_s)]R_s \mu + (\beta_s - \beta_d)(1 + \beta_d R_d \mu)}{4-(\beta_d + \beta_s)^2} \quad (20)$$

$$F_{s,RS}^{D,CUS*} = \frac{[2 - \beta_d(\beta_d + \beta_s)]R_s \mu + (\beta_s - \beta_d)[1 + \beta_d R_d(\mu + l)]}{4-(\beta_d + \beta_s)^2} \quad (21)$$

$$F_{d,RA}^{D,CUS*} = \frac{(\beta_d - \beta_s)R_s \mu + [2 - \beta_s(\beta_d + \beta_s)][1 + \beta_d R_d(\mu - u)]}{4-(\beta_d + \beta_s)^2} \quad (22)$$

$$F_{d,RN}^{D,CUS*} = \frac{(\beta_d - \beta_s)R_s \mu + [2 - \beta_s(\beta_d + \beta_s)](1 + \beta_d R_d \mu)}{4-(\beta_d + \beta_s)^2} \quad (23)$$

$$F_{d,RS}^{D,CUS*} = \frac{(\beta_d - \beta_s)R_s \mu + [2 - \beta_s(\beta_d + \beta_s)][1 + \beta_d R_d(\mu + l)]}{4-(\beta_d + \beta_s)^2} \quad (24)$$

Accordingly, platform users' surplus under differentiated pricing scheme is:

$$CS^{D,CUS*} = a\int_{F_d - R_d \mu - \beta_d n_s + uR_d}^{1} [v + R_d \mu + \beta_d n_s - F_d - uR_d] f(v)dv$$
$$+ b\int_{F_d - R_d \mu - \beta_d n_s}^{1} [v + R_d \mu + \beta_d n_s - F_d] f(v)dv + c\int_{F_d - R_d \mu - \beta_d n_s - lR_d}^{1} [v + R_d \mu + \beta_d n_s - F_d + lR_d] f(v)dv \quad (25)$$
$$= \frac{1}{2[4-(\beta_d + \beta_s)^2]^2}\left\{\begin{array}{l} a\{(\beta_d + \beta_s)R_s \mu + 2[1 + R_d(\mu - u)]\}^2 \\ + b\{(\beta_d + \beta_s)R_s \mu + 2(1 + R_d \mu)\}^2 \\ + c\{(\beta_d + \beta_s)R_s \mu + 2[1 + R_d(\mu + l)]\}^2 \end{array}\right\}$$

$$PS^{D,CUS*} = \frac{1}{2[4-(\beta_d + \beta_s)^2]^2}\left\{\begin{array}{l} a\{(\beta_d + \beta_s + 2R_s \mu(1 + \beta_d \beta_s) + R_d \beta_s(\mu - u))]\}^2 \\ + b[\beta_d + \beta_s + 2R_s \mu(1 + \beta_d \beta_s) + R_d \beta_s \mu]^2 \\ + c[\beta_d + \beta_s + 2R_s \mu(1 + \beta_d \beta_s) + R_d \beta_s(\mu + l)]^2 \end{array}\right\} \quad (26)$$

The platform profit under differentiated pricing is:

$$\pi_p^{D,CUS*} = \frac{1}{4-(\beta_d+\beta_s)^2}\left\{ \begin{array}{l} \alpha\left[\begin{array}{l}(1+R_s\mu(\beta_d+\beta_s R_s)-\mu) \\ +R_d(\mu-\theta\sigma)[2-(\beta_d+\beta_s)R_s]-R_d\mu(1-\theta\mu)\end{array}\right]\sigma \\ +b[1+R_s\mu(\beta_d+\beta_s R_s)-\mu R_d+[2-\mu(\beta_d+\beta_s)R_s-\mu R_d]]\mu \\ +\chi\left[\begin{array}{l}(1+R_s\mu(\beta_d+\beta_s R_s)-\mu) \\ +R_d(\mu+\lambda\sigma)[2-(\beta_d+\beta_s)R_s]+R_d\mu(1+\lambda\mu)\end{array}\right]\sigma \end{array}\right\} - H_d \quad (27)$$

3.2.3 Blockchain Value

In this subsection, we proceed to discuss the impact of the platform's adoption of blockchain technology on the platform's profit as well as its bilateral users' surplus. Here we use $\Delta\pi_p^D = \pi_p^{D,CUS*} - \pi_p^{D,COM*}$, $\Delta CS^D = CS^{D,CUS*} - CS^{D,COM*}$, $\Delta PS^D = PS^{D,CUS*} - PS^{D,COM*}$ to denote the value of adopting blockchain technology by platform and bilateral users, respectively.

LEMMA 4. The heterogeneity of risk-sensitive purchasers yields the value of platform's and users' blockchain adoption as follows

$$\Delta\pi_p^D = \frac{[\alpha(1-\alpha)\theta^2+\chi(1-\chi)\lambda^2+2\alpha\theta\chi\lambda]R_d^2\sigma^2}{4-(\beta_d+\beta_s)^2} - H_d \quad (28)$$

$$\Delta CS^D = -\frac{[2-(\beta_d+\beta_s)^2][6-(\beta_d+\beta_s)^2][\alpha(1-\alpha)\theta^2+\chi(1-\chi)\lambda^2+2\alpha\theta\chi\lambda]R_d^2\sigma^2}{2[4-(\beta_d+\beta_s)^2]^2} \quad (29)$$

$$\Delta PS^D = \frac{(\beta_d+\beta_s)^2[\alpha(1-\alpha)\theta^2+\chi(1-\chi)\lambda^2+2\alpha\theta\chi\lambda]R_d^2\sigma^2}{2[4-(\beta_d+\beta_s)^2]^2} \quad (30)$$

From LEMMA 4, the value incurred by the adoption of blockchain technology into the platform is positively correlated with diverse aspects, such as the sum of bilateral cross-network externalities, the sensitivity of purchasers to the supply reliability, and the volatility of capacity supply.

PROPOSITION 3. Scenario D shows the impact of blockchain technology on the platform's profit and two-sided users' surplus as follows: (1) $\Delta\pi_p^D > 0$ holds only when the inequality $H_d < [\alpha(1-\alpha)\theta^2+\chi(1-\chi)\lambda^2+2\alpha\theta\chi\lambda]R_d^2\sigma^2/[4-(\beta_d+\beta_s)^2]$ established; (2) $\Delta CS^D < 0$; (3) $\Delta PS^D > 0$.

PROPOSITION 3 reveals how the blockchain technology is introduced by the platform to identify risk-sensitive types of purchasers and implement differentiated pricing, and finally affects platform profit and users' surplus. The adoption of blockchain increases suppliers' surplus, although it hurts the purchasers'. The blockchain can provide platform profitability and necessitates the implementation of differentiated pricing only when the fixed cost of the platform's introduction of blockchain is less than the profit added by blockchain technology.

4 The scenario with partial risk-sensitive capacity suppliers (S)

Unlike previous sections, we advance to study the scenario with hybrid risk-sensitive capacity suppliers and risk-neutral capacity purchasers on the platform as shown in Fig. 2. From purchaser's utility $u_d(x) = v + R_d x + \beta_d n_s - F_d$ and expected utility with respect to capacity supply reliability $E[u_d(x)] = v + R_d m + b_d n_s - F_d$, we get the utility of a risk-neutral purchaser as below:

$$U_d = v + R_d m + b_d n_s - F_d \tag{31}$$

Accordingly, supplier's utility function, expected utility and risk are $u_s(x) = R_s x + b_s n_d - F_s - k$, $E[u_s(x)] = R_s m + b_s n_d - F_s - k$ and $Var[u_s(x)] = R_s^2 \sigma^2$, respectively. The utility of the risk-sensitive supplier can be written through mean-variance method as follows

$$U_s = R_s m + b_s n_d - F_s - k - A_s R_s \tag{32}$$

where A_s is supplier's sensitivity to her capacity supply risk, indicating her risk-sensitive types, i.e. $A_s > 0$, $A_s = 0$ and $A_s < 0$ corresponds risk averse, risk neutral and risk-seeking, respectively. Note that other relevant assumptions and notations are consistent with Section 3.

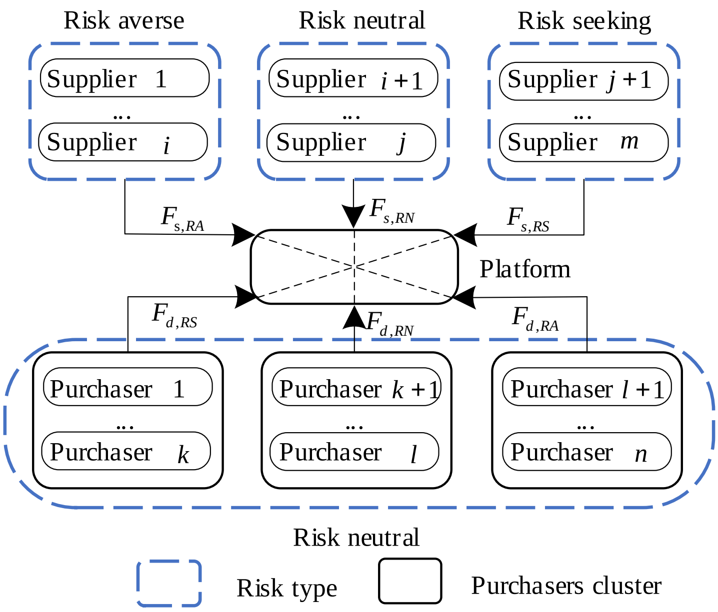


Fig. 2 Capacity sharing platform with partial risk-sensitive suppliers

4.1 Homogenous risk-sensitive suppliers

Consider homogeneous risk-sensitive suppliers in this subsection. That is, suppliers show the same risk attitude as risk-averse (RA), risk-neutral (RN), or risk-seeking (RS) regarding their capacity supply risks.

The numbers of bilateral platform users can be acquired from the utility functions as below:

$$n_s = \frac{R_s m + b_s(1 + R_d m - F_d) - F_s - A_s R_s}{1 - b_d b_s}$$

$$n_d = \frac{1 + R_d m - F_d + b_d(R_s m - F_s - A_s R_s)}{1 - b_d b_s}$$

The platform's profit function can still be expressed by formula (3) since the platform acts as an intermediary and charges usage fees to its bilateral users. Solving platform's optimization problem gives Lemma 5.

Lemma 5 The optimal pricing decision of the platform with homogeneous suppliers is

$$F_s^{S,o*}=\frac{[2-\beta_d(\beta_d+\beta_s)]R_s(\mu-A_s\sigma)+(\beta_s-\beta_d)(1+R_d\mu)}{4-(\beta_d+\beta_s)^2} \tag{33}$$

$$F_d^{S,o*}=\frac{(\beta_d-\beta_s)R_s(\mu-A_s\sigma)+[2-\beta_s(\beta_d+\beta_s)](1+R_d\mu)}{4-(\beta_d+\beta_s)^2} \tag{34}$$

LEMMA 5 states platform pricing decision for homogeneous suppliers. The platform bids low (high) price to high-level risk-averse (risk-seeking) suppliers. However, the relationship between demand-side price and supplier's risk sensitivity degree depends on the comparison of bilateral cross-network externalities. When the demand-side cross-network externality is higher than that of supply side, the demand-side price decreases in supplier's risk-averse level while increases in the her risk-seeking. The result is just the opposite otherwise.

Combining LEMMAS 1 and 5 shows that the platform pricing for risk-sensitive users in one side is always linear with other-side users' risk-sensitive, while how the pricing for risk-neutral users is affected by risk-sensitive level depends on the relative size of bilateral cross-network externalities.

According to the relationship between bilateral users' numbers and platform pricing, the bilateral users' platform numbers can be calculated as follows:

$$n_d^{S,o*}=\frac{(\beta_d+\beta_s)R_s(\mu-A_s\sigma)+2(1+R_d\mu)}{4-(\beta_d+\beta_s)^2} \tag{35}$$

$$n_s^{S,o*}=\frac{2R_s(\mu-A_s\sigma)+(\beta_d+\beta_s)(1+R_d\mu)}{4-(\beta_d+\beta_s)^2} \tag{36}$$

The surpluses of purchasers and suppliers are:

$$\begin{aligned}CS^{S,o*}&=\int_{F_d-R_d\mu-\beta_d n_s}^{1}[v+R_d\mu+\beta_d n_s-F_d]f(v)dv\\&=\frac{1}{2}[1+R_d\mu+\beta_d n_s-F_d]^2=\frac{[(\beta_d+\beta_s)R_s(\mu-A_s\sigma)+2(1+R_d\mu)]^2}{2[4-(\beta_d+\beta_s)^2]^2}\end{aligned} \tag{37}$$

$$\begin{aligned}PS^{S,o*}&=\int_{0}^{R_s\mu+\beta_s n_d-F_s-A_sR_s\sigma}[R_s\mu+\beta_s n_d-F_s-k-A_sR_s\sigma]f(k)dk\\&=\frac{1}{2}[R_s\mu+\beta_s n_d-F_s-A_sR_s\sigma]^2=\frac{[2R_s(\mu-A_s\sigma)+(\beta_d+\beta_s)(1+R_d\mu)]^2}{2[4-(\beta_d+\beta_s)^2]^2}\end{aligned} \tag{38}$$

Accordingly, platform's profit is

$$\pi_p^{S,o*}=\frac{1+R_d\mu(2+R_d\mu)+R_s(\mu-A_s\sigma)[(\beta_d+\beta_s)(R_d\mu+1)+R_s(\mu-A_s\sigma)]}{4-(\beta_d+\beta_s)^2} \tag{39}$$

PROPOSITION 4. (1) The mathematical sign of $F_s^{S,o*}$ depends on supplier's sensitivity to its capacity supply risk when $\beta_d>\beta_s$ and $F_d^{S,o*}>0$, while $F_s^{S,o*}>0$ remains only when $A_s<A_{s_1}$; (2) The sign of $F_d^{S,o*}$ depends on supplier's sensitivity of the to its capacity supply risk when $\beta_d<\beta_s$ and $F_s^{S,o*}>0$, while $F_d^{S,o*}>0$ holds only when $A_s>A_{s_2}$, where we set $A_{s_1}=\frac{(\beta_d-\beta_s)R_s\mu+[2-\beta_s(\beta_d+\beta_s)](1+R_d\mu)}{(\beta_d-\beta_s)R_s\sigma}$ and $A_{s_2}=\frac{[2-\beta_d(\beta_d+\beta_s)]R_s\mu+(\beta_s-\beta_d)(1+R_d\mu)}{[2-\beta_d(\beta_d+\beta_s)]R_s\sigma}$.

PROPOSITION 4 shows the connection between platform's pricing strategy and the bilateral cross-network externalities and suppliers' risk sensitivity. The platform definitely charges users of relatively high cross-network externality, while it may either charge or subsidy users of relatively low cross-network externality in terms of suppliers' risk sensitivity. Specifically, the platform charges suppliers as their suppliers' risk sensitivity is below the threshold A_{s_1}, otherwise it subsidizes suppliers. Similarly, the platform charges (resp. subsidizes) purchasers as suppliers' risk sensitivity level is above (resp. below) the threshold A_{s_2}. Combining proposition 1, we find the platform always charges the users of relatively high cross-network externality under Scenario D and Scenario S.

In addition, comparing platform pricing for suppliers of different risk-sensitivity types shows that $F_{s,RA}^{S,o*} < F_{s,RN}^{S,o*} < F_{s,RS}^{S,o*}$ always holds irrespective of comparison of bilateral cross-network externalities, while $F_{d,RA}^{S,o*} < F_{d,RN}^{S,o*} < F_{d,RS}^{S,o*}$ remains only when $b_d > b_s$. Combining PROPOSITION 2 and PROPOSITION 4 derives the conclusion: Regardless of the relative size of the bilateral cross-network externalities, the price on the side of risk-sensitive users decreases as users' risk attitude varies from risk-seeking through risk-neutrality to risk-aversion. However, how the price on the side of risk-neutral users under diverse risk attitudes of other-side users changes depends on the comparison of bilateral cross-network externalities.

4.2 Heterogeneous risk-sensitive suppliers

Different from prior assumption of platform suppliers' homogeneity of risk attitudes, in this subsection we proceed to consider heterogeneous risk-sensitive suppliers, i.e. being risk-averse, risk-neutral and risk-seeking. Suppose the number of suppliers with three risk attitudes above is $a¡$, $b¡$ and $c¡$, and the associated values A_s is $u¡$, 0 and $-l¡$, where $a¡+b¡+c¡=1$. Denote H_d the fixed cost of platform adopting blockchain technology to identify suppliers' risk attitudes and implement differentiated pricing. To analyze blockchain value, we first discuss the situation where the platform uses uniform pricing without blockchain technology. Differentiated pricing based on blockchain technology will be explored in subsequent subsection.

4.2.1 Uniform pricing

Under uniform pricing, the purchaser's expected utility can still be expressed as formula (31), and the supplier's expected utility is transformed as follows:

$$U_s = R_s m + b_s n_d - F_s - k - (c¡l + ¡a u)R_s \tag{40}$$

According to bilateral users' utility functions, the numbers of platform two sides can be obtained as follows:

$$n_s = \frac{R_s m + b_s(1 + R_d m - F_d) - F_s - (c¡l + ¡a u)R_s ¡}{1 - b_d b_s}$$

$$n_d = \frac{1 + R_d \mu - F_d + \beta_d [R_s \mu - F_s - (c\lambda + \Upsilon \alpha u)\Upsilon]}{1 - \beta_d \beta_s}$$

Platform's objective function in this setting remains as that in Section 3. Solving platform's optimization problem gives LEMMA 6.

LEMMA 6. Considering the heterogeneity of suppliers' risk attitudes, platform's optimal pricing under uniform pricing scheme is

$$F_s^{S,COM*} = \frac{[2 - \beta_d(\beta_d + \beta_s)]R_s(\mu - (c\lambda + \Upsilon\alpha u)\Upsilon) - \sigma(\beta_s + \beta_d)(1 + R_d\mu)}{4 - (\beta_d + \beta_s)^2} \quad (41)$$

$$F_d^{S,COM*} = \frac{(\beta_d - \beta_s)R_s(\mu - (c\lambda + \Upsilon\alpha u)\Upsilon)\sigma + [2 - \beta_s(\beta_d + \beta_s)](1 + R_d\mu)}{4 - (\beta_d + \beta_s)^2} \quad (42)$$

According to platform pricing, bilateral users' numbers on the platform are as follows:

$$n_d^{S,COM*} = \frac{(\beta_d + \beta_s)R_s(\mu - (c\lambda + \Upsilon\alpha u)\Upsilon)\sigma + 2(1 + R_d\mu)}{4 - (\beta_d + \beta_s)^2} \quad (43)$$

$$n_s^{S,COM*} = \frac{2R_s(\mu - (c\lambda + \Upsilon\alpha u)\Upsilon)\sigma + (\beta_d + \beta_s)(1 + R_d\mu)}{4 - (\beta_d + \beta_s)^2} \quad (44)$$

Therefore, the purchasers' surplus is:

$$CS^{S,COM*} = \frac{[(\beta_d + \beta_s)R_s(\mu - (c\lambda + \Upsilon\alpha u)\Upsilon)\sigma + 2(1 + R_d\mu)]^2 \lambda}{2[4 - (\beta_d + \beta_s)^2]^2} \quad (45)$$

From above expressions, the difference of risk-seeking indicator minus risk-aversion one affects risk-neutral purchasers' surplus directly. The purchasers' surplus increases (resp. decreases) in the positive (resp. negative) difference.

The suppliers' surplus is

$$PS^{S,COM*} = \frac{1}{2[4 - (\beta_d + \beta_s)^2]^2} \left\{ \begin{array}{l} a\Upsilon\left[\begin{array}{l}(\beta_d + \beta_s)(1 + R_d\mu) + 2R_s\mu \\ - R_s\sigma\{[2 - (\beta_d + \beta_s)^2](c\lambda + \Upsilon\alpha u)\Upsilon + [4\Upsilon + (\beta_d + \beta_s)^2]\mu\}\end{array}\right]^2 \Upsilon \\ + b\Upsilon[(\beta_d + \beta_s)(1 + R_d\mu) + 2R_s\mu - [2 - (\beta_d + \beta_s)^2]R_s(c\lambda + \sigma\alpha u)]^2 \\ + c\Upsilon\left[\begin{array}{l}(\beta_d + \beta_s)(1 + R_d\mu) + 2R_s\mu \\ - R_s\sigma\{[2 - (\beta_d + \beta_s)^2](c\lambda - \Upsilon\alpha u)\Upsilon + [4\Upsilon - (\beta_d + \beta_s)^2]\mu\Upsilon\}\end{array}\right]^2 \end{array} \right\} \quad (46)$$

The platform's profit is

$$\pi_p^{S,COM*} = \frac{1}{4 - (\beta_d + \beta_s)^2} \left\{ \begin{array}{l} 1 + R_d\mu(2 + R_d\mu) \\ + R_s[\mu - (c\lambda + \Upsilon\alpha u)\Upsilon]\sigma[\Upsilon\beta_d + \beta_s + \beta(\beta_d + \beta_s)R_d\mu + R_s(\mu - (c\lambda + \Upsilon\alpha u)\Upsilon)] \end{array} \right\} \quad (47)$$

4.2.2 Differentiated Pricing

This subsection advances to discuss the pricing decision as platform adopts blockchain technology to identify suppliers' risk attitudes which is used to implement differentiated pricing. First we get LEMMA 7 as follows.

LEMMA 7 Considering heterogeneity of suppliers' risk attitudes, platform's optimal pricing under differentiated pricing scheme is

$$F_{s,RA}^{S,CUS*}=\frac{[2-b_d(b_d+b_s)]R_s(m-a\,i\,s)(1+bR_d)}{4-(b_d+b_s)^2} \tag{48}$$

$$F_{s,RN}^{S,CUS*}=\frac{[2-b_d(b_d+b_s)]R_s\,m(1+bR_d)}{4-(b_d+b_s)^2} \tag{49}$$

$$F_{s,RS}^{S,CUS*}=\frac{[2-b_d(b_d+b_s)]R_s(m+l\,i\,s)(1+bR_d)}{4-(b_d+b_s)^2} \tag{50}$$

$$F_{d,RA}^{S,CUS*}=\frac{(b_d-b_s)R_s(m-u\,i\,s)[2-b_s(b_d+b_s)](1+bR_d)}{4-(b_d+b_s)^2} \tag{51}$$

$$F_{d,RN}^{S,CUS*}=\frac{(b_d-b_s)R_s\,m[2-b_s(b_d+b_s)](1+bR_d)}{4-(b_d+b_s)^2} \tag{52}$$

$$F_{d,RS}^{S,CUS*}=\frac{(b_d-b_s)R_s(m+l\,i\,s)[2-b_s(b_d+b_s)](1+bR_d)}{4-(b_d+b_s)^2} \tag{53}$$

The purchasers' and suppliers' surpluses, and platform's profit are as below, respectively.

$$CS^{S,CUS*}=\frac{1}{2[4-(b_d+b_s)^2]^2}\left\{\begin{array}{l}a\,i[(b_d+b_s)R_s(m-u\,i\,s)+2(1+bR_d)]^2 m\\+b\,i[(b_d+b_s)R_s\,m+2(1+bR_d)]^2 m\\+c\,i[(b_d+b_s)R_s(m+l\,i\,s)+2(1+bR_d)]^2 m\end{array}\right\} \tag{54}$$

$$PS^{S,CUS*}=\frac{1}{2[4-(b_d+b_s)^2]^2}\left\{\begin{array}{l}a\,i[2R_s(m-u\,i\,s)+(b_d+b_s)(1+bR_d)]^2 m\\+b\,i[2R_s\,m+(b_d+b_s)(1+bR_d)]^2 m\\+c\,i[2R_s(m+l\,i\,s)+(b_d+b_s)(1+bR_d)m]^2\end{array}\right\} \tag{55}$$

$$p_p^{S,CUS*}=\frac{1}{4-(b_d+b_s)^2}\left\{\begin{array}{l}a\,i[1+R_d m(2+R_d m)+R_s(m-u\,i\,s)[s_d\,b_s+(b_d+b_s)R_d+b\,R_s(m-u\,i)]]m\\+b\,i[1+R_d m(2+R_d m)+R_s\,m[s_d\,b_s+(b_d+b_s)R_d+b\,R_s\,m]]m\\+c\,i[1+R_d m(2+R_d m)+R_s(m+l\,i\,s)[s_d\,b_s+(b_d+b_s)R_d+b\,R_s(m+l)]]m\end{array}\right\}-H_s \tag{56}$$

4.2.3 Blockchain Value

Define blockchain value to a chain player as her payoff increment incurred by applying blockchain technology in the platform-induced supply chain. Similarly, we use $\Delta\pi_p^S$, ΔCS^S and ΔPS^S to represent the blockchain value for platform, purchasers and suppliers.

LEMMA 8. Considering suppliers' risk sensitivity, the blockchain value to the platform, purchasers and suppliers are as follows:

$$\Delta\pi_p^S=\frac{[a\,i(1-a\,i)u^2+c(1-c\,i)l^2+2a\,c\,i\,u\,l]R_s^2 s^2 i}{4-(b_d+b_s)^2}-H_s \tag{57}$$

$$\Delta CS^S=\frac{(b_d+b_s)^2[a\,i(1-a\,i)u^2+c(1-c\,i)l^2+2a\,c\,i\,u\,l]R_s^2 s^2 i}{2[4-(b_d+b_s)^2]^2} \tag{58}$$

$$\Delta PS^S=\frac{[2-(b_d+b_s)^2][6-(b_d+b_s)^2][a\,i(1-a\,i)u^2+c(1-c\,i)l^2+2a\,c\,i\,u\,l]R_s^2 s^2 i}{2[4-(b_d+b_s)^2]^2} \tag{59}$$

LEMMA 8 shows that the summation of bilateral cross-network externalities, suppliers' sensitivity to supply reliability and capacity supply fluctuation increases various blockchain values. Combined with LEMMA 4, we can see this conclusion remains no matter whether platform introduces blockchain technology to identify the risk attitudes of purchasers or suppliers.

PROPOSITION 5. In Scenario S, the impact of blockchain on the platform's profit and the surplus of purchasers and suppliers can be expressed as follows: $\Delta\pi_p^S > 0$ holds only when $H_s < [a'(1-a)u'^2 + c'(1-c)l'^2 - 2(a'u + c'l)]R_s^2\sigma'^2/[4'(\beta_d' - \beta_s')^2]$; $\Delta CS^S > 0$; $\Delta PS^S < 0$.

PROPOSITIONs 3 and 5 reveals the impact of applying blockchain technology to identify suppliers' (purchasers') risk attitudes and implement differentiated pricing on system firms' surpluses. Specifically, introducing blockchain technology decreases the surplus of risk-sensitive suppliers (purchasers'), while increases the risk-neutral purchasers' (suppliers'). The result shows that platform's blockchain adoption benefits risk-insensitive purchasers but hurts risk-sensitive suppliers. Therefore, whether the platform introduces blockchain or not depends on the comparison of the fixed cost and increased profit of introducing blockchain technology.

5 Comparative analysis of two scenarios

In this section, we proceed to conduct comparative analysis of many aspects in two scenarios i.e. partial risk-sensitive purchasers (D) and partial risk-sensitive suppliers (D), such as platform pricing strategy, bilateral users' surplus, platform profit and blockchain values under two scenarios.

5.1 Bilateral Pricing

COROLLARY 1. (1) When $\beta_d > \beta_s$, $F_{s,RA}^{D,CUS*} > F_{s,RA}^{S,CUS*}$ and $F_{s,RS}^{D,CUS*} < F_{s,RS}^{S,CUS*}$; when $\beta_d < \beta_s$ and $\frac{u}{u'} < \frac{[2-\beta_d(\beta_d+\beta_s)]}{(\beta_s-\beta_d)}\frac{R_s}{R_d}$ ($\frac{l}{l'} < \frac{[2-\beta_d(\beta_d+\beta_s)]}{(\beta_s-\beta_d)}\frac{R_s}{R_d}$), $F_{s,RA}^{D,CUS*} > F_{s,RA}^{S,CUS*}$ ($F_{s,RS}^{D,CUS*} < F_{s,RS}^{S,CUS*}$); otherwise, $F_{s,RA}^{D,CUS*} < F_{s,RA}^{S,CUS*}$ ($F_{s,RS}^{D,CUS*} > F_{s,RS}^{S,CUS*}$). $F_{s,RN}^{D,CUS*} = F_{s,RN}^{S,CUS*}$ always holds regardless of the comparison of bilateral cross-network externalities. (2) When $\beta_d < \beta_s$, $F_{d,RA}^{D,CUS*} < F_{d,RA}^{S,CUS*}$, $F_{d,RS}^{D,CUS*} > F_{d,RS}^{S,CUS*}$; when $\beta_d > \beta_s$ and $\frac{u}{u'} < \frac{(\beta_d-\beta_s)}{[2-\beta_s(\beta_d+\beta_s)]}\frac{R_s}{R_d}$ ($\frac{l}{l'} < \frac{(\beta_d-\beta_s)}{[2-\beta_s(\beta_d+\beta_s)]}\frac{R_s}{R_d}$), $F_{d,RA}^{D,CUS*} > F_{d,RA}^{S,CUS*}$ ($F_{d,RS}^{D,CUS*} < F_{d,RS}^{S,CUS*}$); otherwise, $F_{d,RS}^{D,CUS*} < F_{d,RS}^{S,CUS*}$ ($F_{d,RS}^{D,CUS*} > F_{d,RS}^{S,CUS*}$) . $F_{d,RN}^{D,CUS*} = F_{d,RN}^{S,CUS*}$ holds regardless of the relative size of the bilateral cross-network externalities.

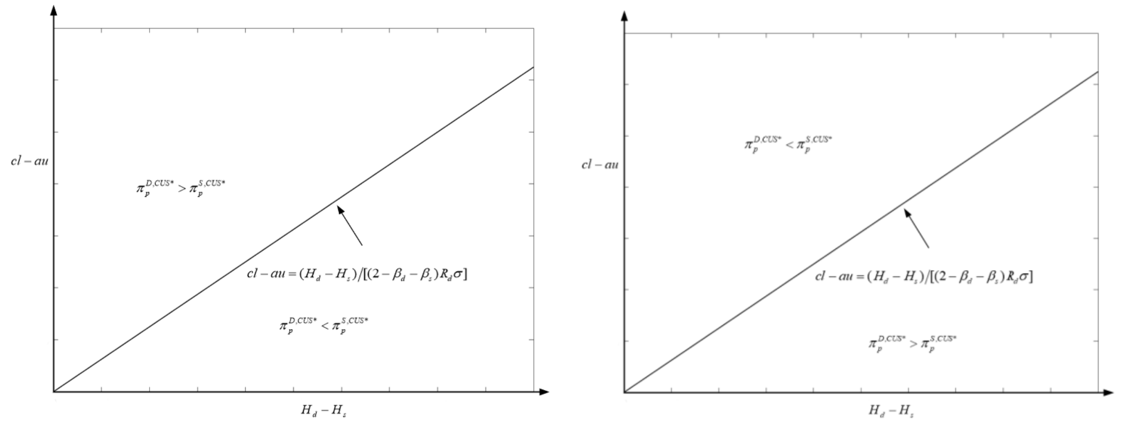
COROLLARY 1 compares platform's bilateral pricing in scenarios *D* and *S*. The results show that the comparison of bilateral pricings in two cases are closely related to the relative size of the cross-network externalities and the ratio of users' risk utilities.

5.2 Platform profit and bilateral users' surplus

COROLLARY 2. Letting $a = a'$, $c = c'$, $u = u'$, $l = l'$ and $R_s = R_d$ yields: (1) $CS_d^{D,CUS*} > CS_d^{S,CUS*}$ and $PS_s^{D,CUS*} < PS_s^{S,CUS*}$ only when $cl > au$; (2) $\pi_p^{D,CUS*} > \pi_p^{S,CUS*}$ iff

$(cl-au)/(H_d-H_s) > 1/[(2-\beta_d-\beta_s)R_d\sigma]$ and $H_d > H_s$.

COROLLARY 2 compares platform profit and bilateral users' surplus in cases D and S when the platform implements a differential pricing strategy. When the users attributes on two sides of the platform are consistent, we show the following findings. When the importance of risk-seeking is higher than risk-aversion, the surplus of purchasers (suppliers) in scenario D is higher (less) than that in scenario S. Supposing the blockchain fixed cost on the demand side is larger (smaller) than that on the supply side, the platform profits more in scenario D when the ratio of risk-sensitivity importances based difference and bilateral blockchain costs difference is above (below) the threshold; otherwise the platform obtains more profits in scenario S. The result demonstrates that the platform should trade off the two-sided blockchain fixed costs and the importance of risk-seeking and risk-averse to maximize her profit.



(a) $H_d > H_s$ (b) $H_d < H_s$

Fig. 3 The platform's profit in Scenario D and Scenario S

5.3 Blockchain Value

COROLLARY 3. (1) If $R_d/R_s > \tilde{R}$, $\Delta\pi_p^D < \Delta\pi_p^S$ holds only when $H_d - H_s > \tilde{H}$. (2) If $R_d/R_s < \tilde{R}$, $\Delta\pi_p^D > \Delta\pi_p^S$ holds only when $H_d - H_s < \tilde{H}$, where $\tilde{H} > 0$ only when $R_d/R_s > \tilde{R}$,

$\tilde{H} = \sigma^2\{[a(1-a)u^2 + c(1-c)l^2 + 2acul]R_d^2 - [a'(1-a')u'^2 + c'(1-c')l'^2 + 2a'c'u'l']R_s^2\}/[4-(\beta_d+\beta_s)^2]$,

$$\tilde{R} = \sqrt{\frac{[a'(1-a')u'^2 + c'(1-c')l'^2 + 2a'c'u'l']}{[a(1-a)u^2 + c(1-c)l^2 + 2acul]}}.$$

COROLLARY 3 shows the blockchain values for the platform in scenario D and scenario S with different attributes of bilateral users. We find that, given the ratio of purchasers' sensitivity over the suppliers' to supply reliability is over some threshold, platform gains more profit in case S (case D) compared with case D (case S) when the value of demand-side fixed cost of introducing blockchain minus supply-side one is relatively large (small). As the ratio of sensitivity comparison is below the threshold, the result goes to just the opposite. The above derivation suggests that the platform can obtain greater blockchain value by introducing blockchain technology to the side with higher adoption cost.

Consider the fact that the same blockchain technology infrastructure is needed no matter which side of the user's risk attitude is identified by the adopted blockchain technology. We therefore assume $H_d = H_s$ and derive the Corollary 4.

COROLLARY 4. (1) When $a = a_i$, $c = c$, $\mu = \mu$, $l_i = l$ and $R_s = R_d$, blockchain technology adds respective equal value on platform profit and risk-neutral users' surplus for cases D and S. (2) $Dp_p^D > Dp_p^S$ holds only when $R_d / R_s > \tilde{R}$.

COROLLARY 4 gives a comparison of the blockchain values in the two scenarios D and S. COROLLARY 4(1) shows equal blockchain value generated in both cases due to the same platform bilateral attributes. But when the bilateral properties of the platform are heterogeneous, whether this observation holds or not is closely related to the ratio of bilateral users' sensitivity to the reliability of capacity supply. As shown in Fig. 4, when the ratio of purchasers' and suppliers' sensitivities is greater than the threshold, the blockchain value under case D is higher than that under case S. Furthermore, when $a = a_i$, $c = c$, $\mu = \mu$ and $l_i = l$, we find that the threshold is 1. The result demonstrates that when the more sensitive to supply reliability the user is, the higher blockchain value.

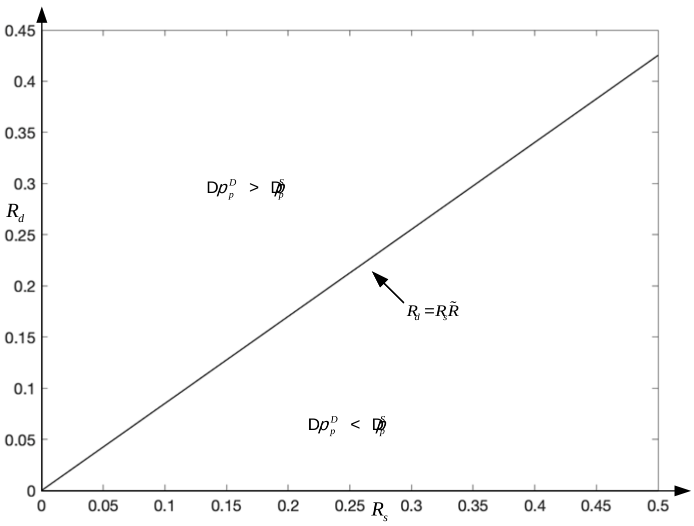


Fig. 4 The blockchain value is scenario D and scenario

6 Extention: The scenario with capacity suppliers and purchasers of hybrid risk attitudes

Consider capacity purchasers or suppliers of hybrid risk attitudes in sections 3 and 4. We focus on discussing the blockchain value and how one-side users' risk attitudes affect other-side pricing through the cross-network externality. This section relaxes previous assumption to explore how platform pricing and blockchain value are generated when both sides of the platform contain risk-sensitive users (scenario B).

6.1 Risk-sensitive type homogenous purchasers and suppliers

In this subsection, we assume that risk attitudes of all purchasers (suppliers) on the platform are homogeneous. Under the circumstances, the utility functions of purchases and suppliers still can be shown by the functions (1) and (32). According to the platform objective function as the sum of usage fees paid by bilateral users, we can calculate the platform pricing as:

$$F_s^{B,o*} = \frac{[2 - b_d(b_d + b_s)]R_s(m - A_s s) + (b_s - b_d)[1 + R_d(m - A_d m)]}{4 - (b_d + b_s)^2} \tag{60}$$

$$F_d^{B,o*} = \frac{(b_d - b_s)R_s(m - A_s s) + [2 - b_s(b_d + b_s)][1 + R_d(m - A_d m)]}{4 - (b_d + b_s)^2} \tag{61}$$

The platform pricing is linear to the users' risk sensitivity level, which is also affected by the difference of bilateral cross-network externalities. The results are consistent with the previous research results. In addition, the pricing of the side with hybrid risk-attitude users decreases from risk-seeking to risk-neutrality to risk-aversion, while how risk attitudes impact on other-side pricing depends on the difference of bilateral cross-network externalities.

The surplus of capacity purchasers is:

$$\begin{aligned} CS^{B,o*} &= \int_{F_d - R_d m - b_d n_s + A_d R_d s}^{1} [v + R_d m + b_d n_s - F_d - A_d R_d s] f(v)dv \\ &= \frac{1}{2}[1 + R_d m + b_d n_s - F_d - A_d R_d s]^2 \\ &= \frac{\{(b_d + b_s)R_s(m - A_s s) + 2[1 + R_d(m - A_d s)]\}^2}{2[4 - (b_d + b_s)^2]^2} \end{aligned} \tag{62}$$

The surplus of capacity suppliers is

$$\begin{aligned} PS^{B,o*} &= \int_{0}^{R_s m + b_s n_d - F_s} [R_s m + b_s n_d - F_s - k - A_s R_s s] f(k)dk \\ &= \frac{1}{2}[R_s m + b_s n_d - F_s - A_s R_s s]^2 \\ &= \frac{\{2R_s(m - A_s s) + (b_d + b_s)[1 + R_d(m - A_d m)]\}^2}{2[4 - (b_d + b_s)^2]^2} \end{aligned} \tag{63}$$

The platform profit is

$$\pi_p^{B,o*} = \frac{\begin{aligned} &1 + R_s(m - A_s s)[(b_d + b_s)R_s(m - A_s s)] \\ &+ R_d(m - A_d s)[2 + (b_d + b_s)R_s(m - A_s s) + R_d(m - A_d m)] \end{aligned}}{4 - (b_d + b_s)^2} \tag{64}$$

Consistent with previous research results, platform profit and the surplus of suppliers and purchasers are affected by an increase in the sum of bilateral cross-network externalities rather than by the difference of these two externalities. In addition, similarly platform profit and its bilateral user surplus decreases from risk-seeking to risk neutrality to risk aversion.

6.2 Risk-sensitive type heterogeneous purchasers and suppliers

After relaxing previous assumption, we discuss here how users' different risk attitudes impact platform pricing. We still assume that the number of three risk types of supplies (purchasers) i.e. risk-seeking, risk-neutrality and risk-aversion is a, b and c (a, b and c) with $a+b+c=1$ ($a+b+c=1$). Accordingly, risk sensitivity levels of suppliers (purchasers) under three types of risk attitudes are u¡, 0 and $-l$ (u, 0 and $-l$). The platform can adopt blockchain technology to capacity supply and demand sides at costs H_s and H_D, respectively, to identify risk attitudes of bilateral users. We first analyze the uniform pricing scheme of the platform, and later discuss differentiated pricing.

6.2.1 Uniform pricing

Under the uniform pricing scheme, the utility functions of capacity supplier and purchaser are still shown in as functions (11) and (40) while the platform pricing is

$$F_s^{B,COM*} = \frac{[2-b_d(b_d+b_s)]R_s[m+(cl ¡ au)¡] s + (b_s+b_d)[1+bR_d(m+(cl-au))]}{4-(b_d+b_s)^2} \quad (65)$$

$$F_d^{B,COM*} = \frac{(b_d-b_s)R_s[m+(cl ¡ au)¡] s[2+b_s(b_d-b_s)][1+bR_d(m+(cl-au))]}{4-(b_d+b_s)^2} \quad (66)$$

The surplus of capacity purchasers is

$$CS^{B,COM*} = \frac{1}{2[4-(b_d+b_s)^2]^2}\left\{ \begin{array}{l} a\left[\begin{array}{l} 2+2R_d m+(b_d+b_s)R_s[m+(cl ¡ au)¡] s \\ -R_d s\{[2-(b_d+b_s)^2](cl-au)-[4+(b_d-b_s)^2]u\} \end{array}\right]^2 \\ +b\left[\begin{array}{l} 2+2R_d m+(b_d+b_s)R_s[m+(cl ¡ au)¡] s \\ -[2-(b_d+b_s)^2](cl-au)R_d s \end{array}\right]^2 \\ +c\left[\begin{array}{l} 2+2R_d m+(b_d+b_s)R_s[m+(cl ¡ au)¡] s \\ -R_d s\{[2-(b_d+b_s)^2](cl-au)-[4-(b_d-b_s)^2]l\} \end{array}\right]^2 \end{array}\right\} \quad (67)$$

The surplus of capacity suppliers is

$$PS^{B,COM*} = \frac{1}{2[4-(b_d+b_s)^2]^2}\left\{ \begin{array}{l} a\left[\begin{array}{l} b_d+b_s+2R_s m+(b_d+b_s)R_d(m+(cl-au))s \\ -R_s s\{[2-(b_d+b_s)^2](cl ¡ au)¡ [4+(b_d-b_s)^2]u\} \end{array}\right]^2 \\ +b\left[\begin{array}{l} b_d+b_s+2R_s m+(b_d+b_s)R_d(m+(cl-au))s \\ -R_s s[2-(b_d+b_s)^2](cl ¡ au)¡ \end{array}\right]^2 \\ +c\left[\begin{array}{l} b_d+b_s+2R_s m+(b_d+b_s)R_d(m+(cl-au))s \\ -R_s s\{[2-(b_d+b_s)^2](cl ¡ au)¡ [4-(b_d+b_s)^2]l\} \end{array}\right]^2 \end{array}\right\} \quad (68)$$

The platform profit is

$$p_p^{B,COM*} = \frac{\begin{array}{l} 1+R_s[m+(cl ¡ au)¡] s[b_d+b_s+bR_s[m+(cl+au)¡]] s \\ +R_d[m+(cl-au)s][2-(b_d+b_s)R_s[m+(cl+au)¡]+bR_d[m+(cl-au)]] \end{array}}{4-(b_d+b_s)^2} \quad (69)$$

6.2.2 Differentiated pricing

Under differentiated pricing, the platform charges different usage fees in terms of users' risk attitudes. Consider that users on platform bilateral sides have three risk attitudes, the platform has nine pricing options for users per side as shown below

$$F_s^{B,CUS*}(A_s,A_d) = \frac{[2-b_d(b_d+b_s)]R_s(m+A_s)s+(b_s+b_d)[1+bR_d(m+A_d)]}{4-(b_d+b_s)^2} \quad (70)$$

$$F_d^{B,CUS*}(A_s, A_d) = \frac{(b_d - b_s)R_s(\mu + A_s)\sigma[2-(b_d+b_s)] + [1+bR_d(\mu + A_d)]\mu}{4-(b_d+b_s)^2} \tag{71}$$

where $A_s \in \{u, 0, -l\}$ and $A_d \in \{u, 0, l\}$.

The surplus of capacity purchasers is

$$CS^{B,CUS*} = \frac{1}{2[4-(b_d+b_s)^2]^2}\left\{ \begin{array}{l} a\left[\begin{array}{l} a\{(b_d+b_s)R_s(\mu+u)\sigma + 2[1+R_d(\mu+u)]\}^2\sigma \\ +b\{(b_d+b_s)R_s(\mu+u)\sigma + 2(1+R_d\mu)\}^2\mu \\ +c\{(b_d+b_s)R_s(\mu+u)\sigma + 2[1+R_d(\mu+l)]\}^2\sigma \end{array}\right] \\ +b\left[\begin{array}{l} a\{(b_d+b_s)R_s\mu\sigma + 2[1+R_d(\mu+u)]\}^2\sigma \\ +b\{(b_d+b_s)R_s\mu\sigma + 2(1+R_d\mu)\}^2\mu \\ +c\{(b_d+b_s)R_s\mu\sigma + 2[1+R_d(\mu+l)]\}^2\sigma \end{array}\right] \\ +c\left[\begin{array}{l} a\{(b_d+b_s)R_s(\mu-l)\sigma + 2[1+R_d(\mu+u)]\}^2\sigma \\ +b\{(b_d+b_s)R_s(\mu-l)\sigma + 2(1+R_d\mu)\}^2\mu \\ +c\{(b_d+b_s)R_s(\mu-l)\sigma + 2[1+R_d(\mu+l)]\}^2\sigma \end{array}\right] \end{array}\right\} \tag{72}$$

The surplus of capacity suppliers is

$$PS^{B,CUS*} = \frac{1}{2[4-(b_d+b_s)^2]^2}\left\{ \begin{array}{l} a\left[\begin{array}{l} a\{(b_d+b_s-2)R_s(\mu+u)\sigma + (b_d+b_s)R_d b(\mu+u)\}^2\sigma \\ +b\{(b_d+b_s-2)R_s(\mu+u)\sigma + (b_d+b_s)R_d b\mu\}^2\mu \\ +c\{(b_d+b_s-2)R_s(\mu+u)\sigma + (b_d+b_s)R_d b(\mu+l)\}^2\sigma \end{array}\right] \\ +b\left[\begin{array}{l} a\{(b_d+b_s-2)R_s\mu\sigma + (b_d+b_s)R_d b(\mu+u)\}^2\sigma \\ +b\{(b_d+b_s-2)R_s\mu\sigma + (b_d+b_s)R_d b\mu\}^2\mu \\ +c\{(b_d+b_s-2)R_s\mu\sigma + (b_d+b_s)R_d b(\mu+l)\}^2\sigma \end{array}\right] \\ +c\left[\begin{array}{l} a\{(b_d+b_s-2)R_s(\mu-l)\sigma + (b_d+b_s)R_d b(\mu+u)\}^2\sigma \\ +b\{(b_d+b_s-2)R_s(\mu-l)\sigma + (b_d+b_s)R_d b\mu\}^2\mu \\ +c\{(b_d+b_s-2)R_s(\mu-l)\sigma + (b_d+b_s)R_d b(\mu+l)\}^2\sigma \end{array}\right] \end{array}\right\} \tag{73}$$

The platform profit is

$$
p_p^{B,CUS*}=\frac{1}{4-(b_d+b_s)^2}\left\{\begin{array}{l}
a'\left\{\begin{array}{l}
a\left[\begin{array}{l}(1+R_s(\mu-u'\sigma)(b_d+b_sR_s(\mu-u'\sigma)))\sigma\\ +R_d(\mu-u\sigma)[2+(b_d+b_s)R_s(\mu-u'\sigma)+b_sR_d(\mu-u\sigma)]\end{array}\right]\sigma\\
+b\left[\begin{array}{l}(1+R_s(\mu-u'\sigma)(b_d+b_sR_s(\mu-u'\sigma)))\sigma\\ +R_d\mu[2+(b_d+b_s)R_s(\mu-u'\sigma)+b_sR_d\mu]\end{array}\right]\mu\\
+c\left[\begin{array}{l}(1+R_s(\mu-u'\sigma)(b_d+b_sR_s(\mu-u'\sigma)))\sigma\\ +R_d(\mu+l\sigma)[2+(b_d+b_s)R_s(\mu-u'\sigma)+b_sR_d(\mu+l\sigma)]\end{array}\right]\sigma
\end{array}\right\}\\
+b'\left\{\begin{array}{l}
a\left[\begin{array}{l}(1+R_s\mu(b_d+b_sR_s\mu))\mu\\ +R_d(\mu-u\sigma)[2+(b_d+b_s)R_s\mu+b_sR_d(\mu-u\sigma)]\end{array}\right]\sigma\\
+b\left[(1+R_s\mu(b_d+b_sR_s\mu))\mu+R_d\mu[2+(b_d+b_s)R_s\mu+b_sR_d\mu]\right]\mu\\
+c\left[\begin{array}{l}(1+R_s\mu(b_d+b_sR_s\mu))\mu\\ +R_d(\mu+l\sigma)[2+(b_d+b_s)R_s\mu+b_sR_d(\mu+l\sigma)]\end{array}\right]\sigma
\end{array}\right\}\\
+c'\left\{\begin{array}{l}
a\left[\begin{array}{l}(1+R_s(\mu+l'\sigma)(b_d+b_sR_s(\mu+l'\sigma)))\sigma\\ +R_d(\mu-u\sigma)[2+(b_d+b_s)R_s(\mu+l'\sigma)+b_sR_d(\mu-u\sigma)]\end{array}\right]\sigma\\
+b\left[\begin{array}{l}(1+R_s(\mu+l'\sigma)(b_d+b_sR_s(\mu+l'\sigma)))\sigma\\ +R_d\mu[2+(b_d+b_s)R_s(\mu+l'\sigma)+b_sR_d\mu]\end{array}\right]\mu\\
+c\left[\begin{array}{l}(1+R_s(\mu+l'\sigma)(b_d+b_sR_s(\mu+l'\sigma)))\sigma\\ +R_d(\mu+l\sigma)[2+(b_d+b_s)R_s(\mu+l'\sigma)+b_sR_d(\mu+l\sigma)]\end{array}\right]\sigma
\end{array}\right\}
\end{array}\right\}+H_d\mu-H_s \qquad (74)
$$

6.2.3 Blockchain value

Although the complication of expressions hinders our analytical analysis of blockchain value in this situation, handling similar situations in Anderson et al. (2014), Tan et al. (2020) and Bakos and Halaburda (2020) inspires us to conduct computational study to observe results and provide corresponding managerial insights. We set following benchmark parameter values: $R_s=0.5$, $R_d=0.5$, $a=0.7$, $b=0.2$, $c=0.1$, $u=0.8$, $l=0.1$, $a'=0.7$, $b'=0.2$, $c'=0.1$, $u'=0.8$, $l'=0.1$, $b_d=0.4$, $b_s=0.4$, $\mu=0.3$, $H_d=0$, $H_s=0$.

The respective blockchain values for platform, suppliers, and purchasers in the scenario of hybrid risk-sensitive suppliers and purchasers are shown in Fig. 5. Numerical analysis shows that the platform's profit increases, but the bilateral users' surplus decreases after introducing blockchain and implementing differentiated pricing. Moreover, the blockchain technology generates the same value for both sides' users when the users of bilateral sides keep the same attributes (as shown in Fig. 5, where the red dashed line overlaps with the blue solid line), which is consistent with corollary 4 (1).

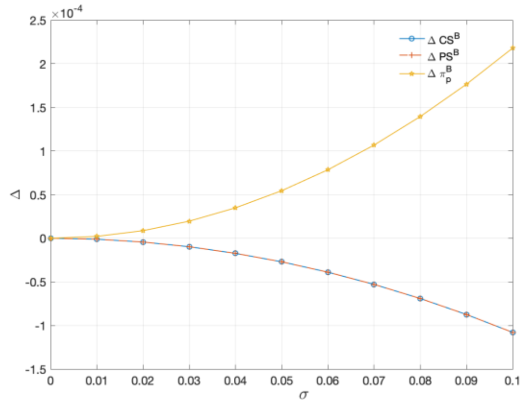


Fig. 5 Blockchain value

Furthermore, we explore the blockchain value for the platform and its users when bilateral users' risk attributes are heterogeneous. The adoption of blockchain technology causes less harm to purchasers' surplus compared to the suppliers' only when risk-averse purchasers is more than risk-averse suppliers or when risk-seeking purchasers is less than risk-seeking suppliers as shown in Fig. 6. In addition, the blockchain value for the platform (its users) increases (decreases) in the variation degree of capacity supply. Intuitively, the larger fluctuation of capacity supply, the more meaningful for the platform to adopt blockchain technology to implement differentiated pricing. Extremely, the platform will abandon blockchain technology when the fluctuation is tiny. However, the surplus of platform users is hurt by the adoption of blockchain technology when confronting large fluctuation.

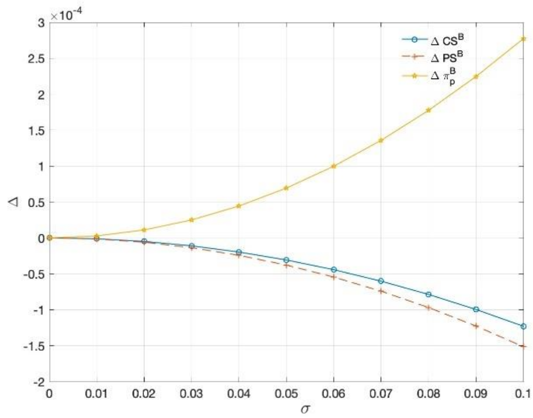


Fig. 6a Blockchain value

$(a = 0.7, b = 0, c = 0.3, a' = 0.5, b' = 0, c' = 0.5)$

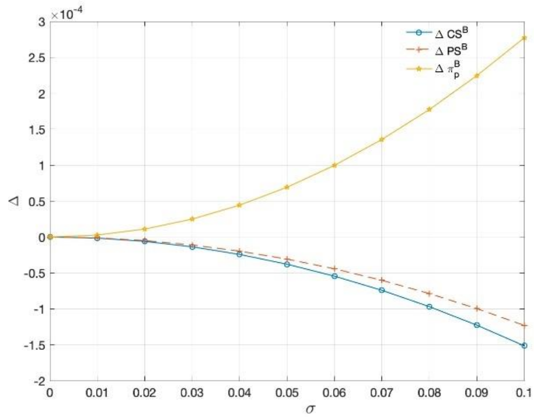


Fig. 6b Blockchain value

$(a = 0.5, b = 0, c = 0.5, a' = 0.7, b' = 0, c' = 0.3)$

7 Conclusion

Inspired by the reality fact that platform users' risk tendency to capacity supply variation affects the efficiency of platform-based capacity sharing economy, this paper investigates how risk attitudes and cross-network externality impact capacity-sharing platform pricing, platform profit and surplus of two sides. Specifically, this paper discusses three scenarios: hybrid risk-sensitive purchasers (scenario D), hybrid risk-sensitive suppliers (scenario S), and hybrid risk-sensitive purchasers and suppliers (scenario B). The analysis of above three situations yields some managerial insights.

In scenario D, we first discuss the platform pricing when the purchasers show the same risk-sensitive types. The result shows that the price on the demand side, the platform profit, and the surplus of bilateral users are higher with risk-seeking purchasers. However, the impact of risk-sensitive types on supply-side pricing depends on the relative size of the bilateral cross-network externalities. The supply-side pricing is higher with risk-seeking purchasers when the cross-network externality of the supply side is greater than that of the demand side; otherwise, the supply-side pricing is higher with risk-averse purchasers. The result is different from Choi et al. (2020b), which only focuses on demand-side pricing. Secondly, we discuss two pricing mechanisms of the platform when purchasers show different risk attitudes: common pricing (without considering the risk-sensitive types of purchasers) and customized pricing (charging different usage fees in terms of purchasers' risk-sensitive types based on blockchain technology). We find the blockchain improves the surplus of suppliers but it hurts purchasers' surplus by comparing the above pricing schemes. The result is the opposite in scenario S. However, Choi et al. (2020b) show that whether blockchain technology is beneficial to consumers depends on the significance of risk-averse and risk-seeking consumers in the market. Song et al. (2022) conclude that blockchain technology always hurts consumer surplus with the high application cost of blockchain. Furthermore, we find that it is wise for the platform to introduce blockchain technology when the fixed cost of introducing blockchain technology is less than the profit added for the platform. While Wu and Wang (2023) reveal that whether the platform adopts blockchain technology is related to the sales mode of suppliers. By comparing Scenario D and Scenario S, the result demonstrates that the platform needs to comprehensively trade off the relative size of the blockchain fixed costs on the two sides and the significance of risk-seeking and risk-averse users on the platform to improve its profitability. Introducing the higher-cost side of blockchain technology on the platform may result in higher blockchain value. Finally, we extended our research to discuss platform pricing when both sides of the platform contain risk-sensitive users, and the results are still robust.

This paper novelly focuses on the platform pricing problem considering two-sided users' risk attitudes and the effect of bilateral cross-network externalities, the research of which adds new theoretical knowledge and expands boundary of platform-based capacity sharing field. Furthermore, this paper uncovers the impact of blockchain technology on platform's profitability and bilateral users' surplus under various scenarios, and depicts the decision-making process of adopting blockchain and conditions of improving revenue and blockchain value. The findings provide suggestions for platform's blockchain technology adoption decision.

Future research can be conducted in aspects as follows. Capacity supply reliability can be regarded as engogenous decision variable rather the exogenous in this paper. Further, complementary to our focus of the cross-network externality, the impact of same-network externality on users' utilities can also be considered in the future, so is the fairness concern of users under differentiated pricing scheme. Finally, discussing how blockchain technology influences product delivery time under capacity-sharing platform will be another research direction.

Acknowledgement

The authors sincerely thank the editor, associate editor and anonymous referees for their very constructive comments and suggestions, which have helped improve this study.

Declaration

Competing interest: The authors declare no conflict of interest.

References

Akter, S., Michael, K., Uddin, M. R., et al. (2020). "Transforming business using digital innovations: The application of ai, blockchain, cloud and data analytics." *Annals of Operations Research* 308 (1-2): 7-39.

Anderson, E. G., Parker, G. G., & Tan, B. (2014). "Platform performance investment in the presence of network externalities." *Information Systems Research* 25 (1): 152-172.

Armstrong, M. (2006). "Competition in two-sided markets." *The Rand Journal of Economics* 37 (3): 668-691.

Bakos, Y., & Halaburda, H. (2020). "Platform competition with multihoming on both sides: Subsidize or not?" *Management Science* 66 (12): 5599-5607.

Behl, A., Sampat, B., Pereira, V., et al. (2023). "Investigating the role of data-driven innovation and information quality on the adoption of blockchain technology on crowdfunding platforms." *Annals of Operations Research* https://doi.org/10.1007/s10479-023-05290-w.

Belleflamme, P., & Peitz, M. (2019). "Platform competition: Who benefits from multihoming?" *International Journal of Industrial Organization* 64 1-26.

Cai, Y.-J., Choi, T.-M., & Zhang, J. (2020). "Platform supported supply chain operations in the blockchain era: Supply contracting and moral hazards*." *Decision Sciences* 54 (2): 866-892.

Charles, V., Emrouznejad, A., & Gherman, T. (2023). "A critical analysis of the integration of blockchain and artificial intelligence for supply chain." *Annals of Operations Research* 1-41.

Chen, M., & Xia, Y. (2010). "Managing supply uncertainties through bayesian information update." *IEEE Transactions on Automation Science & Engineering*

Choi, T.-M. (2019). "Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains." *Transportation Research Part E: Logistics and Transportation Review* 128 17-29.

Choi, T.-M. (2022). "Achieving economic sustainability: Operations research for risk analysis and optimization problems in the blockchain era." *Annals of Operations Research*.

Choi, T.-M., Feng, L., & Li, R. (2020a). "Information disclosure structure in supply chains with rental service platforms in the blockchain technology era." *International Journal of Production*

Economics 221 107473.

Choi, T.-M., Guo, S., Liu, N., et al. (2020b). "Optimal pricing in on-demand-service-platform-operations with hired agents and risk-sensitive customers in the blockchain era." *European Journal of Operational Research* 284 (3): 1031-1042.

Choi, T.-M., & Ouyang, X. (2021). "Initial coin offerings for blockchain based product provenance authentication platforms." *International Journal of Production Economics* 233 107995.

Ciarallo, F. W., Akella, R., & Morton, T. E. (1994). "A periodic review, production planning model with uncertain capacity and uncertain demand—optimality of extended myopic policies." *Management Science* 40 (3): 320-332.

Çınar, E., & Güllü, R. (2012). "An inventory model with capacity flexibility in the existence of advance capacity information." *Decision Support Systems* 53 (2): 320-330.

Clark, R., & Vincent, N. (2012). "Capacity-contingent pricing and competition in the airline industry." *Journal of Air Transport Management* 24 7-11.

Dong, L., Geng, X., Xiao, G., et al. (2022). "Procurement strategies with unreliable suppliers under correlated random yields." *Manufacturing & Service Operations Management* 24 (1): 179-195.

Fan, Z.-P., Wu, X.-Y., & Cao, B.-B. (2022). "Considering the traceability awareness of consumers: Should the supply chain adopt the blockchain technology?" *Annals of Operations Research* 309 (2): 837-860.

Feng, N., Chen, J., Feng, H., et al. (2020). "Optimal product selection and pricing strategies for platform vendors under two-sided network effects." *Electronic Commerce Research and Applications* 43 100990. https://doi.org/10.1016/j.elerap.2020.100990.

Güllü, R., Nol, E., & Erkip, N. (1999). "Analysis of an inventory system under supply uncertainty." *International Journal of Production Economics* 59 (1–3): 377-385.

Guo, L., & Wu, X. (2018). "Capacity sharing between competitors." *Management Science* 64 (8): 3554-3573.

Guo, S., Zhao, L., & Xu, X. (2013). "Impact of supply risks on procurement decisions." *Annals of Operations Research* 241 (1-2): 411-430.

Hwang, W., Bakshi, N., & DeMiguel, V. (2018). "Wholesale price contracts for reliable supply." *Production and Operations Management* 27 (6): 1021-1037.

Kazaz, B., & Webster, S. (2015). "Technical note—price-setting newsvendor problems with uncertain supply and risk aversion." *Operations Research* 63 (4): 807-811.

King, S. P. (2013). "Two-sided markets." *The Australian Economic Review* 46 (2): 247–258.

Kouvelis, P., Xiao, G., & Yang, N. (2021). "Role of risk aversion in price postponement under supply random yield." *Management Science* 67 (8): 4826-4844.

Kung, L.-C., & Zhong, G.-Y. (2017). "The optimal pricing strategy for two-sided platform delivery in the sharing economy." *Transportation Research Part E: Logistics and Transportation Review* 101 1-12.

Lin, M., Pan, X. A., & Zheng, Q. (2020). "Platform pricing with strategic buyers the impact of future production cost." *Production and Operations Management* 29 (9): 1122-1144.

Ma, L., Xue, W., Zhao, Y., et al. (2017). "Loss-averse newsvendor problem with supply risk." *Journal of the Operational Research Society* 67 (2): 214-228.

Ma, W., Wang, Q., Yang, H., et al. (2019). "An analysis of price competition and price wars in australia's domestic airline market." *Transport Policy* 81 163-172.

Merzifonluoglu, Y. (2015). "Impact of risk aversion and backup supplier on sourcing decisions of a firm." *International Journal of Production Research* 53 (22): 6937-6961.

Moghaddam, M., & Nof, S. Y. (2016). "Real-time optimization and control mechanisms for collaborative demand and capacity sharing." *International Journal of Production Economics* 171 495-506.

Nakamoto, S. (2009). "Bitcoin: A peer-to-peer electronic cash system." *consulted* https://bitcoin.org/bitcoin.pdf.

Qin, J., Wang, K., Wang, Z., et al. (2018). "Revenue sharing contracts for horizontal capacity sharing under competition." *Annals of Operations Research* https://doi.org/10.1007/s10479-018-3005-x.

Renna, P., & Argoneto, P. (2011). "Capacity sharing in a network of independent factories: A cooperative game theory approach." *Robotics and Computer-Integrated Manufacturing* 27 (2): 405-417.

Rochet, J.-C., & Tirole, J. (2006). "Two-sided markets-a progress report." *RAND Journal of Economics* 37 (3): 645-667.

Seok, H., & Nof, S. Y. (2014a). "Collaborative capacity sharing among manufacturers on the same supply network horizontal layer for sustainable and balanced returns." *International Journal of Production Research* 52 (6): 1622-1643.

Seok, H., & Nof, S. Y. (2014b). "Dynamic coalition reformation for adaptive demand and capacity sharing." *International Journal of Production Economics* 147 136-146.

Song, Y., Liu, J., Zhang, W., et al. (2022). "Blockchain's role in e-commerce sellers' decision-making on information disclosure under competition." *Ann Oper Res* 1-40. https://doi.org/10.1007/s10479-021-04276-w.

Tan, B., Anderson, E. G., & Parker, G. G. (2020). "Platform pricing and investment to drive third-party value creation in two-sided networks." *Information Systems Research* 31 (1): 217-239.

Tang, S. Y., Gurnani, H., & Gupta, D. (2014). "Managing disruptions in decentralized supply chains with endogenous supply process reliability." *Production and Operations Management* 23 (7): 1198-1211.

Wang, C., Chen, X., Xu, X., et al. (2023). "Financing and operating strategies for blockchain technology-driven accounts receivable chains." *European Journal of Operational Research* 304 (3): 1279-1295.

Wang, S., Chen, H., & Wu, D. (2019). "Regulating platform competition in two-sided markets under the o2o era." *International Journal of Production Economics* 215 131-143.

Wen, X., & Siqin, T. (2020). "How do product quality uncertainties affect the sharing economy platforms with risk considerations? A mean-variance analysis." *International Journal of Production Economics* 224 107544. https://doi.org/10.1016/j.ijpe.2019.107544.

Wu, J., & Wang, X. (2023). "Platform-leading blockchain adoption for traceability under upstream competition." *Annals of Operations Research* https://doi.org/10.1007/s10479-022-05147-8.

Wu, J., & Yu, J. (2022). "Blockchain's impact on platform supply chains: Transaction cost and information transparency perspectives." *International Journal of Production Research* 1-14.

https://doi.org/10.1080/00207543.2022.2027037.

Wu, M., Zhu, S. X., & Teunter, R. H. (2013). "The risk-averse newsvendor problem with random capacity." *European Journal of Operational Research* 231 (2): 328-336.

Xu, Q., & He, Y. (2021). "Optimal information disclosure strategies for a retail platform in the blockchain technology era." *International Journal of Production Research* 1-12. https://doi.org/10.1080/00207543.2021.1976434.

Xu, X., He, P., Zhou, L., et al. (2023a). "Coordination of a platform-based supply chain in the marketplace or reselling mode considering cross-channel effect and blockchain technology." *European Journal of Operational Research* 309 (1): 170-187.

Xu, X., Yan, L., Choi, T.-M., et al. (2023b). "When is it wise to use blockchain for platform operations with remanufacturing?" *European Journal of Operational Research* https://doi.org/10.1016/j.ejor.2023.01.063.

Yavaprabhas, K., Pournader, M., & Seuring, S. (2022). "Blockchain as the “trust-building machine” for supply chain management." *Annals of Operations Research* https://doi.org/10.1007/s10479-022-04868-0.

Yoon, S. W., & Nof, S. Y. (2011). "Affiliation/dissociation decision models in demand and capacity sharing collaborative network." *International Journal of Production Economics* 130 (2): 135-143.

Zennyo, Y. (2016). "Competition between vertically differentiated platforms." *Journal of Industry, Competition and Trade* 16 (3): 309-321.

Zhang, X., Chen, H., & Zhao, D. (2020). "Pricing strategy and business model determination of service platform under demand and output uncertainty." *Chinese Journal of Management Science* 28 (12): 130-139.

Zhao, D., Du, Q., & Xu, C. (2015). "Strategies of manufacturing capability sharing based on internet of things platform." *Journal of Tianjin University(social sciences)* 17 (2): 97-102.

Zhao, D., & Han, H. (2020). "Decisions and coordination in a capacity sharing supply chain considering production cost misreporting." *Complexity* 2020 1-12.

Zhao, D., Han, H., Shang, J., et al. (2020). "Decisions and coordination in a capacity sharing supply chain under fixed and quality-based transaction fee strategies." *Computers & Industrial Engineering* 150 https://doi.org/10.1016/j.cie.2020.106841.

Zhao, D., Hao, J., Cao, C., et al. (2019). "Evolutionary game analysis of three-player for low-carbon production capacity sharing." *Sustainability* 11 (11): https://doi.org/10.3390/su11112996.

Zhao, D., & Li, R. (2018). "Research on decision-making of firm's surplus resources sharing in cloud manufacturing." *Industrial Engine ering and Management* 23 (2): 33-39.