

## Research Article

# Decisions and Coordination in a Capacity Sharing Supply Chain considering Production Cost Misreporting

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Received 23 April 2020; Revised 10 June 2020; Accepted 22 June 2020; Published 27 July 2020

Guest Editor: Baogui Xin

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In the manufacturing capacity sharing platform, considering the manufacturing capacity provider's cost misreporting behavior and the collusion behavior of the platform operator, this paper built a supply chain consisting of a platform operator, a capacity provider with surplus capacity, and a manufacturer with insufficient capacity. This paper studied the influence of the cost misreporting behavior on the supply chain members' decisions and profits. By use of the game theory, in the scenarios including the supplier misreporting to other supply chain members and the supplier colluding with the platform, the paper analyzed the optimal pricing decision, misreporting coefficient decision, and platform's service fee decision and further compared the profits of the supply chain and its members. The results show that the capacity provider tends to overstate the production cost for gaining more profits, which exerts negative effects on profits of other members and the supply chain. Compared with the case of misreporting to both the manufacturer with insufficient capacity and the platform, the case of colluding with platform is more favorable to the profits of the manufacturer, the platform, and the supply chain, while the supplier prefers to choose the former situation. When the sales revenue-sharing proportion, cost-sharing proportion, and service fee satisfy certain conditions, the sales revenue-sharing and cost-sharing contract can avoid the capacity provider's cost misreporting behavior and coordinate the supply chain.

## 1. Introduction

In recent years, with the development of the Internet of Things (IoT), big data, cloud computing, and other technologies, sharing economy has attracted extensive attention. The manufacturing industry is also undergoing a radical transformation driven by the IoT-related technologies and business innovation. An increasing number of intermediary manufacturing capacity sharing platforms have arisen to integrate fragmented manufacturing capacity from enterprises with surplus capacities in a sharable resource pool and provide manufacturing services to manufacturers or retailers with inadequate capacity, for example, Thomas platform in the United States, CASICloud platform, and Tao factory in China. The intermediary manufacturing capacity sharing platform offers an effective manufacturing solution to facilitate the match between capacity supply and demand,

improving the utilization rate of capacities and expediting transaction processes. Participants of the platform are able to easily provide or obtain manufacturing service through online sharing platforms. In this paper, we consider a supply chain (SC) composed of a platform operator, a capacity provider with surplus capacity, and a manufacturer with insufficient capacity. We focus on investigating the influence of manufacturing cost misreporting behavior of the capacity provider on the SC members' decisions and profits and further strive to propose a contract to avoid the cost misreporting behavior and coordinate the SC.

It is worth noting that the intermediary manufacturing capacity platform has dual attributes, i.e., the attribute of marketplace and the attribute of enterprise. On the one hand, the platform, as the online trading place of capacity sharing transactions and the maker of trading rules, should be safe, fair, and stable. The platform operator should

regulate the participants' operations to ensure orderly and fair competition in the platform and facilitate the sharing transaction. However, since the number of participants in the platform is continuously increasing, it is difficult for the platform to grasp all the information on capacities of participants. There is an opportunity for participants to take advantage of their information for seeking more benefits. For example, in the Tao Factory platform of China, although the platform's in-depth factory inspection service can enable the manufacturing capacity requestor have a comprehensive understanding of the production line, warehousing, and quality control capabilities of the capacity provider, the capacity requestor still cannot accurately grasp the manufacturing cost information of the capacity provider due to the difficulty in real-time supervision of the whole manufacturing process. Since many suppliers misreport their cost to charge an excessively high price, the Alibaba group takes measures to punish suppliers for their false quotation, according to the rules of the website. In the platform, the capacity provider may have three choices on the cost information: disclosing the real cost information, misreporting the cost information, or hiding the cost information. In this paper, we consider the scenario that the capacity provider misreports the cost information and examine its influence on the decision-making process.

On the other hand, the platform is also a profit-oriented enterprise. It may conceal certain information or collude with participating companies for the purpose of pursuing benefits. With the rapid expansion of the capacity sharing platform, the highly clustered platform is more likely to breed opportunistic behavior such as misreporting information. For example, the Tao factory platform will offer the order supervision service to the capacity requestor that orders a quantity of more than 100 pieces. The order supervisor will help the requestor find a more appropriate capacity provider and monitor the production process to guarantee the product quality and delivery time. Since order supervisors from different places know well the capacity providers in their nearby regions, respectively, the platform will assign a proper order supervisor for the capacity requestor according to their requirements on the location of the capacity provider. Order supervisors may help the capacity providers misreport information to attain more benefits because they usually have long-term cooperative relationships with capacity providers in their vicinity. If this collusion behavior can also bring higher benefits to the platform, the platform may also connive at this behavior. This will cause potential loss for the capacity requestor and disturb the orderly and fair transaction in the platform.

Therefore, we consider three scenarios in this paper, i.e., the capacity provider reporting real cost information; the capacity provider misreporting cost information without being noticed by both the capacity provider and the platform operator; the capacity provider misreporting cost information with the acquiescence of the platform operator. We investigate the pricing decisions and profits of SC members under each scenario. Through comprehensive analysis on the equilibrium results, we analyze the impact of the capacity provider's cost misreporting and the platform operator's

acquiescence. Finally, we propose the contract to incentivize the capacity provider to disclose the real cost information and coordinate the SC. The contributions of this research are threefold. First, we take the cost misreporting behavior into account in the context of capacity sharing through platform. Second, we investigate the impact of the platform operator's acquiescence on decisions and provide insights on platform governance. Third, we propose a coordination contract for the capacity sharing SC to avoid the cost misreporting behavior.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 formulates the models and derives and compares the equilibrium outcomes. Section 4 proposes the coordination contracts for the SC. Section 5 gives numerical analysis. Section 6 presents conclusions.

## 2. Literature Review

This research is highly related to three areas of literature: manufacturing capacity sharing platform, cost information asymmetry and SC coordination. We review them in the following sections.

**2.1. Manufacturing Capacity Sharing Platform.** Although great attention has been paid on capacity sharing between enterprises, most previous studies have focused on capacity sharing among enterprises without the online platform. For example, Renna and Argoneto [1] studied the cooperation mechanism of capacity sharing among factories based on game theory and evaluated the benefits of this mechanism under different market conditions and capacity conditions. With the goal of cost minimization, Moghaddam and Nof [2] proposed an optimal matching mechanism for sharing demand and capabilities among enterprises in the supply network. Moghaddam and Nof [3] further proposed a real-time optimization and control mechanism for demand and capacity sharing among enterprises. Yu et al. [4] studied the circumstances under which capacity sharing among independent companies is advantageous and proposed a cost-sharing mechanism to ensure the stability of the capacity sharing alliance in the queuing system. Guo and Wu [5] studied capacity sharing among competitors under contracts considering before and after the decision-making on capacity sharing prices. Qin et al. [6] studied the design of revenue-sharing contract under capacity sharing between two companies with horizontal competition. Zeng et al. [7] studied the cooperation of service providers based on capability sharing in the queuing system and proposed a cost-sharing mechanism that can encourage providers to reach cooperation based on the principles of fairness and easy implementation. Although these studies investigate matching mechanisms, cost-sharing mechanisms, and cooperative game between manufacturers, their researches pay attention to the game problems between the supply and demand sides of the manufacturing capacity, without incorporating the decision-making process of platform operators and opportunistic behaviors of capacity providers.

With the vigorous development of the sharing economy, an increasing number of scholars began to pay attention to sharing platforms, such as housing sharing platform [8], vehicle sharing platform [9], car-hailing platform [10], and personal to personal product sharing platform [11–13]. Although these platforms are similar to manufacturing capacity sharing platforms in the nature of sharing, manufacturing capacity sharing platforms connects manufacturing enterprises with relatively greater complexity than individuals. This puts forward higher requirements for analyzing the behaviors and decisions of the platform operator. The intermediary manufacturing capacity platform highlighted in our paper can gather scattered manufacturing resources and reduce the difficulties for firms in finding sufficient manufacturing capacity or utilizing the idle capacities. Moreover, the platform has mastered a large amount of transaction data, enabling the platform to take advantage of big data to increase the added value of participants. For example, it can help the factory to integrate upstream and downstream resources and provide more flexible services. The platform offers the order processing supervision services to ensure the product quality and the timely delivery. In contrast, the traditional capacity sharing among enterprises suffers the lack of assistance and supervision in capacity transaction. However, the platform, as an enterprise, has the nature of pursuing profits, in which opportunistic behaviors may occur.

In terms of research on manufacturing capacity sharing platforms, Aloui and Jebsi [14] studied the optimal capacity sharing strategy between two different but interdependent consumers on the platform, pointing out that the optimal strategy depends on the level of bilateral participation and externalities between them. Li et al. [15] studied the sharing and scheduling problem of decentralized manufacturing resources and proposed an optimization algorithm based on multiagent. As a kind of manufacturing capacity sharing platform, i.e., cloud manufacturing platform has attracted the attention of many scholars. Ren et al. [16], Adamson et al. [17], and Yang et al. [18] have deeply discussed the concept, characteristics, and industry applications of cloud manufacturing platforms. These studies conceptually explained the functional characteristics of the cloud manufacturing platform. Argoneto and Renna [19] proposed a cloud manufacturing capacity sharing framework based on cooperative games and fuzzy theory, which showed that this allocation strategy can enable enterprises to faithfully report their demand information. Tao et al. [20] proposed a manufacturing service supply and demand matching system in the cloud environment. Based on cloud design and cloud computing, Thekinen and Panchal [21] provide matching services for providers and demanders including services and products.

Most of the abovementioned studies on the capacity sharing platform have focused on the capacities and resources matching and optimization in the manufacturing platform, considering the intermediary role of the platform. Some studies explain the role of the capacity sharing platform from a theoretical framework. Few studies have considered the opportunistic behavior of participating

companies and the platform operator. This paper focuses on the influence of capacity providers' misreporting of cost information and collusion with the platform operator on decisions and profits of SC members.

**2.2. Cost Information Asymmetry.** In the traditional supply chain without the consideration of sharing platform, the problem of cost information asymmetry has been studied by many scholars. Scholars mainly focus on how to design contracts to encourage SC members to share real information when the owner conceals the cost information or discloses the false cost information. For example, Xu et al. [22] studied the impact of the emergency supplier with private cost information on the performance of primary suppliers and manufacturers and pointed out that a combined contract including lead time and transfer payment can encourage emergency suppliers to report real cost information. Çakanyıldırım et al. [23] investigated how retailers design profit-sharing contracts to achieve supply chain coordination when the production cost is private information. Cao et al. [24] studied the design of the optimal wholesale price contract considering the private cost information of retailers in the dual-channel supply chain. Kayış et al. [25] discussed whether the manufacturer directly purchases from the second-level supplier or delegates the first-level supplier to purchase under cost information asymmetry. Lei et al. [26] explored the game between suppliers with private production cost information and retailers facing inventory inaccuracy issues and designed a revenue-sharing contract to coordinate the supply chain.

Ma et al. [27] investigated decisions and profits of supply chain members under the wholesale price contract and the two-part tariff contract when the cost of social responsibility input is private information. Wang et al. [28] studied the production and pricing decisions of an assembly system composed of a single manufacturer and two complementary suppliers and analyzed the value of production cost information sharing. Dai et al. [29] focused on the information-sharing strategies of manufacturers with private production cost information when facing competitive retailers in different market competition environments and found that the optimal strategy is related to the degree of competition, the return cost, and the relationship between the retailer's estimated and real production costs. In these literature, most researchers considered that other members of the supply chain will predict the cost information or offer different contracts to identify high or low-cost types. Yan et al. [30] studied the impact of manufacturers' misreporting cost information on decision-making and profits when there is a competition between two manufacturers and between manufacturers and retailers.

They analyzed the value of cost information sharing, the impact of cost misreporting, and further studied the design of incentive mechanisms for gaining real information, which provides insights into the mechanism design to avoid cost misreporting in this paper. Since they do not involve the participation of the capacity sharing platform, they do not consider the impact of misreporting on platform operator's

service fee decision and profits and not involve in the situation where the platform may acquiesce to the cost misreporting. Thereby, mechanism design with the participation of platform operator is not discussed.

**2.3. SC Coordination.** A large number of researches have been done on SC coordination. Revenue-sharing or revenue and cost-sharing contract has been widely adopted by many researchers. To cite a few in recent years, Hu and Feng [31] investigate the optimization of a supply chain under both supply and demand uncertainty and propose the revenue-sharing contract and service requirement to coordinate the supply chain and further give conditions of achieving coordination. Xie et al. [32] propose the revenue and cost-sharing contract to coordinate a dual-channel closed-loop supply chain and increase the retailer's efforts regarding servicing and recycling. Su et al. [33] propose a cost profit-sharing contract to coordinate a closed-loop supply chain with third-party recycling, taking environmental protection factors into account. Jian et al. [34] design a revenue-sharing contract to coordinate a supply chain with competing manufacturers, considering the manufacturer's peer-induced fairness concern model and the manufacturer's distributional fairness concern model.

Coordination of SC under cost information asymmetry has also attracted the attention of researchers. For example, Wang et al. [35] propose an innovative coordination contract including the trading quantity, the transfer payment, and the profit allocation rules to coordinate a supply chain under asymmetric information on manufacturing cost and degree of risk aversion. Wang et al. [36] propose the collaboration mechanism consisting of the order quantity and the innovative transfer payment under production cost information asymmetry. Liu et al. [37] propose a coordination mechanism for a corporate social responsibility-sensitive supply chain to inspire the supplier to reveal the true corporate social responsibility cost information and to improve the performance of the supply chain.

The abovementioned literature on SC coordination mostly focuses on the supply chain without the third-party platform. They provide guidance for us to design coordination contracts as well as the avoidance mechanism of cost misreporting behavior. The main difference of this paper with them is in that the incorporation of the service fee decision and the possible acquiescence of the platform in our decision-making and coordination models. This paper investigates the cost of misreporting behavior in a capacity sharing SC. Like the previous study such as Xin and Sun [38], we also investigate equilibrium results under different scenarios. Specifically, we built models of disclosing real cost information, misreporting cost without being noticed, and misreporting cost with the platform operator's acquiescence. We try to analyze the influence of the misreporting behavior on decisions and profits of SC members and further design the contract to enable the capacity provider to report the real cost information and achieve SC coordination.

### 3. Models

**3.1. Model Description.** In a supply chain consisting of a capacity provider ( $M_1$ ), a capacity demand side ( $M_2$ ), and a capacity sharing platform operator ( $P$ ),  $M_2$  purchases the manufacturing service of a single product from  $M_1$ . The paper considers a platform at a mature stage, i.e., the platform has a large number of participants.  $P$  has strong market power and is the leader of the SC. The dominant power of the leader in this paper refers to the priority of pricing. All SC members are risk-neutral and completely rational, that is, they make decisions based on the principle of maximizing their own profits.  $M_1$  is a small and medium-sized manufacturing company with surplus capacity, and it is not directly oriented to the end market.  $M_2$  is a more comprehensive manufacturing and sales-oriented manufacturing company with a market power higher than  $M_1$ .  $P$  charges a service fee for  $M_1$ , for example, the Tao Factory platform charges a service fee for capacity providers but does not charge a fee for capacity requestors in the current stage. Based on the service fee,  $M_2$  determines the sales margin and  $M_1$  determines its wholesale price.

The market demand  $D$  of the product is a linear function of the market price  $p$ , i.e.,  $D = a - bp$ , where  $a$  is the potential market size. We assume that  $a$  is large enough to avoid meaningless situations.  $b$  is the price sensitivity coefficient, and  $a$  and  $b$  are both positive values.  $p$  is the sales price of  $M_2$ .  $p = w + r$ , where  $M_1$  decides the wholesale price  $w$  and  $M_2$  decides the sales margin  $r$ . Suppose the real unit product production cost of  $M_1$  is  $c$ , and  $M_1$  may lie about the production cost for its own benefit. We denote the cost reported to  $M_2$  as  $kc$ , and  $k$  is the cost misreporting coefficient of  $M_1$ ,  $k > 0$ .  $M_1$  will determine  $k$  with the goal of profit maximization.  $M_1$  may underestimate the production cost (i.e.,  $0 < k < 1$ ) to attract  $M_2$  in order to win the contract, or  $M_1$  may overstate the production cost (i.e.,  $k > 1$ ) to charge a higher wholesale price. We will investigate the optimal decision of  $k$  for  $M_1$  in this paper.  $P$  charges  $M_1$  a service fee  $s$  for the transaction,  $s > 0$ , and  $s$  is the decision variable of  $P$ . Since the fixed investment at the platform's start stage exerts no effect on our analytical results, the marginal service cost of processing online transactions is relatively low, and we normalize the platform's cost to zero. We consider that  $M_1$  can completely meet the capacity demand of  $M_2$ . In addition, to simplify the calculation and highlight the focus on production cost misreporting, we also normalize the unit inventory cost and the sales cost to zero. The notations in this paper are summarized in Table 1, and the supply chain structure of this article is shown in Figure 1. In this article, subscripts  $s$ ,  $m$ ,  $p$ , and  $sc$  represent  $M_1$ ,  $M_2$ ,  $P$ , and the entire SC; the subscript  $r$  represents the reaction function of a member's decision or profit to a certain decision variable.

**3.2. Decentralized Model with Real Cost Information (Model DR).** In this section, we first analyze decisions and profits of SC members when  $M_1$  reports real production costs. Profit functions of  $M_2$ ,  $M_1$ , and  $P$  are as follows:

TABLE 1: List of notations.

Notation	Definition
$D$	Market demand
$M_1$	Capacity provider
$M_2$	Capacity requestor
$P$	Manufacturing capacity sharing platform
$a$	Potential market size
$b$	Price sensitivity coefficient
$c$	Real unit product production cost of $M_1$
$k$	Cost misreporting coefficient, decision variable of $M_1$
$p$	Unit sales price of the product
$r$	Unit sales margin, decision variable of $M_2$
$s$	Unit service fee, decision variable of $P$
$w$	Unit wholesale price, decision variable of $M_1$
$\lambda$	Ratio of sales revenue shared by $M_1$ , $0 < \lambda < 1$
$\phi$	Proportion of production cost shared by $M_1$ , $0 < \phi < 1$
$\rho$	Service fee proportion, $0 < \rho < 1$
$\pi_s$	Profit of $M_1$
$\pi_m$	Profit of $M_2$
$\pi_p$	Profit of $P$
$\pi_{sc}$	Profit of the entire SC

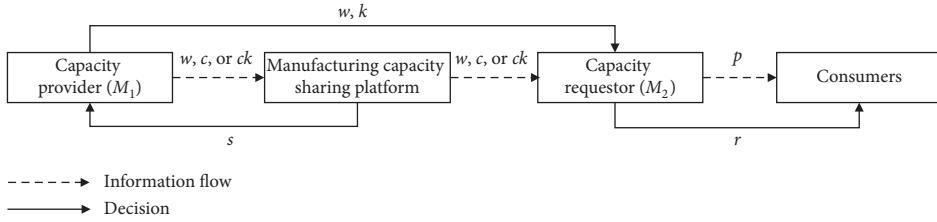


FIGURE 1: Supply chain structure.

$$\pi_m^{DR} = r(a - b(w + r)); \quad (1)$$

$$\pi_s^{DR} = (a - b(r + w))(w - c - s); \quad (2)$$

$$\pi_p^{DR} = s(a - b(w + r)). \quad (3)$$

Since this paper assumes that  $P$  is the leader of the SC and the channel power of  $M_2$  is higher than that of  $M_1$ , the decision-making process of SC members in this section is as follows.  $P$  first decides the service fee  $s$ ; then  $M_2$  determines the sales margin by  $r$ , and during this period,  $M_2$  should consider the reaction of  $M_1$ , and then  $M_1$  decides the wholesale price  $w$ . We adopt the backward induction to solve this Stackelberg game and derive the Proposition 1. Please refer to the Appendix for proofs of all propositions.

**Proposition 1.** When  $M_1$  discloses real cost information, equilibrium solutions and profits are given as follows:  $w^{DR} = (5a + 3bc)/(8b)$ ;  $r^{DR} = (a - bc)/(4b)$ ;  $s^{DR} = (a - bc)/(2b)$ ;  $\pi_s^{DR} = (a - bc)^2/(64b)$ ;  $\pi_m^{DR} = (a - bc)^2/(32b)$ ;  $\pi_p^{DR} = (a - bc)^2/(16b)$ ;  $\pi_{sc}^{DR} = 7(a - bc)^2/(64b)$ .

Proposition 1 shows that the profits of all SC members under the model DR increase with the market size and

decrease with the price sensitivity and the production cost. And, it is easy to get that the platform operator's profit is the highest compared with the profits of other SC members. It implies that changes in exogenous variables such as an increase in market size, a decrease in the cost of  $M_1$ , and a decrease in the sensitivity of consumers to product prices are beneficial to all SC members, while these changes benefit  $P$  the most.

**3.3. Decentralized Model with Cost Misreporting to  $M_2$  and  $P$  (Model DH).** In this section, we consider that  $M_1$  deliberately misreports its production cost information to both  $M_2$  and  $P$  and construct a decentralized decision-making game model. For example, Tao Factory platform in China provides in-depth factory inspection services. The capacity provider may deliberately misrepresent the production capacity information to the platform during the factory inspection or misreport the cost of raw materials and processing costs when making quotations. In this case, the profit function of  $M_2$  is the same as equation (1), the profit function of  $P$  is the same as equation (3), and the profit function of  $M_1$  thought by  $M_2$  and  $P$  is

$$\pi_s^{DH} = (a - b(r + w))(w - ck - s). \quad (4)$$

The real profit function of  $M_1$  is equal to equation (2). In model DH,  $M_1$  decides the optimal  $k$  to maximize its own

profit and then announces its own production cost as  $kc$ .  $M_2$  and the platform believe that  $kc$  is its true cost; similar to the sequence of decisions under the model DR, the platform first decides  $s$  and  $M_2$ , then decides  $r$ , and then  $M_1$  decides the wholesale price  $w$ . It is notable that when deciding  $w$ , the objective function of  $M_1$  is to maximize the profit function with cost misreporting, i.e., equation (4) instead of its real profit function equation (2). It is because that each of SC members can predict others' reactions to a certain decision under information disclosure.  $M_1$ 's pricing decision should coincide with its misreporting behavior [30].

**Proposition 2.** *The optimal response function of each SC member to the  $k$  under model DH:  $w_r^{DH} = (5a + 3bck)/(8b)$ ;  $r_r^{DH} = (a - bck)/(4b)$ ;  $s_r^{DH} = (a - bck)/(2b)$ , where  $0 < k < \bar{k} = a/(bc)$ .*

Proposition 2 shows that the wholesale price increases with the cost misreporting coefficient, the sales margin decreases with the cost misreporting coefficient, and the service fee decreases with the cost misreporting coefficient. By simple calculation, we can further know that the sales price increases with the cost misreporting coefficient. The service fee will also decrease with the cost misreporting coefficient. This shows that when  $M_1$  overstates cost information, its wholesale price will increase, and manufacturers will reduce sales margins in order to avoid excessively high sales prices that will affect sales volume. Since the sales price increases with the cost misreporting coefficient, the increase in the wholesale price has a greater impact on the sales price than the decrease of sales margin. Overstatement of cost information will adversely affect the customers' benefit. Based on the reaction functions in Proposition 2, we can derive the reaction function of  $M_1$ 's profit:

$$\pi_{sr}^D = \frac{(a - bck)(a + bc(-8 + 7k))}{64b}. \quad (5)$$

Taking the first derivative of  $\pi_{sr}^D$  with respect to  $k$ , we get  $\partial\pi_{sr}^D/\partial k = (1/32)c(3a + bc(4 - 7k))$ . Taking the second derivative of  $\pi_{sr}^D$  to  $k$  yields  $\partial^2\pi_{sr}^D/\partial k^2 = -(1/32)(7bc^2) < 0$ . Therefore, the optimal  $k$  can be obtained by solving the first-order condition and we can get the optimal cost misreporting coefficient as follows:

$$k^{DH} = \frac{3a + 4bc}{7bc}. \quad (6)$$

When  $0 < k < (3a + 4bc)/(7bc)$ ,  $\pi_{sr}^D$  is an increasing function of  $k$ ; when  $(3a + 4bc)/(7bc) < k < \bar{k}$ ,  $\pi_{sr}^D$  is a decreasing function of  $k$ . Due to  $a > bc$ , it is easy to get  $k^{DH} > 1$ . Therefore,  $M_1$ 's optimal strategy is to overstate the production cost to  $k^{DH}$ .  $M_1$ 's excessively overstatement on production cost information will damage its profit, since the excessively high production cost information will exert negative impacts on sales volumes which will be greater than the positive impact on wholesale prices with the increasing  $k$ .

Bringing the optimal cost misreporting coefficient  $k^{DH}$  into each reaction function in Proposition 2, we can obtain  $w^{DH} = (11a + 3bc)/(14b)$ ,  $r^{DH} = (a - bc)/(7b)$ ,  $s^{DH} = (2(a - bc))/(7b)$ ,  $\pi_s^D = (a - bc)^2/(28b)$ ,  $\pi_m^{DH} = (a - bc)^2/(144b)$ .

$(98b)$ ,  $\pi_p^{DH} = (a - bc)^2/(49b)$ , and  $\pi_{sc}^{DH} = 13(a - bc)^2/(196b)$ . Comparing the profits of SC members and the entire SC under model DH and model DR yields the results in Proposition 3.

**Proposition 3.**  $\pi_s^D > \pi_m^{DH} > \pi_p^{DH}$ ,  $\pi_s^D > \pi_s^{DR}$ ,  $\pi_m^{DH} < \pi_m^{DR}$ ,  $\pi_p^{DH} < \pi_p^{DR}$ , and  $\pi_{sc}^{DH} < \pi_{sc}^{DR}$ .

Proposition 3 indicates that the profit of  $M_1$  among the profits of SC members under model DH is the highest, and the profit of  $M_2$  is the lowest. In comparison to the model DR, the profit of  $M_1$  jumps from the lowest to the highest with cost misreporting. Proposition 3 shows that  $M_1$  will benefit from misreporting the production cost, which is unfavorable to both  $M_2$ 's profit and  $P$ 's profit. The reason is that overstating the cost will increase the sales price and reduce the sales volume, the sales margin, and the service fee, leading to the decrease in profits of  $M_2$  and  $P$ . Thereby, it is advisable for  $M_2$  and  $P$  to propose a contract for avoiding the cost misreporting behavior. Moreover, Proposition 3 also implies that the cost misreporting will cause losses to the entire SC, which shows the necessity of a hedging mechanism. As the rule maker of the platform and the leader of SC,  $P$  should actively inspire SC members to reach an agreement for SC coordination.

**3.4. Decentralized Model under Cost Misreporting with the Platform Operator's Acquiescence (Model DC).** In this section, we consider that  $M_1$  misrepresents the cost information.  $P$  is aware of  $M_1$ 's cost misreporting behavior and colludes with  $M_1$  by acquiescing in cost misreporting behavior to gain more profits. Specifically, the sequence of the Stackelberg game in model DC is as follows.  $P$  determines the service fee  $s$  with the knowledge of the real cost information  $c$ , and  $M_1$  determines  $k$  and  $M_1$  lies to  $M_2$  about the production cost information. Regarding  $kc$  as the real production cost,  $M_2$  decides the sales margin  $r$ .  $M_1$  then determines the wholesale price  $w$  to maximize its profits and ensure consistency with the misreporting behavior.

The profit function of  $M_2$  is the same as equation (1), and the profit function of  $P$  is the same as equation (3). The  $M_1$ 's profit function thought by  $M_2$  is equal to equation (4), and the  $M_1$ 's real profit function is the same as equation (2). Similar to the model DR, we adopt backward induction to solve this Stackelberg game and show the equilibrium solutions and profits in Proposition 4.

**Proposition 4.** *Under model DC, equilibrium solutions and profits are given as follows:  $k^{DC} = (1/6)((a/bc) + 5)$ ,  $w^{DC} = (3a + bc)/(4b)$ ,  $r^{DC} = (a - bc)/(6b)$ ,  $s^{DC} = (a - bc)/(2b)$ ,  $\pi_s^{DC} = (a - bc)^2/(48b)$ ,  $\pi_m^{DC} = (a - bc)^2/(72b)$ ,  $\pi_p^{DC} = (a - bc)^2/(24b)$ , and  $\pi_{sc}^{DC} = 11(a - bc)^2/(144b)$ .*

We can learn that the profit of  $P$  under model DC is the highest, and the profit of  $M_2$  is the lowest. It implies that after misreporting  $M_2$ 's profit became the lowest among the three SC members in both model DH and model DC, and after collision with  $M_1$ , the proportion of the  $P$ 's profit in the profit of entire SC turns back to the highest. We further

compare the equilibrium results of model DR, model DH, and model DC and obtain Proposition 5.

**Proposition 5.** (1)  $1 < k^{DC} < k^{DH}$ ,  $s^{DR} = s^{DC} > s^{DH}$ ,  $r^{DR} > r^{DC} > r^{DH}$ ,  $w^{DR} < w^{DC} < w^{DH}$ ,  $p^{DR} < p^{DC} < p^{DH}$ . (2)  $\pi_m^{DR} > \pi_m^{DC} > \pi_m^{DH}$ ,  $\pi_s^{DR} < \pi_s^{DC} < \pi_s^D$ ,  $\pi_p^{DR} > \pi_p^{DC} > \pi_p^{DH}$ , and  $\pi_{sc}^{DR} > \pi_{sc}^{DC} > \pi_{sc}^{DH}$ .

Proposition 5 points out that compared with misreporting costs to both  $M_2$  and  $P$ , the cost misreporting coefficient under collusion is lower, the platform service fee is higher, the sales margin is higher, the wholesale price is lower, and the final sales price is lower. Although the  $P$ 's profits in model DH and model DC are lower than those in model DR,  $P$  can gain more profits when colluding with  $M_1$  in comparison to model DH. The same applies to the profit of the entire SC. It implies that, under cost misreporting behavior,  $P$ 's collusion with  $M_1$  is conducive to both  $M_2$  and  $P$ . In contrast, misreporting to both  $M_2$  and the  $P$  is the most favorable to  $M_1$ . Therefore, it is easy for  $M_1$  to exaggerate production costs, which will be detrimental to  $M_2$ ,  $P$ , and the entire SC. Furthermore, for gaining more profits than that  $M_1$  can earn in model DR,  $M_1$  may be willing to pay a transfer payment which is up to the difference between  $M_1$ 's profit in model DC and  $M_1$ 's profit in model DR to  $P$  for persuading  $P$  to acquiesce in the cost misreporting behavior.  $M_2$  has a big motivation to initiate the coordination contract to avoid the cost misreporting behavior.

At present, many capacity sharing platforms are actively advocating the manufacturing enterprise's digital transformation, which can improve the visualization of the whole production process and strengthen real-time data interaction. It can help the capacity requestor and the platform operator monitor the operations of capacity provider to reduce the misstatement of information. However, the digitalization of SC is still in the early stage in China. For example, a small number of manufacturers have finished the digital transformation in the Tao factory platform. In this paper, we tried to use the coordination mechanism to avoid cost misreporting and improve the performance of SC.

#### 4. Coordination Contract for the SC

In this section, we first investigate the centralized decision model of the SC to find out the SC performance gap between decentralized and centralized settings and take the centralized model as the benchmark of SC coordination. Under centralized decision-making, SC members make decisions as an integrated entity, and their profit function is

$$\pi_{sc}^C = (p - c)(a - bp). \quad (7)$$

It is easy to derive the optimal sales price  $p^C = (a + bc)/(2b)$ . The optimal profit of the entire SC is given by  $\pi_{sc}^C = (a - bc)^2/(4b)$ . By comparing the decisions and profits under centralized and decentralized models, we can get Proposition 6.

**Proposition 6.**  $p^C < p^{DR} < p^{DC} < p^{DH}$  and  $\pi_{sc}^C > \pi_{sc}^{DR} > \pi_{sc}^{DC} > \pi_{sc}^{DH}$ .

Proposition 6 shows that the sales price under a centralized setting is lower than that under a decentralized setting. The profit of the entire SC is the highest under centralized setting, due to the double marginal effect and information misreporting in the decentralized setting.

Based on the equilibrium results in SC under a centralized setting, we explore the role of sales revenue-sharing and cost-sharing contracts in avoiding the cost of misreporting behavior and coordinating the SC. In this contract,  $M_2$  sells products directly to consumers at the wholesale price of  $M_1$  and shares part of the production cost of  $M_1$ . At the end of the sales season,  $M_1$  and  $M_2$  share sales revenue. For example, in the Tao Factory platform in China, the capacity requestor can choose to provide the raw materials of the product and bear the corresponding cost. Let  $\lambda$  denote the ratio of sales revenue shared by  $M_1$ ,  $0 < \lambda < 1$ ; let  $\phi$  represent the proportion of production cost-shared by  $M_1$ ,  $0 < \phi < 1$ . Thus, the proportion of sales revenue shared by  $M_2$  is  $1 - \lambda$ , and the proportion of production cost borne by  $M_2$  is  $1 - \phi$ . We assume the unit service fee charged by  $P$  is proportional to the wholesale price, which is denoted by  $s = \rho w$ , where  $\rho$  is the service fee proportion. On this basis, the profit functions of  $M_1$ ,  $M_2$ , and  $P$  under the sales-revenue-sharing and cost-sharing contract are as follows:

$$\pi_s^{RS} = (a - bw)(-ck\phi + \lambda w - \rho w); \quad (8)$$

$$\pi_m^{RS} = (1 - \lambda)w(a - bw) - ck(1 - \phi)(a - bw); \quad (9)$$

$$\pi_p^{RS} = \rho w(a - bw). \quad (10)$$

When  $k = 1$ , equations (7) and (8) are, respectively, the profits of  $M_1$  and  $M_2$  when  $M_1$  reports real production cost. Under the sales revenue-sharing and cost-sharing contract,  $M_1$  and  $M_2$  negotiate on the value of  $\lambda$  and  $\phi$ . On this basis, the decision-making sequence is as follows:  $P$  determines the proportion  $\rho$ , and then  $M_1$  decides the cost misreporting coefficient  $k$  and the wholesale prices  $w$ . Using backward induction, we get the sales revenue-sharing and cost-sharing contract as shown in Proposition 7.

#### Proposition 7

(1) In the sales revenue-sharing and cost-sharing contract,  $\rho = \lambda - \phi$ ;  $k^{RS} = 1$ ,  $w^{RS} = (a + bc)/(2b) = p^C$ ,  $\pi_s^{RS} = (\phi(a - bc)^2)/(4b)$ ,  $\pi_m^{RS} = (bc - a)(a(\lambda - 1) + bc(\lambda - 2\phi + 1))/(4b)$ ,  $\pi_p^{RS} = (\lambda - \phi)(a - bc)(a + bc)/(4b)$ , and  $\pi_{sc}^{RS} = (a - bc)^2/(4b) = \pi_{sc}^C$ .

(2) When  $1/7 \leq \phi \leq 5/8$  and  $(4a\phi + a + bc(4\phi - 1))/(4(a + bc)) \leq \lambda \leq (7a + bc(16\phi - 7))/(8(a + bc))$ , we can ensure  $0 < \rho < 1$  and  $\pi_s^{RS} \geq \max\{\pi_s^{DR}, \pi_s^D, \pi_s^{DC}\}$ ,  $\pi_m^{RS} \geq \max\{\pi_m^{DR}, \pi_m^D, \pi_m^{DC}\}$ , and  $\pi_p^{RS} \geq \max\{\pi_p^{DR}, \pi_p^D, \pi_p^{DC}\}$ .

Proposition 7 shows that, under the sales revenue-sharing and cost-sharing contract, the supplier will choose to report the true cost. Thereby, this contract can effectively avoid the cost misreporting behavior of  $M_1$ . The profit of the entire SC has also reached the profit of SC under a

centralized setting. Under the conditions of the parameters given in Proposition 7, the profit of each SC member is not lower than their respective profit under a decentralized setting. Therefore, the sales revenue-sharing and cost-sharing contract can coordinate the SC.

The platform should act as the coordinator in the capacity sharing transaction and be committed to improving the performance of the entire SC rather than focusing solely on its own profits. Although  $P$ 's profit increases with the service fee proportion,  $P$  should set the proportion with a moderate value, i.e.,  $\lambda - \phi$ , to facilitate the coordination of SC. When  $P$  offers order processing supervision service, the order supervisor is suggested to actively facilitate the coordination contract in the SC. For example, in Tao factory platform, instead of punishing the supplier which misreports cost information and offers false quotation as mentioned in Introduction, the platform operator can utilize the coordination contract to address the essential drive of the misreporting behavior.

On the premise of guaranteeing that each SC member's profit with coordination contract is no less than that without coordination contract,  $M_2$  can properly concede to  $M_1$  in the bargaining of  $\lambda$  and  $\phi$ , so as to encourage  $M_1$ 's acceptance of the coordination contract. It is advisable for  $M_1$  to sign the coordination contract to improve its own profit and benefit the entire SC. It is worth noting that the wise strategy for the  $M_1$  in reaching the coordination contract is to struggle for a higher production cost-sharing ratio.

## 5. Numerical Analysis

On the manufacturing capacity sharing platform, the market demand faced by  $M_2$  is given by  $D = 10 - 0.5p$ , i.e., the potential market size  $a = 10$ , and the customers' price sensitivity coefficient for the product  $b = 0.5$ ;  $M_2$  seeks product processing capacity through the platform, and  $M_1$  on the platform reached a processing agreement with it. The actual product production cost of  $M_1$  is  $c = 0.2$ . Bringing these parameter values into Proposition 7, we can get the range of  $\lambda$  and  $\phi$  that can coordinate the SC, as shown in Figure 2. When  $\lambda$  and  $\phi$  lie within the range of triangle ABC (including three sides and vertices) in Figure 2, the contract can effectively coordinate the SC.

To visually show the coordination effect of this contract, Table 2 gives profits of SC members and the entire SC before and after coordination. First, we can derive the optimal sales price of the SC is  $p = 10.1$  under centralized setting, and the profit of entire SC is  $\pi_{sc}^C = 49$ . Table 2 shows that the relationship between the profits of SC members and the entire SC under a decentralized setting before coordination verifies Proposition 5. The profit of the entire SC under each decentralized model is much lower than that under the centralized setting, which demonstrates the Proposition 6. With the coordination of sales revenue-sharing and cost-sharing contracts, the profit of the entire SC can reach the level of centralized setting, which verifies Proposition 7. Table 1 also shows that if parameters  $\lambda$  and  $\phi$  are defined as point A in Figure 2,  $M_1$  is the biggest beneficiary after coordination. Similarly,  $M_2$  benefits the most from the

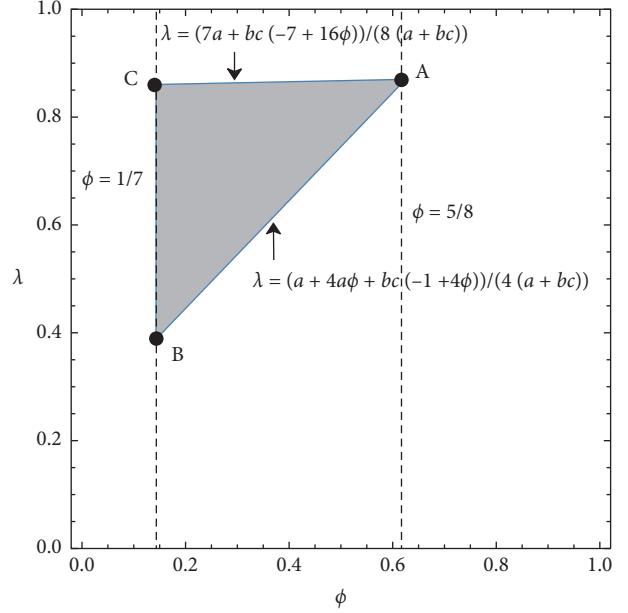


FIGURE 2: The range of  $\lambda$  and  $\phi$  when achieving SC coordination.

TABLE 2: Effect of the coordination contract on profits of SC members and the entire SC.

	$\lambda$	$\phi$	$\pi_s$	$\pi_m$	$\pi_p$	$\pi_{sc}$
Model DR	—	—	3.06	6.13	12.25	21.44
Model DH	—	—	7	2	4	13
Model DC	—	—	4.08	2.72	8.17	14.97
Figure 2, point A	0.87	0.625	30.63	6.13	12.25	49
Figure 2, point B	0.39	0.14	7	29.75	12.25	49
Figure 2, point C	0.86	0.14	7	6.15	35.85	49

coordination contract when  $\lambda$  and  $\phi$  are defined as point B in Figure 2; the platform operator's profit is improved to the largest extent under the coordination contract if  $\lambda$  and  $\phi$  are defined as point C in Figure 2. The values of  $\lambda$  and  $\phi$  reflect the negotiation power of  $M_1$  and  $M_2$ .

The sales revenue-sharing and cost-sharing contract designed in this paper serve as guidance for  $P$  to inspire the collaboration among SC members. A moderate service fee, which equals to the difference between the revenue-sharing ratio and the cost-sharing proportion, is critical to facilitate the coordination. The ranges of the revenue-sharing ratio and production cost-sharing proportion derived in this paper provide references for  $M_1$  and  $M_2$  in their negotiation. It is wise for  $M_2$  to assume a greater share of production cost in the meantime of struggling for a higher share of sales revenue, in order to achieve profit maximization. Under the service fee charged by  $P$ ,  $M_1$  is prone to share a large ratio of the production cost, since the service fee proportion in the coordination contract decreases with the production cost-sharing ratio.

## 6. Conclusions

In the manufacturing capacity sharing platform, the transactions between capacity requestors and capacity

providers are often short-term and flexible. Although the platform can conduct qualification supervision on participants, the platform cannot fully control the production capacity information disclosed by participants due to limitations of current technology and management capacity. Capacity providers can easily use their information advantages to generate opportunistic behavior. And, the platform may collude with it for the purpose of profit-seeking and acquiesce in the opportunistic behavior, which will affect the interests of capacity requestors and even damage the overall performance of the SC. This paper investigates a SC consisting of a capacity requestor, a capacity provider, and a platform operator. Taking the cost misreporting behavior of capacity providers into account, we use game theory to analyze the decisions and profits of SC members in models of disclosing the real cost information, misreporting cost information to both the capacity requestor and the platform operator and misreporting cost to the capacity requestor with the acquiescence of the platform operator. By comprehensive comparisons between decisions and profits in different models, we examine the influence of cost misreporting and the platform's collusion. Finally, we propose the coordination contract for the SC to avoid the cost misreporting behavior and improve the performance of the SC. The main findings are as follows.

In the manufacturing capacity sharing platform, capacity providers have the incentive to overstate the production cost, and they can set higher wholesale prices by misrepresenting their production costs. Exaggerating production cost within a certain range can help capacity providers gain more profits, while the excessive exaggeration will be detrimental to their own interests. When the capacity provider overstates the cost information, the sales price will increase, profits of the capacity requestor and the platform operator will be damaged, and the profit of the entire SC will also decline. Compared with misreporting to both the platform operator and the capacity requestor, the platform operator's collusion with the capacity provider is favorable to the capacity requestor and the platform operator. However, the capacity provider will be inclined to lie to both of them. The sales revenue-sharing and cost-sharing contract can effectively avoid cost misreporting behavior of the capacity provider, and when the revenue-sharing ratio and cost-sharing proportion are within a certain range, the contract can improve the supply chain members' profit and achieve the SC coordination.

Theoretically, this paper enriches the literature on production cost information asymmetry and capacity sharing SC by investigating the cost of misreporting behavior in the context of capacity sharing SC and by considering the service fee decision and the possible acquiescence behavior of the capacity sharing platform. Besides, the sales revenue-sharing and cost-sharing contracts proposed in this paper throw lights on supply chain coordination under cost information asymmetry. In practice, the platform operator is suggested to facilitate the coordination contract designed in this paper when handling the capacity transaction between the capacity provider and the capacity requestor.

This paper has conducted research on the capacity provider's cost misreporting behavior in the capacity sharing SC. This paper provides a reference for the future research on opportunistic behavior in capacity sharing transaction. However, we made some assumptions to simplify the calculation such as the linear demand function. Relaxing these assumptions may generate different results. In the future, we can further explore other opportunistic behaviors such as falsely reporting production capacity. And, the problem of joint supply under capacity insufficiency of a single capacity provider under the impact of opportunistic behavior is also an interesting direction. Exploring how the government can govern the platform is also one of future research directions.

## Appendix

### Proof of Proposition 1

Taking the second derivative of  $\pi_s^{DR}$  with respective to  $w$ , we can get  $\pi_s^{DR''} = -2b < 0$ . It implies that there exists the optimal  $w$  to maximize  $\pi_s^{DR}$ , which satisfies  $\pi_s^{DR'} = 0$ . Solving  $\pi_s^{DR'} = a - b(-c + w - s) - b(r + w) = 0$  yields  $w_r^{DR} = (a + b(c - r + s))/(2b)$ . Substituting  $w_r^{DR}$  into  $\pi_m^{DR}$ , we can get that  $\pi_m^{DR} = -(1/2)r(b(c + r + s) - a)$ . Similarly, taking the second derivative of  $\pi_m^{DR}$  with respective to  $r$ , we can get  $\pi_m^{DR''} = -b < 0$ . Solving the first-order condition, we can get that  $r^{DR} = (a - b(c + s))/(2b)$ . Substituting  $w_r^{DR}$  and  $r_r^{DR}$  into  $\pi_p^{DR}$ , we can get  $\pi_p^{DR} = -(1/4)s(b(c + s) - a)$ . Taking the second derivative of  $\pi_p^{DR}$  with respective to  $s$ , we can get  $\pi_p^{DR''} = -(b/2) < 0$ . Solving the first-order condition, we can get that  $s^{DR} = (a - bc)/(2b)$ . On the basis of  $s^{DR}$ ,  $w_r^{DR}$ , and  $r_r^{DR}$ , we can derive the optimal  $w^{DR}$  and  $r^{DR}$ . Bringing  $w_r^{DR}$ ,  $r_r^{DR}$ , and  $s^{DR}$  back to the profit functions, we can get  $\pi_s^{DR}$ ,  $\pi_m^{DR}$ ,  $\pi_p^{DR}$ , and  $\pi_{sc}^{DR}$ .

### Proof of Proposition 2

Taking the second derivative of  $\pi_s^{DH}$  with respective to  $w$ , we can get  $\pi_s^{DH''} = -2b < 0$ . It implies that there exists the optimal  $w$  to maximize  $\pi_s^{DH}$ . Solving  $\pi_s^{DH'} = a - b(-ck + w - s) - b(r + w) = 0$  yields  $w_r^{DH} = (a + b(ck - r + s))/(2b)$ . Substituting  $w_r^{DH}$  into  $\pi_m^{DH}$ , we can get  $\pi_m^{DH} = -(1/2)r(b(ck + r + s) - a)$ . Similarly, taking the second derivative of  $\pi_m^{DH}$  with respective to  $r$ , we can derive  $\pi_m^{DH''} = -b < 0$ . Solving the first-order condition yields  $r_r^{DH} = (a - b(ck + s))/(2b)$ . Substituting  $w_r^{DH}$  and  $r_r^{DH}$  into  $\pi_p^{DH}$ , we can get  $\pi_p^{DH} = -(1/4)s(b(ck + s) - a)$ . Taking the second derivative of  $\pi_p^{DH}$  with respective to  $s$ , we can get  $\pi_p^{DH''} = -(b/2) < 0$ . Thus, we solve the first-order condition and derive that  $s^{DH} = (a - bck)/(2b)$ . To ensure all decisions are positive,  $k$  should satisfy  $k < a/(bc)$ , and let  $\bar{k} = a/(bc)$ .

### Proof of Proposition 3

$$\begin{aligned} \pi_s^D - \pi_p^{DH} &= (3(a - bc)^2)/(196b) > 0. & \pi_p^{DH} - \pi_m^{DH} &= (a - bc)^2/(98b) > 0. & \pi_m^{DH} - \pi_{sc}^{DH} &= 9(a - bc)^2/(448b) > 0. & \pi_{sc}^{DH} - \pi_m^{DH} &= -33(a - bc)^2/(1568b) < 0. & \pi_p^{DH} - \pi_s^{DR} &= -33(a - bc)^2/(784b) < 0. & \pi_{sc}^{DH} - \pi_s^{DR} &= -135(a - bc)^2/(3136b) < 0. \end{aligned}$$

## Proof of Proposition 4

Since  $\partial^2 \pi_s / \partial w^2 = -2b < 0$ , we can get  $w_r^{DC} = (a + b(ck + s - r)) / (2b)$  by solving the first-order condition; Substituting  $w_r^{DC}$  into  $\pi_m^{DC}$ , we can get  $\partial^2 \pi_m / \partial r^2 = -b < 0$ . Solving the first-order condition, we can get  $r = (a - b(s + ck)) / (2b)$ , since the objective function of  $M_1$  when deciding the optimal  $k$  is its real profit function with the real production cost. Since  $\partial^2 \pi'_s / \partial k^2 = -1/8(3bc^2)$ , we can get the optimal reaction function  $k = (a + 2bc - bs) / (3bc)$  by solving the first-order condition. Finally, substituting  $w_r^{DC}, r_r^{DC}$ , and  $k_r^{DC}$  into  $\pi_p^{DC}$  and taking the second derivative, we can get  $\partial^2 \pi_p / \partial s^2 = -b/3 < 0$ . Then, solving the first-order condition yields  $s = (a - bc) / (2b)$ . Substituting the optimal  $s$  into the abovementioned reaction functions, we can get the optimal decisions and profits, respectively.

## Proof of Proposition 5

- (1) Since  $k^{DH} - k^{DC} = (11(a - bc)) / (42bc) > 0$  and  $k^{DC} = 1/6((a/bc) + 5) > 1$ , we can get  $1 < k^{CC} < k^{CH}$ . Since  $s^{DR} = s^{DC}$  and  $s^{DC} - s^{DH} = 3(a - bc) / (14b) > 0$ , we have  $s^{DR} = s^{DC} > s^{DH}$ . Since  $r^{DR} - r^{DC} = (a - bc) / (12b) > 0$  and  $r^{DC} - r^{DH} = (a - bc) / (42b) > 0$ , we can get  $r^{DR} > r^{DC} > r^{DH}$ . Since  $w^{DR} - w^{DC} = -(a - bc) / (8b) < 0$  and  $w^{DC} - w^{DH} = -(a - bc) / (28b) < 0$ , we derive  $w^{DR} < w^{DC} < w^{DH}$ . Since  $p^{DC} - p^{DH} = -(a - bc) / (84b) < 0$  and  $p^{DC} - p^{DR} = (a - bc) / (24b) > 0$ , we have  $p^{DR} < p^{DC} < p^{DH}$ .
- (2) Since  $\pi_m^{DR} - \pi_m^{DC} = 5(a - bc)^2 / (288b) > 0$  and  $\pi_m^{DC} - \pi_m^{DH} = 13(a - bc)^2 / (3528b) > 0$ , we get  $\pi_m^{DR} > \pi_m^{DC} > \pi_m^{DH}$ . Since  $\pi_s^{DR} - \pi_s^{DC} = -(a - bc)^2 / (192b) < 0$  and  $\pi_s^{DC} - \pi_s^D = -5(a - bc)^2 / (336b) < 0$ , we have  $\pi_s^{DR} < \pi_s^{DC} < \pi_s^D$ . Since  $\pi_p^{DR} - \pi_p^{DC} = (a - bc)^2 / (48b) > 0$  and  $\pi_p^{DC} - \pi_p^{DH} = 25(a - bc)^2 / (1176b) > 0$ , we can get  $\pi_p^{DR} > \pi_p^{DC} > \pi_p^{DH}$ . Since  $\pi_{sc}^{DR} - \pi_{sc}^{DC} = 19(a - bc)^2 / (576b) > 0$  and  $\pi_{sc}^{DC} - \pi_{sc}^{DH} = 163(a - bc)^2 / (3528b) > 0$ , we have  $\pi_{sc}^{DR} > \pi_{sc}^{DC} > \pi_{sc}^{DH}$ .

## Proof of Proposition 6

Since  $p^C - p^{DR} = -3(a - bc) / (8b) < 0$ , we have  $p^C < p^{DR}$ . Since  $p^C - p^{DH} = -3(a - bc) / (7b) < 0$ , we get  $p^C < p^{DH}$ . Considering  $p^{DR} < p^{DC} < p^{DH}$  in Proposition 5, we can get  $p^C < p^{DR} < p^{DC} < p^{DH}$ . Since  $\pi_{sc}^C - \pi_{sc}^{DR} = 9(a - bc)^2 / (64b) > 0$ , we can get  $\pi_{sc}^C > \pi_{sc}^{DR}$ . Considering  $\pi_{sc}^{DH} < \pi_{sc}^{DC} < \pi_{sc}^{DR}$  in Proposition 5, we have  $\pi_{sc}^C > \pi_{sc}^{DR} > \pi_{sc}^{DC} > \pi_{sc}^{DH}$ .

## Proof of Proposition 7

- (1) Taking the second derivative of  $\pi_s$  with respective to  $w$ , we can get  $\partial^2 \pi_s / \partial w^2 = 2b(\rho - \lambda)$ , Since  $\rho < \lambda$ , we have  $\partial^2 \pi_s / \partial w^2 < 0$  and there exists the optimal  $w$  to maximize  $\pi_s^{DR}$ .  $w_r^{RS} = (-\alpha\lambda + \alpha\rho - bck\phi) / (2bp - 2b\lambda)$ . The  $w_r^{RS}$  predicted by  $M_2$  and the platform operator is given by  $w_r^{RS} = (-\alpha\lambda + \alpha\rho - bck\phi) / (2bp - 2b\lambda)$ .

Substituting the  $w_r^{RS}$  into  $M_1$ 's product function with real cost information, we can get that  $\pi_s = ((a(\lambda - \rho) + bc(k - 2)\phi) - (a(\rho - \lambda) + bck\phi)) / (4b(\rho - \lambda))$ . Taking the second derivative of  $\pi_s$  with respective to  $k$  yields  $\partial^2 \pi_s / \partial k^2 = bc^2\phi^2 / (2\rho - 2\lambda) < 0$ . And thus, there exists the optimal  $k$  to maximize  $\pi_s$ . Solving the first-order condition  $\partial \pi_s / \partial k = (bc^2(k - 1)\phi^2) / (2(\rho - \lambda)) = 0$  yields  $k^{RS} = 1$ . Therefore, the optimal strategy of  $M_1$  is to disclose the real cost information and thus  $w_r^{RS} = (-\alpha\lambda + \alpha\rho - bck\phi) / (2bp - 2b\lambda)$ . To achieve the SC coordination, the sales price in the coordination contract should be equal to that in SC under decentralized setting, i.e.,  $(-\alpha\lambda + \alpha\rho - bck\phi) / (2bp - 2b\lambda) = (a + bc) / (2b)$ . To facilitate the coordination contract, the platform operator should set the service fee proportion as  $\rho = \lambda - \phi$ .

To ensure  $\rho > 0, \lambda > \phi$  should be satisfied. Therefore, in the coordination contract,  $k = 1, \rho = \lambda - \phi$ , and  $w^{RS} = (a + bc) / 2b = p^C$ . The profits of SC members can be given by  $\pi_s^{RS} = \phi(a - bc)^2 / (4b), \pi_m^{RS} = ((bc - a)(a(\lambda - 1) + bc(\lambda - 2\phi + 1))) / (4b)$ , and  $\pi_p^{RS} = ((\lambda - \phi)(a - bc)(a + bc)) / (2b)$ . The profit of entire SC is  $\pi_{sc}^{RS} = (a - bc)^2 / (4b)$ .

- (2) Since  $\max\{\pi_s^{DR}, \pi_s^D, \pi_s^{DC}\} = \pi_s^D, \max\{\pi_m^{DR}, \pi_m^{DH}, \pi_m^{DC}\} = \pi_m^{DR}$ , and  $\max\{\pi_p^{DR}, \pi_p^{DH}, \pi_p^{DC}\} = \pi_p^{DR}$ , we can get  $\phi \geq (1/7)$  by solving  $\pi_s^{RS} \geq \pi_s^D$ . Solving  $\pi_m^{RS} \geq \pi_m^{DR}$  yields  $\lambda \leq (7a + bc(16\phi - 7)) / (8(a + bc))$ . Solving  $\pi_p^{RS} \geq \pi_p^{DR}$ , we can get  $\lambda \geq (4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$ . Taking the intersection of these three range, we can derive the conditions that  $\lambda$  and  $\phi$  should satisfy.

Comparing  $(7a + bc(16\phi - 7)) / (8(a + bc))$  with 0 and 1, we know that  $0 < (7a + bc(16\phi - 7)) / (8(a + bc)) < 1$ . Similarly, comparing  $(4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$  with 0 and 1, we get that  $(4a\phi + a + bc(4\phi - 1)) / (4(a + bc)) > 0$ ; when  $\phi < (3a + 5bc) / (4a + 4bc), (4a\phi + a + bc(4\phi - 1)) / (4(a + bc)) < 1$ . Comparing  $(7a + bc(16\phi - 7)) / (8(a + bc))$  and  $(4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$ , we know that when  $\phi > (5/8), (7a + bc(16\phi - 7)) / (8(a + bc)) < (4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$ . Under such situation,  $\lambda \leq (7a + bc(16\phi - 7)) / (8(a + bc))$  and  $\lambda \geq (4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$  have no intersection. When  $\phi \leq (5/8), (7a + bc(16\phi - 7)) / (8(a + bc)) \geq (4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$ . Since  $\phi \leq (5/8)$  also satisfies  $\phi < (3a + 5bc) / (4a + 4bc)$ , and  $\lambda \geq (4a\phi + a + bc(4\phi - 1)) / (4(a + bc))$  satisfies  $\lambda > \phi$ ; therefore,  $(4a\phi + a + bc(4\phi - 1)) / (4(a + bc)) \leq \lambda \leq 7a + bc(16\phi - 7) / (8(a + bc))$ . The conditions that the parameters should satisfy are given by  $1/7 \leq \phi \leq 5/8$  and  $(4a\phi + a + bc(4\phi - 1)) / (4(a + bc)) \leq \lambda \leq (7a + bc(16\phi - 7)) / (8(a + bc))$ .

## Data Availability

The data used to support the findings of our paper have been included within the article.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

The research was supported by the National Natural Science Foundation of China (Grant number 71472134).

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