

Research Article

Contract Strategies in Competing Supply Chains with Risk-Averse Suppliers

Baixun Li,¹ Yongwu Zhou,² and Baozhuang Niu³

¹ School of Business Administration, Guangdong University of Finance and Economics, Guangzhou 510320, China

² School of Business Administration, South China University of Technology, Guangzhou 510640, China

³ Lingnan College, Sun Yat-sen University, Guangzhou 510275, China

Correspondence should be addressed to Baozhuang Niu; niubzh@mail.sysu.edu.cn

Received 2 August 2013; Accepted 22 September 2013

Academic Editor: Tsan-Ming Choi

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This paper investigates the equilibrium contract strategies of two competing supply chains. Each chain is composed of one risk-averse supplier and one risk-neutral retailer. The two suppliers, as Stackelberg leaders, can choose either wholesale price or revenue sharing contract. We compare the outcomes obtained from different scenarios and study the impact of competition density and risk attitudes on the suppliers' contract choices. We find that it is always optimal for the first-moving supplier to choose revenue sharing contract if the follower chooses wholesale price contract. We also find that the retail price under revenue sharing contract is lower than that under wholesale price contract. Compared to Pan et al. (2010), we find that a threshold policy with respect to the degree of product substitutability holds in a sequential competition environment. There also exists a threshold policy with respect to the degree of risk aversion for the suppliers to choose their individual contract types and the corresponding chain-to-chain contract strategies.

1. Introduction

Nowadays, with the development of information technology, many “pure” service companies have arisen, such as Expedia, Alibaba.com, Ctrip.com, and China Mobile. In these companies, no physical products are sold—what they can provide are intangible products, that is, services. Even some companies, who traditionally produce and sell physical products, are changing to be service providers. One typical example is IBM, who uses its LotusLive Connections to apply a new business model named “Software-as-a-Service (SaaS)”, under which customers need only “pay a subscription fee to use a software over the internet” [1]. To find more customers, these service companies rely on agents/retailers and hence form service supply chains. For example, China Mobile contracts with agents to sell its telecommunication services. As the key supply chain member, China Mobile is very powerful. They determine the service charges, the service contracts, and so on. Retailers just follow China Mobile's decisions to earn some agent fee.

Similar phenomena can be observed in nonservice supply chains. For example, in the petrol retailing industry, Caffarra and Mattei [2] find that UK oil companies hold the right of selecting the organizational structures (and hence the contract parameters such as the wholesale price) in their retail networks. It is suggested that the petrol suppliers would be significantly “rewarded or penalized” according to their contract strategies. For the other industries, such as the electronic industry [3, 4], the television industry [5], and the agriculture industry [6], the determination of contract type and/or parameters are continuously discussed and investigated. This indicates that the competing suppliers, especially those who sell their products through retailers, must be very careful at the contract design stage so as to gain some competitive advantages.

In practice, different suppliers may choose different kinds of contracts with retailers. A variety of contractual relationships have been discussed in the literature, for example, wholesale-price contract [7], revenue sharing contract [8], quantity-discount contract [9], and consignment contract

[10]. See Cachon [11] for the literature review on supply chain contracts. Among these studies, we note that Pan et al. [8] study the contract choice problems (revenue sharing versus wholesale price) by assuming two competing manufacturers make their decisions simultaneously, which is reasonable but ignores the more common sequential-moving supply chains. Therefore, in this paper, we relax their assumption and examine scenarios where suppliers have imbalanced power, so that suppliers can act as Stackelberg leaders. Such supply chains can be found in many industries, for example, the domestic appliance industry, tourism industry, telecommunication industry, and beverage industry. Moreover, we note that more and more suppliers are concerning the loss minimization of their companies; thus, it is important to investigate the role of risk aversion in the competing supply chains. Tsay [12] points out that the “risk sensitivity” has an important impact on the decisions of the supply chain members. However, few studies have addressed risk aversion in chain-to-chain competition environments. Thus, in this paper, we relax the risk-neutral assumption of Pan et al. [8] to examine scenarios where suppliers are risk-averse, and analyze the effects of the degree of risk aversion on the suppliers’ contract decisions. Readers hence can view this paper as an extension of that of Pan et al. [8] with the consideration of sequential-moving supply chains and risk-averse suppliers.

Our analysis leads to the following insights. (I) Revenue sharing contract is the best option for the first-moving supplier if the follower chooses wholesale price contract, regardless of the degree of competition density and risk aversion. However, if the follower chooses revenue sharing contract, it is possible for the leader to choose wholesale price contract. (II) There exist threshold policies with respect to the degree of competition density and risk aversion for the suppliers to choose contract strategies. The retail price under revenue sharing contract is lower than that under wholesale price contract. Thus, if the follower could not afford the loss due to low retail price, he/she has incentives to switch to wholesale price contract.

The remainder of this paper is organized as follows. Section 2 briefly reviews related literature. Section 3 presents our basic model. Section 4 derives close form equilibrium solutions for different contract structures, including the WW, WR, RW, and RR cases. Section 5 compares the equilibrium profits under different cases and identifies the conditions under which the suppliers should choose wholesale price contract or revenue sharing contract. Finally, we summarize the paper and suggest research extensions in Section 6.

2. Literature Review

This paper is related to the work on chain-to-chain competition. McGuire and Staelin [13] investigate the effect of product substitutability on the suppliers’ decision of integrating with an outside retailer or not. Trivedi [14] looks into two manufacturers and two common retailers and analyzes the effect of product and channel substitution. Boyaci and Gallego [15] consider a market comprising two supply chains

and explore the value and limitation of channel coordination. Wu et al. [16, 17] extend the seminal work of McGuire and Staelin [13] by considering demand uncertainty. They build competitive newsvendor models to investigate the channel design problems. Allon and Federgruen [18] build multiple stage models to study competition in the service industries. Shou et al. [19] study the chain-to-chain competition problems with the consideration of supply uncertainty. Chiu et al. [20] consider price-dependent demand and study methods to avoid price war among multiple retailers. Xie et al. [21] consider the selection of supply chain structures and quality improvement strategies of two supply chains. Li et al. [22] investigate the channel choice problem in two competing supply chains with asymmetric cost information. Different from the aforementioned literature, we study the contract strategies with the consideration of sequential-moving supply chains and risk-averse suppliers.

The literature on supply chain contract is also related. Cachon [11] gives an excellent review on supply chain contract and coordination. This work has extensively reviewed the one-to-one or one-to-N supply chain structures (see, e.g., [23–25]). One conclusion is that the wholesale-price contract is Pareto inferior for the supply chain, which leads to the double marginalization effect. To eliminate the double marginalization effect, manufacturers need to design sophisticated contracts, such as quantity flexibility contract, quantity discount contract, and revenue sharing contract. However, are sophisticated contracts always better for all the supply chains?

Recently, some papers find that the degree of competition has a significant impact on the contract choice decision. Ha and Tong [26] investigate contracting and information sharing problems in two competing supply chains. They highlight that contract type is a key driver of the value of information sharing. Differing from Ha and Tong [26], Ha et al. [27] assume imperfect demand signals, production diseconomy, and both Cournot and Bertrand competition with differentiated products. Cachon and K ok [9] study the problem of contract choice in the supply chain structure comprising two competing manufacturers and a single retailer. They show that sophisticated contracts (e.g., quantity discount, two-part tariff contract) may make manufacturers worse off and the retailer substantially better off. Pan et al. [8] discuss different contract strategies (wholesale price contract versus revenue sharing contract) under both manufacturer dominated and retailer dominated scenarios in a supply chain with either two-one structure or one-two structure. Zhao and Shi [10] consider two supply chains, each with multiple upstream suppliers producing complementary products and selling to a single buyer. They focus on the channel structure (integration versus decentralization) issues and the contract strategies (wholesale price contract versus revenue sharing contract) issues. Ai et al. [28] demonstrate the impact of demand uncertainty and retailers’ forecasting precision on contract decisions of the manufacturers in two competing supply chains. Feng and Lu [7] analyze contract strategies in a supply chain comprising two competing manufacturers and two competing retailers. They derive the outcomes of Stackelberg games via generalized Nash bargaining scheme. Li et al. [29] explore the effect of supply chain structure

and competition at both manufacturer and retailer levels on contract choices of two competing supply chains.

In the literature above, most studies assume that manufacturers are risk-neutral. When facing random demand, however, the manufacturers will be more concerned with the risk associated with demand uncertainties. The inclusion of risk into decision making has gained increasing interest in supply chain studies (e.g., [30–34]). Different methods have been used to study risk aversion; for example, Hsieh and Lu [35] characterize each retailer's risk-embedded objects and compare them with conditional value-at-risk. They study the manufacturer's return policy and the retailers' decisions. Caliskan-Demirag et al. [36] model risk aversion by adopting the conditional-value-at-risk (CVaR) decision criterion, and analyze the manufacturer's rebate amount decisions and the retailer's joint inventory and pricing decisions.

Some other papers develop the risk aversion model in a mean-variance framework. Chen and Seshadri [37] consider a single period model in which multiple risk-averse retailers purchase a single product from a common distributor with a mean-variance utility approach. Choi et al. [38] carry out a mean-variance analysis of the newsvendor problems. Choi and Chow [39] study quick response program using a mean-variance approach. Xiao and Choi [40] focus on channel structure strategies in a two-echelon system consisting of two manufacturers and two retailers, where all players are risk-averse. Wei and Choi [32] explore the use of wholesale price contract and profit sharing contract to coordinate supply chains under the mean-variance decision framework. Chiu et al. [41] carry out a mean-variance analysis of supply chains under target sales rebate contracts. Chiu et al. [42] explore the performance of sales rebate contract in fashion supply chains under a mean-variance framework. Ma et al. [43] examine the impact of bargaining powers and the retailer's risk attitudes using a CVaR framework. Li et al. [44] conduct a mean variance analysis of a fast fashion supply chain with return policy. Ma et al. [45] study the inventory control problem for a loss-averse retailer with financial constraint in a finite periodic review system. Shen et al. [46] explore how markdown money policy performs in a two-stage TC/fashion supply chain with an upstream risk-averse manufacturer and a downstream risk-neutral retailer under the mean-variance framework. See Chiu and Choi [47] for an excellent review of this line of literature.

Our paper is most closely related to Cachon and Kök [9], Pan et al. [8], Feng and Lu [7], and Li et al. [29]. We extend their models in two dimensions. First, we examine scenarios where manufacturers have imbalanced power, so that manufacturers can move first. Second, we examine scenarios where manufacturers are risk-averse and investigate the impact of the degree of risk aversion on the contract choice decisions. Referring to Xiao and Choi [40], we model the risk aversion with mean-variance utility functions in this paper.

3. Model Settings

Consider a market in which two supply chains (denoted by SC_1 and SC_2) compete with each other. Each supply

chain is composed of a single supplier (denoted by M_i , $i = 1, 2$) and a single exclusive retailer (denoted by R_i , $i = 1, 2$). Without loss of generalization, we assume SC_1 is the market leader who produces and launches a product first. This is a common phenomenon in practice, for example, China Mobile launches its M-Zone service earlier than China Unicom, whose competing product is Up-Power (admittedly, it is possible to investigate the timing decisions of the two supply chains, named as endogenous leadership game; see Wang et al. [3, 4, 48] for further information. However, here our focus is the contract type choice and the impact of risk attitudes we leave the timing decisions for future research). We assume the two chains compete strictly in retail price, p_i , which directly determines their respective customer demand, \widetilde{D}_i . Referring to McGuire and Staelin [13], we assume the following linear demand function:

$$\widetilde{D}_i = \widetilde{A}_i - p_i + \theta p_{3-i}, \quad (1)$$

where $i = 1, 2$. \widetilde{A}_i denotes the stochastic market potential for product i , with the mean $\overline{A}_i > 0$ and variance σ_i^2 . The parameter $\theta \in (0, 1)$ represents the degree of product substitutability, which can be viewed as a measurement of demand competition density [26]. When $\theta \rightarrow 0$, there is no cross market influence, implying that the products are independent. When $\theta \rightarrow 1$, there is a perfect product substitution.

Towards the contract types adopted in each supply chain, we consider wholesale price contract (denoted by W) and revenue sharing contract (denoted by R). The reasons for choosing these two contract types are as follows. First, both wholesale price contract and revenue sharing contract are widely studied and used in theory and practice; we can thus compare our results directly with previous literature such as Pan et al. [8] and Zhao and Shi [10]. Second, these contract types represent the “simple” contract and the “sophisticated” contract, respectively.

Under a wholesale price contract, w_i is the wholesale price of product i , p_i is the retail price, and u_i is the unit profit margin of retailer i , where $u_i = p_i - w_i$. Under a revenue sharing contract, the retailer keeps a portion of channel revenue ($\phi_i p_i$), and $(1 - \phi_i) p_i$ is the fraction the supplier earns. Moreover, as Pan et al. [8] have pointed out, the supplier who chooses a revenue-sharing contract should make sure that the retailer's profit for each unit of product sold is not less than the marginal profit under a wholesale price contract, that is, $\phi_i p_i - w_i \geq u_i$. As the leader of a supply chain, service providers are authorized to decide whether wholesale price contract or revenue sharing contract should be offered to the exclusive retailer. Similar assumption has been made by Pan et al. [8]. Combing the suppliers' choices, in the two supply chains, there will be four possible scenarios: WW, WR, RW, and RR, where WW denotes that two supply chains are restricted to choose the wholesale price contract; WR means that supplier 1 (M_1) chooses the wholesale-price contract, while supplier 2 (M_2) chooses the revenue sharing contract. RW and RR are similar. Our model includes a two-level game. On the one hand, there is a Stackelberg game between SC_1 and SC_2 . The market leader SC_1 determines his/her contract

strategies to maximize its own profit, anticipating the follower SC_2 's possible actions. On the other hand, the individual members of each supply chain maximize their own profits, and there is a Stackelberg relationship between the supplier and the retailer.

In particular, similar to Xiao and Choi [40] and Choi et al. [49], we model the risk attitudes of the suppliers with mean-variance utility function as follows:

$$U_{M_i}^l(\pi_{M_i}^l) = E(\pi_{M_i}^l) - \lambda_i \text{Var}(\pi_{M_i}^l), \quad (2)$$

where $U_{M_i}^l(\pi_{M_i}^l)$ denotes the utility function of supplier i and $E(\pi_{M_i}^l)$ and $\text{Var}(\pi_{M_i}^l)$ represent the mean and the variance of supplier i 's expected profit, respectively. $l = WW, WR, RW$, and RR and the parameter $\lambda_i \geq 0$ denotes the constant absolute risk aversion of supplier i . The larger λ_i is, the more conservative supplier i 's behavior will be.

4. Equilibrium Solutions

In this section, we derive the close form solutions for different contract structures, including WW, WR, RW, and RR. We use backward induction to find the equilibriums for all of the participants.

4.1. Symmetric Subgame 1: WW. In the WW case, both M_1 and M_2 are restricted to choose wholesale price contracts. We consider SC_2 's decisions first. Given wholesale price w_2^{WW} , R_2 determines u_2^{WW} (note that $u_i^{WW} = p_i^{WW} - w_i^{WW}$, so R_i 's decision of u_i^{WW} is equivalent to the decision of retail price p_i^{WW}) by maximizing his/her expected profit:

$$\begin{aligned} & \max_{u_2^{WW} \geq 0} \pi_{R_2}^{WW} \\ & = u_2^{WW} [\bar{A}_2 - (u_2^{WW} + w_2^{WW}) + \theta(u_1^{WW} + w_1^{WW})]. \end{aligned} \quad (3)$$

It can be shown that $\pi_{R_2}^{WW}$ is concave with respect to u_2^{WW} ; thus, the best response u_2^{WW} can be written as

$$u_2^{*WW}(w_2^{WW}, u_1^{WW}, w_1^{WW}) = \frac{\bar{A}_2 - w_2^{WW} + \theta(u_1^{WW} + w_1^{WW})}{2}. \quad (4)$$

Anticipating the R_2 's actions, M_2 determines wholesale price to maximize his/her utility:

$$\begin{aligned} & \max_{w_2^{WW} \geq 0} U_{M_2}^{WW}(\pi_{M_2}^{WW}) \\ & = (w_2^{WW} - c_2) \times D_2(u_2^{*WW}) - \frac{1}{2} \lambda_2 \sigma_2^2 (w_2^{WW} - c_2)^2, \end{aligned} \quad (5)$$

where c_i denotes the manufacturing cost of product i , $i = 1, 2$. The first-order condition of (5) leads to the best response wholesale price:

$$w_2^{*WW}(u_1^{WW}, w_1^{WW}) = c_2 + \frac{\bar{A}_2 - c_2 + \theta(u_1^{WW} + w_1^{WW})}{2 + 2\lambda_2 \sigma_2^2}. \quad (6)$$

We now turn to SC_1 's decisions. Anticipating SC_2 's actions, M_1 and R_1 of SC_1 determine their best responses sequentially. Using similar event sequence, we derive the equilibriums with respect to u_1^{WW} and w_1^{WW} . For the convenience, let $\Delta_i = 1 + \lambda_i \sigma_i^2$, $i = 1, 2$. We have

$$\begin{aligned} & u_1^{*WW}(w_1^{WW}) \\ & = \frac{4\Delta_2 \bar{A}_1 + 2\theta \Delta_2 \bar{A}_2 + \theta(2\Delta_2 c_2 - c_2 + \bar{A}_2)}{4\Delta_2 \theta^2 + 2\theta^2 - 8\Delta_2} \\ & \quad + \frac{(\theta^2 + 2\Delta_2 \theta^2 - 4\Delta_2) w_1^{WW}}{4\Delta_2 \theta^2 + 2\theta^2 - 8\Delta_2}, \\ & w_1^{*WW} \\ & = \frac{2\Delta_2(2c_1 + 2\bar{A}_1 + 4c_1 \lambda_1 \sigma_1^2 - c_1 \theta^2 + \theta \bar{A}_2 + \theta c_2)}{8\Delta_1 \Delta_2 - 2\theta^2(2\Delta_2 + 1)} \\ & \quad + \frac{\theta(\bar{A}_2 - c_2 - c_1 \theta)}{8\Delta_1 \Delta_2 - 2\theta^2(2\Delta_2 + 1)}. \end{aligned} \quad (7)$$

We use superscript WW to represent the optimal solutions in the WW case. Substituting w_1^{*WW} back to $u_1^{*WW}(w_1^{WW})$, $w_2^{*WW}(u_1^{WW}, w_1^{WW})$, $u_2^{*WW}(w_2^{WW}, u_1^{WW}, w_1^{WW})$, we get all the equilibriums u_1^{*WW} , w_2^{*WW} , u_2^{*WW} and the corresponding production quantities and profits.

4.2. Hybrid Subgame 1: WR. The WR case represents that the M_1 chooses wholesale price contract while the M_2 chooses revenue sharing contract. Similar to the WW case, we first analyze SC_2 's decisions. As pointed out by Pan et al. [8], under a revenue sharing contract, the supplier M_2 should make sure that $\phi_2 p_2^{WR} - w_2^{WR} \geq \nu_2$, where $\nu_2 = u_2^{*WW}$; otherwise, the retailer will prefer a wholesale price contract to a revenue sharing contract. As for M_2 , he/she expects that the retailer shares the revenue as small as possible such that $\phi_2^{WR} p_2^{WR} - w_2^{WR} = \nu_2$. Therefore, given ϕ_2^{WR} , the decision of p_2^{WR} and w_2^{WR} is equivalent. The profit maximization problem of M_2 is

$$\begin{aligned} & \max_{p_2^{WR} \geq 0} U_{M_2}^{WR}(\pi_{M_2}^{WR}) \\ & = (p_2^{WR} - c_2 - \nu_2) [\bar{A}_2 - p_2^{WR} + \theta(w_1^{WR} + u_1^{WR})] \\ & \quad - \frac{1}{2} \lambda_2 \sigma_2^2 (p_2^{WR} - c_2 - \nu_2)^2. \end{aligned} \quad (8)$$

The first-order condition of (8) leads to the best response p_2^* :

$$\begin{aligned} & p_2^{*WR}(u_1^{WR}, w_1^{WR}) \\ & = c_2 + \nu_2 + \frac{\bar{A}_2 - c_2 - \nu_2 + \theta(u_1^{WR} + w_1^{WR})}{2 + \lambda_2 \sigma_2^2}. \end{aligned} \quad (9)$$

Then, M_1 and R_1 of SC_1 determine their best response conditional on the response of SC_2 , $p_2^{*WR}(u_1^{WR}, w_1^{WR})$. It can be shown that

$$\begin{aligned}
 u_1^{*WR}(w_1^{WR}) &= \frac{(1 + \Delta_2)(\bar{A}_1 - w_1^{WR})}{2[(1 + \Delta_2) - \theta^2]} \\
 &\quad + \frac{\theta(\bar{A}_2 + c_2\Delta_2 + \nu_2\Delta_2 + \theta w_1^{WR})}{2[(1 + \Delta_2) - \theta^2]}, \\
 w_1^{*WR} &= \frac{\theta[\bar{A}_2 - c_1\theta + \Delta_2(c_2 + \nu_2)]}{2[\Delta_1(1 + \Delta_2) - \theta^2]} \\
 &\quad + \frac{(1 + \Delta_2)(\bar{A}_1 - c_1 + 2c_1\Delta_1)}{2[\Delta_1(1 + \Delta_2) - \theta^2]}.
 \end{aligned} \tag{10}$$

We use superscript WR to represent the optimal solutions in the WR case. Substituting w_1^{*WR} into $u_1^{*WR}(w_1^{WR})$ and $p_2^{*WR}(u_1^{WR}, w_1^{WR})$ yields all the equilibriums in the WR case.

4.3. Hybrid Subgame 2: RW. The RW case represents that M_1 chooses revenue sharing contract while M_2 chooses wholesale price contract. The detail of solution process is similar to that in WR case. The best responses u_2^{*RW} , w_2^{*RW} , and p_1^{*RW} are given by

$$\begin{aligned}
 u_2^{*RW}(w_2^{RW}, p_1^{RW}) &= \frac{\bar{A}_2 - w_2^{RW} + \theta p_1^{RW}}{2} \\
 w_2^{*RW}(p_1^{RW}) &= c_2 + \frac{\bar{A}_2 - c_2 + \theta p_1^{RW}}{2 + 2\lambda_2\sigma_2^2}, \\
 p_1^{*RW} &= \frac{2\Delta_2(2\bar{A}_1 + \theta\bar{A}_2) + \theta(2c_2\Delta_2 - c_2 + \bar{A}_2)}{2[2\Delta_1\Delta_2 - \theta^2(1 + 2\Delta_2) + 2\Delta_2]} \\
 &\quad - \frac{(c_1 + \nu_1)(2\theta^2\Delta_2 + \theta^2 - 4\Delta_2 + 4\Delta_2\lambda_1\sigma_1^2)}{2[2\Delta_1\Delta_2 - \theta^2(1 + 2\Delta_2) + 2\Delta_2]},
 \end{aligned} \tag{11}$$

where $\nu_1 = u_1^{*WW}$. Substituting p_1^{*RW} into $w_2^{*RW}(p_1^{RW})$ and $u_2^{*RW}(w_2^{RW}, p_1^{RW})$ yields all the equilibriums in the RW case.

4.4. Symmetric Subgame 2: RR. The RR case represents that both M_1 and M_2 choose revenue sharing contract. Note that M_1 and M_2 have to guarantee R_1 and R_2 to obtain at least the same profits as those they can obtain under a wholesale price contract. We derive the best response retail price of SC_2 first as

$$p_2^{*RR}(p_1^{RR}) = c_2 + \nu_2 + \frac{\bar{A}_2 - c_2 - \nu_2 + \theta p_1^{RR}}{2 + 2\lambda_2\sigma_2^2}. \tag{12}$$

Anticipating the SC_2 's actions, SC_1 determines his best response p_1^{*RR} as

$$\begin{aligned}
 p_1^{*RR} &= \frac{2\Delta_2\bar{A}_1 - (c_1 + \nu_1)(\theta^2 - 2\Delta_2 + 4\Delta_2\lambda_1\sigma_1^2)}{2(2\Delta_2 - \theta^2 + \Delta_2\lambda_1\sigma_1^2)} \\
 &\quad + \frac{\theta[(2\Delta_2 - 1)(c_2 + \nu_2) + \bar{A}_2]}{2(2\Delta_2 - \theta^2 + \Delta_2\lambda_1\sigma_1^2)}.
 \end{aligned} \tag{13}$$

Substituting p_1^{*RR} back yields all the equilibriums in the RR case.

5. Analysis of Contract Strategies

In this section, we compare the suppliers' equilibrium profits under different cases and identify the conditions under which they choose wholesale price contract or revenue sharing contract. We also would like to find the equilibrium contract structure. According to previous literatures such as Choi et al. [38], Xiao and Choi [40], and Pan et al. [8], the degree of product substitutability and risk attitudes are the critical factors; therefore, we assume a symmetric scenario in the sense that $\bar{A}_1 = \bar{A}_2 = \bar{A}$, $\sigma_1 = \sigma_2 = \sigma$, $c_1 = c_2 = c$. Then their impacts are ruled out, leaving M_1 and M_2 differing from each other via their risk attitudes: λ_1 and λ_2 . We find that under this assumption, all of the optimal $U_{M_i}^l$, $l = WW, WR, RW, RR$, $i = 1, 2$, can be expected as a function of a common factor $(\bar{A} - c + c\theta)^2$. Then, the comparison of the utilities depends only on three parameters: the degree of product substitutability (θ), the degree of risk aversion (λ_i), and the variance of stochastic market base (σ). Moreover, the parameters λ_i and σ always arise together with the form of $\lambda_i\sigma^2$, therefore, to focus on the impact of risk aversion, we first set σ as a given positive constant. Next we investigate how the degree of product substitutability and the risk attitudes of the suppliers influence the supply chain contract decisions and compare our results with the previous literature. We analyze symmetric and asymmetric risk attitudes of the two suppliers.

5.1. Impact of Product Substitutability (Risk-Neutral Suppliers).

To obtain analytical comparison results with respect to the degree of product substitutability, we assume $\lambda_1 = \lambda_2 = \lambda = 0$, in other words, both suppliers are risk-neutral. We analyze the incentive of a supplier to switch from wholesale price contract (revenue sharing contract) to revenue sharing contract (wholesale price contract). Lemmas 1 and 2 describe M_1 's (M_2 's) preference given M_2 's (M_1 's) choice.

Lemma 1. *From M_1 's perspective, (i) if M_2 chooses wholesale price contract, then it is optimal for M_1 to choose revenue sharing contract. θ has no impact. (ii) If M_2 chooses revenue sharing contract, then M_1 is better to choose revenue sharing contract when $0 < \theta \leq 0.69$, otherwise, wholesale price contract.*

TABLE 1: Stability analysis of risk-neutral suppliers' perspectives.

Original structure	M_1		M_2	
	New structure	Change in profits	New structure	Change in profits
WW	RW	$0 < \theta < 1, \uparrow^*$	WR	$0 < \theta \leq 0.55, \uparrow$ $0.55 < \theta < 1, \downarrow$
RW	WW	$0 < \theta < 1, \downarrow$	RR	$0 < \theta \leq 0.51, \uparrow$ $0.51 < \theta < 1, \downarrow$
WR	RR	$0 < \theta \leq 0.69, \uparrow$ $0.69 < \theta < 1, \downarrow$	WW	$0 < \theta \leq 0.55, \downarrow$ $0.55 < \theta < 1, \uparrow$
RR	WR	$0 < \theta \leq 0.69, \downarrow$ $0.69 < \theta < 1, \uparrow$	RW	$0 < \theta \leq 0.51, \downarrow$ $0.51 < \theta < 1, \uparrow$

*When the utility of new structure is more than the original structure, we denote it by “ \uparrow ”, otherwise, “ \downarrow ”.

Lemma 2. From M_2 's perspective, (i) if M_1 chooses wholesale price contract, then M_2 is better off with revenue sharing contract under $0 < \theta \leq 0.55$, otherwise, wholesale price contract. (ii) If M_1 chooses revenue sharing contract, then M_2 is better off with revenue sharing contract under $0 < \theta \leq 0.51$, otherwise, wholesale price contract.

Based on Lemmas 1 and 2, Table 1 summarizes the suppliers' incentives to switch from one structure to another one.

This leads to the equilibrium contract strategies summarized in Theorem 3.

Theorem 3. Assuming risk-neutral suppliers, the equilibrium contract strategies for the two competing supply chains is RR if θ is smaller than $\hat{\theta}$, and RW otherwise.

Thus, there exists a unique threshold value of $\hat{\theta}$ which guides M_2 's choice of contract type. When competition is tense, that is, θ is large, it is better for M_2 to adopt a different contract type. As the degree of product substitutability decreases, competition becomes not so tense, then it is optimal for the market follower to copy the leader's strategy: adopting a revenue sharing contract. Note that, with simultaneous competition, Pan et al. [8] show that it is optimal for the suppliers to choose revenue-sharing contract when there is no tense competition. Here, we verify this finding in a sequential competition environment. The underlying reason lies in their different preferences towards the “low-price-high-volume” strategy. To further explain our findings, we compare the retail prices in different scenarios and have the following lemma.

Lemma 4. Assuming risk-neutral suppliers, the following orders always hold:

$$p_1^{*RR} - p_1^{*WW} < 0; \quad p_2^{*RR} - p_2^{*WW} < 0; \quad p_2^{*RR} < p_1^{*RR}. \quad (14)$$

As we show in Lemma 4, the retail price under revenue sharing contract is lower than that under wholesale price contract. Market leader has to decide a low retail price to snatch a large market share, while market follower has the right of cutting down the leader's retail price and hence

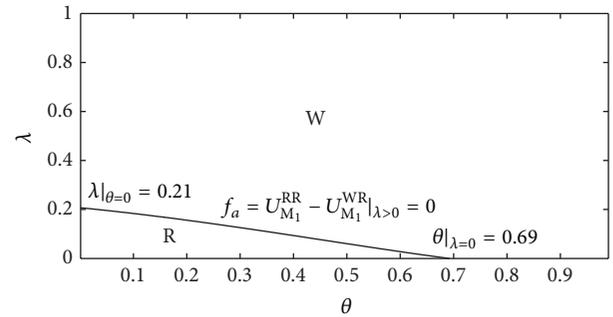


FIGURE 1: M_1 's preference given M_2 choosing revenue sharing contract ($\lambda > 0$).

enjoys a second-mover advantage in the price competition ($p_2^{*RR} < p_1^{*RR}$). This behavior will not occur when there is no information interaction under simultaneous competition, as Pan et al. [8] have studied. On the other hand, facing tense competition, the follower's profits with “low-price-high-volume” strategy may not compensate its loss due to low retail price. Thus, the follower has to switch to the wholesale price contract so as to enjoy a higher profit margin. This is consistent with Pan et al. [8].

5.2. Impact of Product Substitutability and Risk Attitudes (Identical Risk-Averse Suppliers). We now turn to the case $\lambda_1 = \lambda_2 = \lambda > 0$, that is, both suppliers are risk-averse, but they are identical. With this assumption, suppliers' choices are influenced by the degree of product substitutability and risk aversion. We find that given M_2 's choice of wholesale price contract, M_1 always prefers revenue sharing contract. This is consistent with our previous finding shown in Lemma 1. However, it is not easy to analytically find M_1 's preference when M_2 chooses revenue sharing contract. We conduct numerical studies and observe similar curves; see Figure 1 for illustration. The parameters are $\bar{A} = 1$, $\sigma = 1$, $c = 0.5$, $\lambda \in (0, 1)$, and $\theta \in (0, 1)$.

The rectangular area $\{(\theta, \lambda) \mid 0 < \theta < 1, 0 < \lambda < 1\}$ is divided into two distinct regions by the curve $f_a = U_{M_1}^{RR} - U_{M_1}^{WR}|_{\lambda > 0} = 0$, where “W” denotes that M_1 prefers wholesale price contract and “R” denotes that M_1 prefers

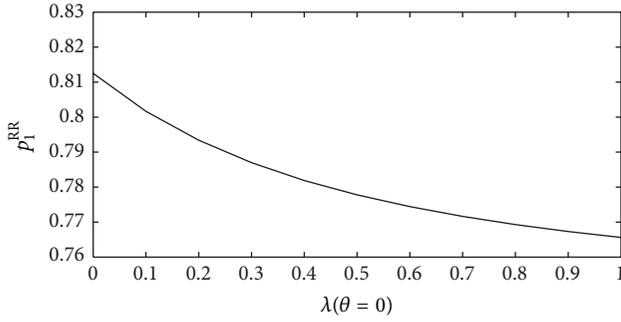


FIGURE 2: Impact of λ on p_1^{*RR} .

revenue sharing contract. From Figure 1 we can obtain the following observations. (i) If $\lambda = 0$, that is, both suppliers are risk-neutral, given M_2 choosing revenue sharing contract, M_1 prefers revenue sharing contract when $0 < \theta \leq 0.69$, otherwise, wholesale price contract. This is consistent with Lemma 1. (ii) As the degree of risk aversion increases (e.g., $\lambda > 0.21$), given M_2 choosing revenue sharing contract, the wholesale price contract is attractive for M_1 no matter what the value of θ is. This observation can be explained as follows. When M_1 becomes more and more conservative (λ becomes larger and larger), it can be observed that p_1^{*RR} is decreasing (see Figure 2). Thus, to avoid the retail price dropping too much, M_1 tends to replace the revenue sharing contract by the wholesale price contract, owing to the fact that the retail price under the revenue sharing contract is always lower than that under the wholesale price contract (see Lemma 4 and Figure 3).

We now also illustrate the follower M_2 's preference given M_1 's choice, by assuming the same numerical parameters.

Similar observations can be found in Figures 4(a) and 4(b). "W" denotes that M_2 prefers wholesale price contract, and "R" denotes that M_2 prefers revenue sharing contract. We can obtain the following observations. (i) In Figure 4(a), if $\lambda = 0$, given M_1 choosing wholesale price contract, M_2 prefers revenue sharing contract, when $0 < \theta \leq 0.55$, otherwise, wholesale price contract. In Figure 4(b), if $\lambda = 0$, given M_1 choosing revenue sharing contract, M_2 prefers revenue sharing contract, when $0 < \theta \leq 0.51$, otherwise, wholesale price contract. This is consistent with Lemma 2. (ii) As the degree of risk aversion increases (e.g., $\lambda > 0.19$), regardless of M_1 choosing wholesale price contract or revenue sharing contract, it is optimal for M_2 to choose the wholesale price contract. A possible reason is that as M_2 becomes more and more conservative, he/she tends to avoid the retail price dropping too much (p_2^{*RR} is decreasing in λ). We obtain equilibrium contract strategies illustrated by Figure 5.

In Figure 5, "RW" denotes that M_1 chooses revenue sharing contract and M_2 chooses wholesale price contract. "RR" denotes that both M_1 and M_2 choose revenue sharing contract. We first verify the findings summarized in Theorem 3, that is, "RR" is the equilibrium contract strategy when $0.51 < \theta < 1$, and "RW" is the equilibrium contract strategy when $0.51 < \theta < 1$. Then, we find that if the

degree of risk aversion and product substitutability are both low, "RR" sustains as the equilibrium contract strategy. Recall that when the competition intensity is low, suppliers tend to keep a relatively low retail price to stimulate demand by adopting revenue sharing contract. However, when suppliers are very conservative, as we have observed, the retail price will become too low. Consequently, M_2 may switch to the wholesale price contract, which guarantees a larger profit margin. This differentiates our work from that of Pan et al. [8], in which the impact of risk attitude is not studied.

5.3. Verification with Asymmetric Risk Attitudes (Heterogeneous Risk-Averse Suppliers). In this subsection, we assume that the risk aversion between two suppliers is asymmetric, that is, $\lambda_1 \neq \lambda_2$. Interestingly, given M_2 's choice of wholesale price contract, it can be shown that M_1 always prefers revenue sharing contract. Combining our previous findings with symmetric risk attitudes, this phenomenon is rather robust.

Consider the following:

$$\begin{aligned} & U_{M_1}^{RW} - U_{M_1}^{WW} \Big|_{\lambda_1 \neq \lambda_2} \\ &= (\bar{A} - c + c\theta)^2 (4 + 4\lambda_2\sigma^2 - 2\lambda_2\theta^2\sigma^2 - 3\theta^2)^2 \\ & \quad \times (2\theta\lambda_2\sigma^2 + 3\theta + 4 + 4\lambda_2\sigma^2)^2 \\ & \quad \times (256\Gamma(1 + \lambda_2\sigma^2)(\Gamma + 2\lambda_1\lambda_2\sigma^4 + 2\lambda_1\sigma^2)^2)^{-1} > 0, \end{aligned} \quad (15)$$

where $\Gamma = 4 - 2\lambda_2\theta^2\sigma^2 + 2\lambda_1\lambda_2\sigma^4 - 3\theta^2 + 4\lambda_2\sigma^2 + 2\lambda_1\sigma^2$.

Clearly, $U_{M_1}^{RW} - U_{M_1}^{WW} \Big|_{\lambda_1 \neq \lambda_2} > 0$ always holds regardless of the value of λ_1 , λ_2 , and θ .

Now, we analyze M_1 's preference given M_2 's choice of revenue sharing contract. The parameters are $\bar{A} = 1$, $\sigma = 1$, $c = 0.5$, $\theta \in (0, 1)$, $\lambda_2 \in (0, 20)$, and $\lambda_1 = 0, 0.1$.

As observed from Figures 6(a) and 6(b), when λ_1 increases, it becomes more likely for M_1 to choose wholesale price contract. A possible reason is that M_1 tend to avoid sharply lowered retail price. Another observation is when λ_2 is large, it is better for M_1 to choose revenue sharing contract. The reason lies in M_2 's possible choice of wholesale price contract when he/she is very conservative. It has been shown that M_1 's optimal strategy is revenue sharing, given M_2 's choice wholesale price contract.

We now also illustrate M_2 's preference given M_1 's choice under asymmetric risk attitudes. First of all, assuming M_1 chooses wholesale price contract, we use the following parameters: $\bar{A} = 1$, $\sigma = 1$, $c = 0.5$, $\theta \in (0, 1)$, $\lambda_1 \in (0, 20)$, and $\lambda_2 = 0, 0.1$. As seen from Figures 7(a) and 7(b), the outcomes can be classified into two distinct regions by the critical curves $f_g = 0$, $f_h = 0$, $f_i = 0$, respectively. Again, with larger λ_2 , M_2 tends to choose wholesale price contract. Assuming M_1 chooses revenue sharing contract, the observation is similar.

5.4. Verification with Stochastic Market Variance. In this sub-section, we investigate the role that stochastic market variance (σ) plays in the suppliers' contract choices. First,

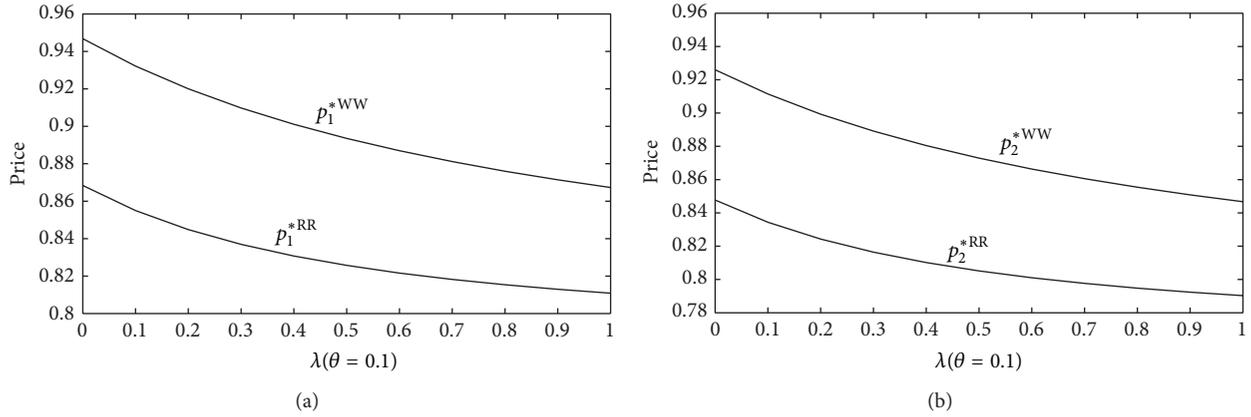


FIGURE 3: Comparison of the retail prices with $\lambda_1 = \lambda_2 = \lambda > 0$.

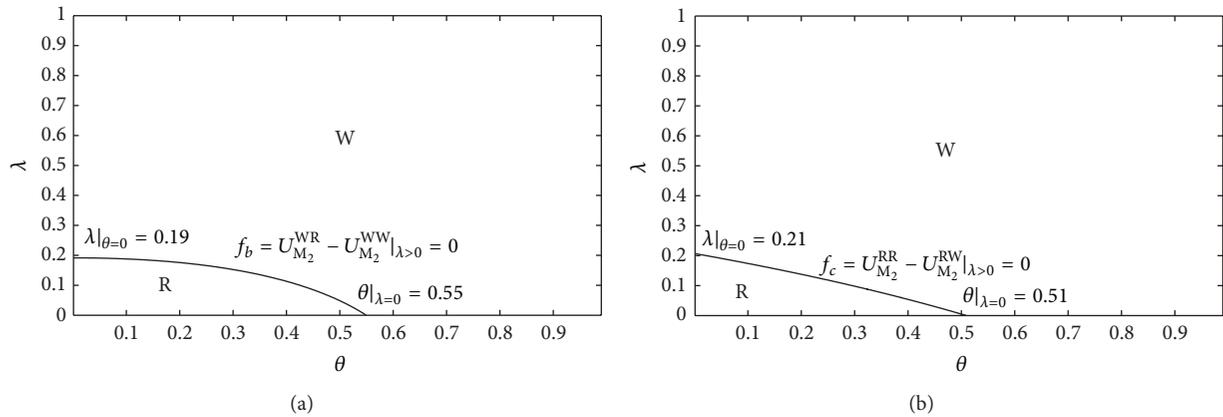


FIGURE 4: (a) M_2 's preference given M_1 's choice of wholesale price contract ($\lambda > 0$). (b) M_2 's preference given M_1 's choice of revenue sharing contract ($\lambda > 0$).

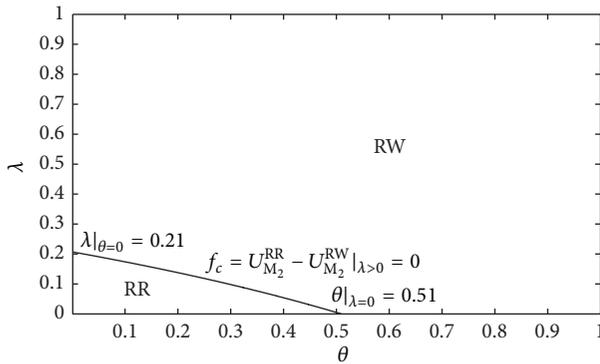


FIGURE 5: Equilibrium contract strategies of suppliers ($\lambda > 0$).

we examine M_1 's preference. Given M_2 's choice of wholesale price contract, it can be shown that M_1 always prefers revenue sharing contract. Second, we illustrate M_1 's preference given M_2 's choice of revenue sharing contract and M_2 's preference given M_1 's choice of wholesale price contract or revenue sharing contract. The parameters are $\bar{A} = 1$, $c = 0.5$, $\theta \in (0, 1)$, $\sigma \in (0, 2)$, and $\lambda = 0.1, 0.5$. As seen from Figure 8(a),

the rectangular area $\{(\theta, \sigma) \mid 0 \leq \theta < 1, 0 \leq \sigma < 2\}$ is divided into two parts by the curves $f_j(\theta, \sigma) = 0$, $f_k(\theta, \sigma) = 0$, $f_l(\theta, \sigma) = 0$. In the upper right part (i.e., region I) of the area, all functions $f_j(\theta, \sigma)$, $f_k(\theta, \sigma)$, and $f_l(\theta, \sigma)$ are less than zero. In contrast, in the lower left part (i.e., region II) of the area, all functions $f_j(\theta, \sigma)$, $f_k(\theta, \sigma)$, and $f_l(\theta, \sigma)$ are greater than zero. These observations imply that if the competition density is small and the market variance is also small, revenue sharing contract will be the best option for the two suppliers. This indicates a threshold policy with respect to σ for the suppliers to select the contract type. Figure 8(b) shows similar curves. Possible explanation is as follows. Recall that the comparison of the suppliers' utilities depends only on θ , λ_i , and σ , and the parameters λ_i and σ always arise together with the form of $\lambda_i \sigma^2$. Thus, keeping λ_i as a constant, the impact of σ is similar to that of λ_i shown previously (threshold type).

6. Conclusion Remarks and Future Research

In this paper, we consider two sequential-moving supply chains, where each supply chain is composed of one risk-averse supplier and one risk-neutral retailer. We investigate the impact of competition intensity and risk aversion on

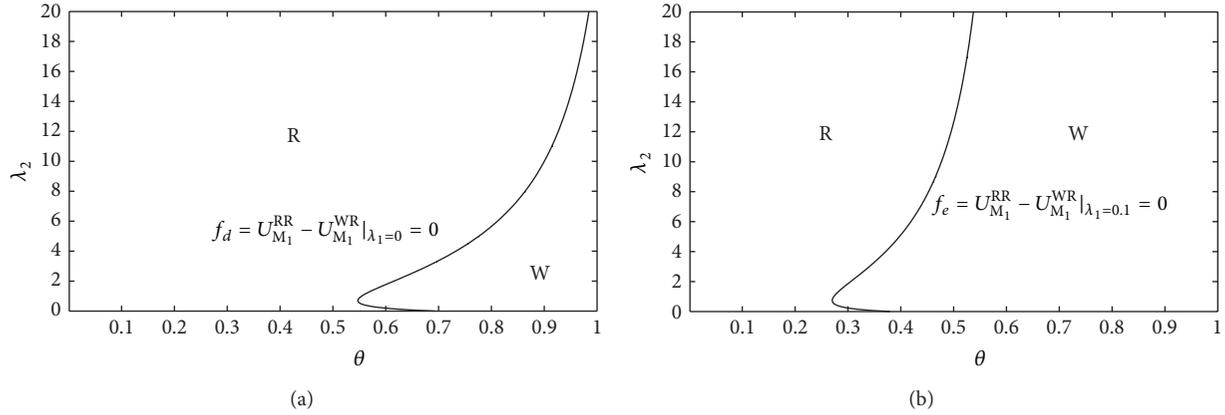


FIGURE 6: (a) M_1 's preference given M_2 's choice of revenue sharing contract ($\lambda_1 = 0$). (b) M_1 's preference given M_2 's choice of revenue sharing contract ($\lambda_1 = 0.1$).

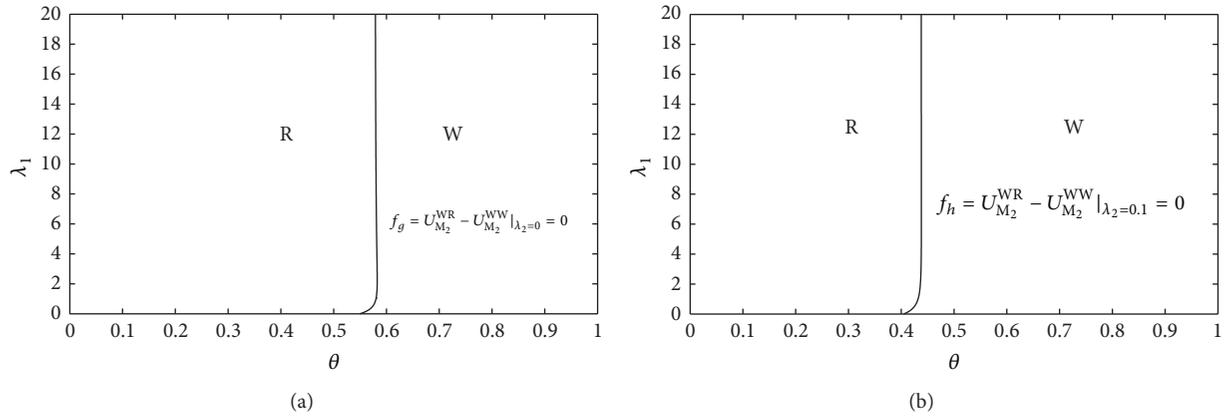


FIGURE 7: (a) M_2 's preference given M_1 's choice of wholesale price contract ($\lambda_2 = 0$). (b) M_2 's preference given M_1 's choice of wholesale price contract under ($\lambda_2 = 0.1$).

the contract choice problems. We study by deriving and comparing the equilibria under the symmetric subgames (including WW and RR case) and hybrid subgames (including WR and RW case), respectively.

Our paper differs from the previous studies of contract choice in two important ways. First, we consider contract choice in the context of two sequential-moving supply chains. Second, we assume that two competing suppliers are risk-averse and analyze how risk aversion of one supplier affects his/her and rival's decisions. We show that the retail prices under revenue sharing contract are lower than that under wholesale price contract. Thus, when the degrees of product substitutability and risk aversion are beyond a threshold value; the second-moving supplier may suffer from too low retail price and hence switch from revenue sharing contract to wholesale price contract. These results complement the current literature that assumes players are risk-neutral and help to explain why sophisticated contracts (e.g., revenue sharing contract) have not completely eliminated the Pareto inferior wholesale-price contract in reality.

We would like to mention two potential directions for future research. First, it is worthy studying the other risk

aversion models (e.g., [31, 50]) to see whether our insights hold or not. Second, we have assumed that information is common knowledge. Relaxing this assumption would lead to studies with asymmetric information and would generate insights on the value of information. As Ha and Tong [26] have pointed out, the value of information may significantly influence the choice of contract type.

Appendices

A. Proof of Lemma 1

Proof. (i) Given M_2 's choice of wholesale price contract, we compare the utilities of M_1 under revenue sharing contract and wholesale price contract as follows:

$$U_{M_1}^{RW} - U_{M_1}^{WW} \Big|_{\lambda=0} = \frac{(3\theta + 4)^2 (\bar{A} - c + c\theta)^2}{256(4 - 3\theta^2)} > 0. \quad (\text{A.1})$$

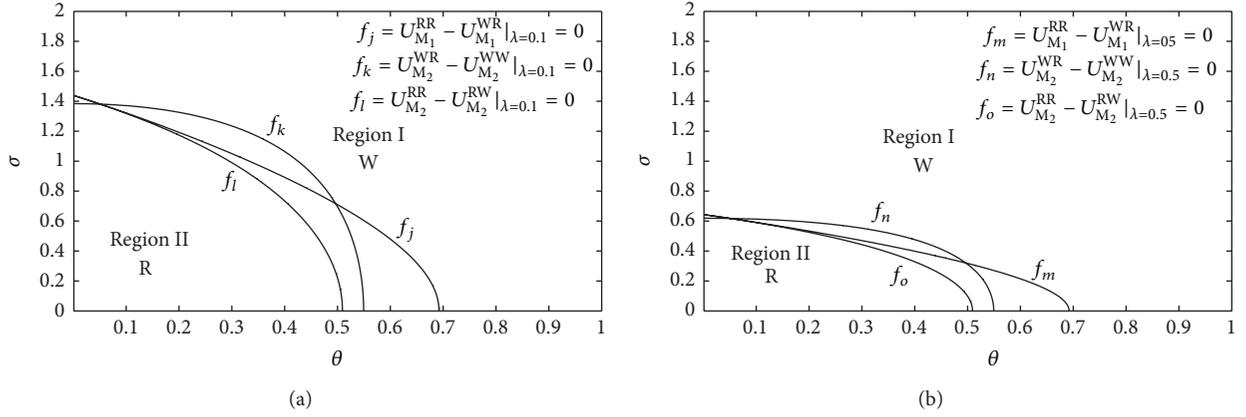


FIGURE 8: (a) M_1 's and M_2 's preference given ($\lambda = 0.1$). (b) M_1 's and M_2 's preference given ($\lambda = 0.5$).

(ii) Given M_2 's choice of revenue sharing contract, we compare the utilities of M_1 under revenue sharing contract and wholesale price contract, finding that

$$U_{M_1}^{RR} - U_{M_1}^{WR}|_{\lambda=0} = \frac{(\bar{A} - c + c\theta)^2 \Phi_1(\theta)}{4096(2 - \theta^2)(4 - 3\theta^2)^2}, \quad (\text{A.2})$$

where

$$\begin{aligned} \Phi_1(\theta) &= 2048 + 1024\theta - 4736\theta^2 - 3712\theta^3 \\ &\quad + 1616\theta^4 + 2040\theta^5 + 441\theta^6 \\ &= 441(\theta - 1.22)(\theta - 0.69)(\theta + 1.18) \\ &\quad \times (\theta + 1.74)(\theta + 1.05)(\theta + 2.57). \end{aligned} \quad (\text{A.3})$$

As $0 < \theta < 1$, we have $U_{M_1}^{RR} - U_{M_1}^{WR}|_{\lambda=0} \geq 0$ if $0 < \theta \leq 0.69$, otherwise, $U_{M_1}^{RR} - U_{M_1}^{WR}|_{\lambda=0} < 0$. \square

B. Proof of Lemma 2

Proof. (i) Given M_1 's choice of wholesale price contract, we compare the utilities of M_2 under revenue sharing contract and wholesale price contract and find that

$$U_{M_2}^{WR} - U_{M_2}^{WW}|_{\lambda=0} = -\frac{(\bar{A} - c + c\theta)^2 \Phi_2(\theta)}{16384(8 - 10\theta^2 + 3\theta^4)^2}, \quad (\text{B.1})$$

where

$$\begin{aligned} \Phi_2(\theta) &= 423\theta^8 + 1800\theta^7 - 23232\theta^6 - 56832\theta^5 + 12224\theta^4 \\ &\quad + 102912\theta^3 + 50176\theta^2 - 24576\theta - 16384 \\ &= 423(\theta - 0.55)(\theta - 1.28)(\theta - 6.7)(\theta + 1.07) \\ &\quad \times (\theta + 1.33)(\theta + 8.77)(\theta^2 + 1.62\theta + 0.66). \end{aligned} \quad (\text{B.2})$$

As $0 < \theta < 1$, we have $U_{M_2}^{WR} - U_{M_2}^{WW}|_{\lambda=0} \geq 0$ if $0 < \theta \leq 0.55$.
Otherwise, $U_{M_2}^{WR} - U_{M_2}^{WW}|_{\lambda=0} \leq 0$.

(ii) Given M_1 's choice of revenue sharing contract, we compare the utilities of M_2 with revenue sharing contract and wholesale price contract as follows:

$$U_{M_2}^{RR} - U_{M_2}^{RW}|_{\lambda=0} = \frac{(\bar{A} - c + c\theta)^2 \Phi_3(\theta)}{4096(8 - 10\theta^2 + 3\theta^4)^2}, \quad (\text{B.3})$$

where

$$\begin{aligned} \Phi_3(\theta) &= 81\theta^8 - 1224\theta^7 + 488\theta^6 + 10432\theta^5 + 6512\theta^4 \\ &\quad - 15232\theta^3 - 15104\theta^2 + 2048\theta + 4096 \\ &= 81(\theta - 0.51)(\theta - 14)(\theta - 3.69)(\theta - 1.29) \\ &\quad \times (\theta + 1.1)(\theta + 1.36)(\theta^2 + 1.93\theta + 1). \end{aligned} \quad (\text{B.4})$$

As $0 < \theta < 1$, we have $U_{M_2}^{RR} - U_{M_2}^{RW}|_{\lambda=0} \geq 0$ if $0 < \theta \leq 0.51$, otherwise, $U_{M_2}^{RR} - U_{M_2}^{RW}|_{\lambda=0} \leq 0$. \square

C. Proof of Lemma 4

Proof. Consider the following:

$$\begin{aligned} p_1^{*RR} - p_1^{*WW}|_{\lambda=0} &= -\frac{(\bar{A} - c + c\theta)(32 + 40\theta + 4\theta^2 - 9\theta^3)}{32(8 - 10\theta^2 + 3\theta^4)} < 0, \\ p_2^{*RR} - p_2^{*WW}|_{\lambda=0} &= -\frac{(\bar{A} - c + c\theta)(64 + 80\theta - 4\theta^2 - 20\theta^3 - 3\theta^4)}{64(8 - 10\theta^2 + 3\theta^4)} < 0, \end{aligned}$$

$$\begin{aligned}
& \left. p_2^{*RR} - p_1^{*RR} \right|_{\lambda=0} \\
&= -\frac{\theta^2 (\bar{A} - c + c\theta) (60 - 2\theta - 39\theta^2)}{64 (8 - 10\theta^2 + 3\theta^4)} < 0, \\
& \left. D_2^{*RR} - D_1^{*RR} \right|_{\lambda=0} \\
&= \frac{\theta^2 (1 + \theta) (\bar{A} - c + c\theta) (60 - 2\theta - 39\theta^2)}{64 (2 - \theta^2) (4 - 3\theta^2)} > 0.
\end{aligned}
\tag{C.1}$$

□

Acknowledgments

This research was supported in part by the National Natural Science Foundation of China under Grants nos. 71201175, 71131003, the Youth Foundation of Ministry of Education in China, Humanities and Social Science Research Projects under Grant nos. 13YJC630068, 13YJC630197, and 13YJC630234, the Guangdong Natural Science Foundation under Grants nos. S2012040008081 and S2011040001069, and the 2012 Annual Youth Foundation of Guangdong University of Finance and Economics under Grant no. 12GJPY63001.

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