INFORMATION SHARING IN TWO-TIER SUPPLY CHAINS CONSIDERING COST REDUCTION EFFORT AND INFORMATION LEAKAGE

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Abstract. This study investigates information sharing in two-tier supply chains considering cost reduction effort and information leakage, with either upstream competition (system SC) or downstream competition (system RC). Results show that in system SC without information leakage, the retailer shares information with one supplier when suppliers are efficient in cost reduction, shares information with neither supplier when suppliers are inefficient in cost reduction, and shares information with two suppliers when suppliers are intermediate in cost reduction efficiency. Information leakage won’t affect the information sharing decisions of the retailer. In system RC with or without information leakage, both retailers share information with the supplier when the supplier is efficient in cost reduction and neither retailer shares information with the supplier when the supplier is inefficient in cost reduction. However, the threshold of cost reduction efficiency without information leakage is always lower than that with information leakage, which demonstrates that it is less likely for retailers to share information with information leakage. What’s more, the two retailers choose the same information sharing strategies without information leakage but the opposite information sharing strategies with information leakage when the cost reduction efficiency is intermediate.

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1. Introduction. With the rapid development of big data and cloud computing technology, retailers regularly capture, store, and analyze large amounts of data on their consumer base every day[23]. However, these data are often asymmetric since retailers sell products directly to consumers and have easier access to demand data than suppliers[19]. So here's the problem: “Do retailers have incentives to share demand information with suppliers?” Supporters of this view have listed the advantages of sharing demand information, which include improving inventory and merchandising strategies, ensuring deeper insight into local and regional performance, increasing sell-through, and enhancing the effectiveness of sales promotions[26]. Opponents argue that demand information sharing hurts retailers because it weakens their power to negotiate with suppliers, and the information may be leaked to their competitors[30]. According to[21], 40% of more than 100 retailers that were investigated did not share data with suppliers at all. Then, what are the reasons for retailers to share or not to share information?

Many scholars have explored the factors that affect the incentive for retailers to share their private demand information, such factors include, but are not limited to, supply chain structure[11], warranty policies[3], capacity constraint[16], information confidentiality[20], and cost reduction effort[9]. However, the studies above only focused on a single factor that influences retailers’ demand information sharing strategies, and only a few studies have examined the comprehensive impact of multiple factors. In practice, it is more realistic that multiple factors coexist in the current complex supply chain system. Furthermore, the combined effect of multiple factors is not a simple addition of each one but a complicated synthetic result since different factors affect retailers’ information sharing motivation in different magnitude and direction.

Take the e-commerce supply chains in China for example, there are different supply chain structures: two suppliers may produce two substitutable products separately and sell them to a common retail platform; or a single supplier may produce two substitutable products simultaneously and sell them to different retail platforms respectively, such as Jingdong Mall and Tmall. These retail platforms accumulated massive sales data and decide whether to share them with their suppliers. Suppliers that have access to the data can then make cost reductions and wholesale prices decisions accordingly, which may in turn benefit or hurt the retail platforms. In addition, suppliers who obtain the information may disclose it to other supply chain members intentional or not, which may also affect the profits of the retail platforms. Then, what are the optimal information sharing strategies for retailers in different supply chain structures when considering cost reduction effort and information leakage simultaneously?

To solve this problem, we consider two types of supply chain structures, with two suppliers and one retailer (system SC), and one supplier and two retailers (system RC) respectively. Two substitutable products that compete in quantity (Cournot competition) are sold in both supply chains. Each retailer possesses a forecast about demand information and decides whether to share information with suppliers. Each supplier can make effort to reduce production cost, and decides on cost reduction level and wholesale price based on the demand information received. Using the backwards method, the suppliers’ optimal cost reduction effort and wholesale price, the retailers’ optimal order quantity, as well as their ex-ante profits are calculated under different information sharing arrangements. To recognize the different effects of cost reduction and information leakage, we conduct equilibrium analysis in scenarios
without and with information leakage. Finally, the retailers’ optimal information sharing strategies are derived. Our study answers the following questions: What’s the optimal decisions for supply chain members under different information sharing arrangements in system SC and RC respectively? Will retailers share information to suppliers in two supply chain structures without and with information leakage? How information leakage affects the information sharing strategies of retailers in system SC and RC respectively?

Results show that supply chain members’ decisions, information sharing strategies and the effects of information leakage differs in system SC and RC. Firstly, the optimal wholesale prices and cost reduction efforts for suppliers, and the optimal order quantities for retailers under different information sharing arrangements in these two supply chain structures are different. In system SC, if a supplier is informed of the common retailer’s demand signal, its cost reduction level is increasing with the demand signal, whereas its wholesale price is increasing with the demand signal when the supplier is inefficient in cost reduction and decreasing otherwise. What’s more, suppliers are more likely to decrease wholesale prices with demand signal when competition is more intense and the retailer adjusts order quantity in the opposite direction with the adjustment in the supplier’s wholesale price. However, in system RC, the supplier adjusts wholesale price and cost reduction level in much more complicated ways since these decisions are made based on both retailers’ demand signals. Furthermore, the supplier sets different wholesale prices and cost reduction levels for retailers with different information sharing strategies without considering information leakage, while it sets the same wholesale prices and cost reduction levels for retailers with different information sharing strategies considering information leakage. In addition, the supplier is more likely to increase wholesale price with demand signal when competition is more intense considering information leakage.

Secondly, information sharing strategies for retailers differ in system SC and RC. In system SC, with or without information leakage, the retailer shares information with one supplier when cost reduction efficiency is high, with neither supplier when cost reduction efficiency is low, and with both suppliers when cost reduction efficiency is intermediate. What’s more, the retailer is more likely to share information when competition is more intense. Whereas in system RC, with or without information leakage, both retailers share information with the supplier when cost reduction efficiency is high and neither retailer shares information with the supplier when cost reduction efficiency is low. What’s more, retailers are more likely to share information when either competition is less intense or information is more accurate with information leakage. In addition, the two retailers choose the same information sharing strategies without information leakage but the opposite information sharing strategies with information leakage when the cost reduction efficiency is intermediate.

Finally, the effects of information leakage on the incentive for retailers to share information in system SC and RC are different. In system SC, an informed supplier will leak demand information to an uninformed one actively when suppliers are inefficient in cost reduction and information leakage won’t affect the information sharing strategies of the retailer. Whereas in system RC, with information leakage, a retailer can infer the demand signal of its rival retailer from the wholesale price of
the supplier. Information leakage raises the threshold of the supplier’s cost reduction efficiency for retailers to share information and thus precludes retailers from information sharing to some extent.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the basic model and assumptions. Section 4 and 5 investigate retailers’ optimal information sharing strategies in system SC and system RC respectively considering cost reduction effort and information leakage. Finally, Section 6 summarizes the paper and proposes potential areas for future research.

2. Literature review. Our paper belongs to the literature on vertical demand information sharing in supply chains. Lee and Whang[15] described the types of information shared in a supply chain, including inventory, sales, demand forecast, order status, and production schedule. They discussed how this information is shared by means of industry examples and related them to academic research. Lee et al.[14], Cachon and fisher[2], and Yu et al.[31] emphasized the high value of information sharing in reducing supply chain cost. Although information sharing benefits the whole supply chain significantly, the informed party may be reluctant to share information with the uninformed party voluntarily due to self-interest. Li[18] and Zhang[34] showed that competing retailers won’t share demand information with their suppliers for fear of information leakage. When voluntary information is not possible, they identified conditions under which information can be traded through side payment. In addition to information leakage and side payment, there are many other factors that affect the incentive of the informed party in a supply chain to share information. For example, Mukhopadhyay et al.[24] examined retailers' information sharing motivation with value-adding cost in a dual channel supply chain. Ha et al.[9] studied demand information sharing in competing supply chains with production diseconomies, where the retailers engage in Cournot or Bertrand competition. Shang et al.[25] explored the impact of nonlinear production cost on information sharing in a supply chain with two competing manufacturers and a common retailer. Guan et al.[7] explored information sharing among two competing supply chains with after-sales service and found that information sharing is more likely to occur when manufacturers are more efficient in service investment, consumers care more about service, or competition is more intense.

Our paper is related to the literature on information leakage in supply chains. Once a retailer shares demand information with a supplier, the supplier may leak the information to other supply chain members intentional or not. Many scholars focused on optimal information sharing strategies of the informed party under information leakage. Anand and Goyal[1] stressed the importance of strategic information management (demand information acquiring, sharing, and disseminating strategy) under information leakage in a supply chain with one supplier and two retailers. They found that the supplier will always leak the demand information acquired from the incumbent retailer to the entrant retailer actively. Wang et al.[29] extended the model of Anand and Goyal [1] by considering imperfect downstream competition and information acquisition cost. Fang and Ren[6] further studied the strategic information management in a dual-channel supply chain consisting of one supplier and one retailer with information leakage and distortion. Other scholars focused on how to evaluate and mitigate the risk of information leakage. Zhang et al.[33] put forward a conceptual model and a quantitative approach to assess and reduce the risk of potential information leakage caused by inferences in supply chains.
Zhang et al. [32] proposed a method to alleviate the risk of information leakage through optimal supplier selection. Tan et al. [28] further investigated the factors triggering information and knowledge leakage, and create a mitigation framework to soften the impact of leakage on supply chain performance. What’s more, supply chain contract is an effective way to stimulate information sharing and restrain information leakage. Kong et al. [13] demonstrated that revenue-sharing contracts can facilitate information sharing and mitigate the negative effects of information leakage. Liu et al. [22] extended the research of Kong et al. [13] by introducing different contract configurations and found that no-leakage equilibrium only exists when the incumbent retailer signs a specific revenue sharing contract with the supplier. Chen and Özer [5] classified various kinds of contracts into four categories and compared their performance in precluding information leakage among competing newsvendors. However, none of the above literatures consider cost reduction effort.

This study is also related to the literature on vertical information sharing in a supply chain with cost reduction effort, which has received vastly less research attention. Ha et al. [8] studied demand information sharing in two competing supply chains and found that cost reduction efficiency plays an important role in retailers’ information sharing decisions. Sun et al. [27] obtained some insights into retailer’s information management considering manufacturer encroachment with cost reduction effort. Nevertheless, the two literatures omit the effect of information leakage. Our paper is mostly related to the study of Cao and Chen [4], who considered cost reduction effort and information leakage simultaneously. However, we differ from Cao and Chen [4] in three aspects. First, in Cao and Chen [4], the two retailers are asymmetric in demand information, with an informed retailer and an uninformed retailer. But in our study, each retailer has a forecast about demand information, which is common in practice and academia. Second, Cao and Chen [4] assumed that the manufacturer may distort the wholesale price due to the inference effect. In our model, the supplier has no incentive to distort the wholesale price, as demonstrated in Li [18]. Third, Cao and Chen [4] investigated information sharing in a supply chain with downstream (retailers) competition. Our study explores the information sharing problem in two supply chain structurers with either upstream (suppliers) or downstream (retailers) competition, and draws different conclusions. We compare the similarities and differences of the closely related literature in Table 1 to highlight our contribution. Specifically, our paper focuses on the retailer’s information sharing strategies considering cost reduction and information leakage in two-tier supply chains. We conduct equilibrium analysis under different information sharing arrangements without and with information leakage to identify the different effects of cost reduction and information leakage. Combining the two effects together, we obtain the optimal information sharing arrangements for the retailers.

3. The model. We consider two-tier supply chains with either upstream competition or downstream competition. Two substitutable products engaged in Cournot competition are sold in each supply chain to the market with uncertain demand. The inverse demand function for product $i$ is (e.g., [11], [8], [4]) given as follows:

$$p_i = \alpha + \theta - q_i - \gamma q_j \quad \text{for} \quad i \neq j \quad \text{and} \quad i, j = 1, 2,$$

where $p_i$ represents the retail price and $q_i$ represents the order quantity of product $i$. $\theta$ is a random variable and depicts demand uncertainty; the mean of $\theta$ is 0, and the variance of $\theta$ is $\sigma^2$. $\gamma \in (0, 1)$ is a measure of competition intensity, and a larger $\gamma$ implies more intense competition.
Table 1. Summary table of literature review

| Papers                  | Influence factors | Supply chain structures |
|-------------------------|-------------------|-------------------------|
|                         | Information leakage | Cost reduction | System SC | System RC |
| Fang and Ren[6]         | ✓                  | ×                     | ×         | ×         |
| Wang et al.[29]         | ✓                  | ×                     | ×         | ✓         |
| Chen and Özer[5]        | ✓                  | ×                     | ×         | ✓         |
| Ha et al.[8]            | ×                  | ✓                     | ×         | ×         |
| Sun et al.[27]          | ×                  | ✓                     | ×         | ×         |
| Cao and Chen[4]         | ✓ ✓                |                        | ✓         | ✓         |
| Our paper               | ✓ ✓                | ✓                     | ✓         | ✓         |

Suppliers can make effort to cut down the production cost $c_i$ by an amount of $x_i$ at the expense of $\frac{1}{2}k_i x_i^2$, where $k_i$ describes suppliers’ efficiency in cost reduction on product $i$. The higher the $k_i$, the lower the cost reduction efficiency because a higher $k_i$ results in a higher expense of effort for a given cost reduction level. The quadratic form of the expense of effort means that the return of effort diminishes as the cost reduction level $x_i$ increases, which is widely used in the literature (e.g., [12], [8], [10]). As is assumed in the literature (e.g., [34], [18], [8]), the demand signal satisfies the following conditions:

(1) $E[Y_i | \theta] = \theta$, which means that the demand signal $Y_i$ of retailer $i$ is an unbiased estimator of $\theta$.

(2) $E[\theta | Y_1, Y_2] = \lambda_0 + \lambda_1 Y_1 + \lambda_2 Y_2$, where $\lambda_0, \lambda_1, \lambda_2$ are constants, that is to say, the expectation of $\theta$ conditional on demand signal is a linear function of the signal.

(3) $Y_1, Y_2$ are independent and identically distributed conditional on $\theta$. Based on Lemma 1 in the study of Li[17], the above three assumptions indicate that

$$E[\theta | Y_i] = E[Y_j | Y_i] = \frac{Y_i}{1+s} \quad \text{and} \quad E[\theta | Y_1, Y_2] = \frac{Y_1 + Y_2}{2+s},$$

(3)

where $s \equiv \frac{E[\text{Var}[Y_i | \theta]]}{\text{Var}[\theta]}$ represents the accuracy of information and a larger $s$ indicates a less accurate information. Note that from Equation (3), $Y_1$ and $Y_2$ are sufficient for estimating $\theta$. Given $Y_1$ and $Y_2$,

$$E[(Y_i)^2] = (1+s)\sigma^2 \quad \text{and} \quad E[Y_1 Y_2] = \sigma^2.$$

(4)

Without loss of generality, the constant marginal operating costs of the retailers can be normalized to zero. Note that in system SC, $Y_1 = Y_2 = Y$.

We consider two supply chain structures of system SC and RC in the following two sections, and the sequence of the three-stage game is as follows:

Stage 1: Retailers make their information sharing decision $n = (n_1, n_2)$ before observing the demand signal. In system SC, $n_i = 1$ ($n_i = 0$, resp.) implies that the common retailer shares (doesn’t share, resp.) information with supplier $i$. Whereas, in system RC, $n_i = 1$ ($n_i = 0$, resp.) implies that retailer $i$ shares (doesn’t share, resp.) information with the common supplier.

Stage 2: After observing the demand signal, each retailer truthfully discloses it to the supplier based on the information sharing decision $n = (n_1, n_2)$ made
earlier. Suppliers decide on the optimal wholesale price $\omega_i^{(n_1,n_2)}$ and cost reduction effort $x_i^{(n_1,n_2)}$ for product $i$ based on the information received in both supply chain structures to maximize their profits.

Stage 3: Given the wholesale price $\omega_i^{(n_1,n_2)}$ and cost reduction effort $x_i^{(n_1,n_2)}$, retailers decide on the optimal order quantities $q_i^{(n_1,n_2)}$ for product $i$ to maximize their profits.

Upon receiving retailers’ orders, suppliers produce to meet the retailers’ demand, and then retailers sell the products to customers.

Note that in system SC, with information leakage, an informed supplier may leak the demand information to an uninformed supplier, which is not the case without information leakage. Whereas, in system RC, without information leakage, each retailer couldn’t infer the demand information of the rival retailer according to the determined wholesale price, which is on the opposite with information leakage.

The parameters and notations adopted in our paper are shown in Table 2.

| Parameters and notations | Description |
|--------------------------|-------------|
| $p_i$                    | Selling price of product $i$ |
| $q_i$                    | Order quantity of product $i$ |
| $\alpha$                | Potential market size |
| $\theta$                | Demand uncertainty with the mean of 0 and variance of $\theta^2$ |
| $\gamma$                | Competition intensity and a larger $\gamma$ implies more intense competition |
| $c_i$                    | Production cost of product $i$ |
| $x_i$                    | Production cost reduction level of product $i$ |
| $k_i$                    | Cost reduction efficiency of product $i$ and a lower $k_i$ indicates a higher efficiency |
| $Y_i(i)$                 | Demand signal of retailer $(i)$ |
| $s$                      | Accuracy of demand signal and a larger $s$ indicates a less accurate information |
| $n = (n_1,n_2)$          | Information sharing decisions |
| $\omega_i$              | Wholesale price of product $i$ |
| $\pi_{R(i)}^{(n_1,n_2)}$ | Profit of the retailer $(i)$ under information sharing arrangement $n = (n_1,n_2)$ |
| $\pi_{S(i)}^{(n_1,n_2)}$ | Profit of the supplier $(i)$ under information sharing arrangement $n = (n_1,n_2)$ |

4. **Information sharing in system SC.** Similar to Ha et al.[8] and Cao et al.[4], we assume that the two suppliers are identical in production cost and production cost reduction efficiency, that is $c_1 = c_2 = c$ and $k_1 = k_2 = k$. We further assume $k > \frac{\alpha}{2(2-\gamma)(1+\gamma)c}$ to guarantee that the optimal cost reduction level cannot exceed the original production cost $c$, and both $c$ and $\sigma$ are small relative to $\mathcal{N}$ so that the equilibrium quantity and cost reduction level are nonnegative with a probability close to one.
In order to draw a distinction between cost reduction effect and information leakage effect, we first conduct equilibrium analysis under different information sharing arrangements without information leakage. Without information leakage, an informed supplier won’t leak information to the uninformed one. We derive the decisions and ex-ant profits for supply chain members by means of backward induction method. In the first stage, there are three possible information sharing arrangements: the retailer shares demand information with both suppliers, neither supplier or only supplier. Hence, in the following three information sharing arrangements, we first derive the retailer’s optimal order quantity as a function of the wholesale price, then figure out the suppliers’ optimal wholesale prices and cost reduction efforts, and finally calculate the expected profits of supply chain members.

Given the wholesale prices \( \omega = (\omega_1, \omega_2) \) and demand signal \( Y \), the retailer orders \( q = (q_1, q_2) \) to maximize its profit of

\[
\sum_{i=1}^{2} (\alpha + E[\theta \mid Y] - q_i - \gamma q_j - \omega_i)q_i. \tag{5}
\]

The retailer’s best-response order quantity is:

\[
\hat{q}_i(\omega_i, \omega_j) = \frac{\alpha(1 - \gamma - \omega_i + \gamma \omega_j)}{2(1 - \gamma^2)} + \frac{Y}{2(1 + s)(1 + \gamma)}. \tag{6}
\]

When \( n = (0, 0) \), each supplier \( i \) has no demand signal and maximize its profit based on the anticipation of the retailer’s order quantity

\[
(\omega_i - c_i + x)E[\hat{q}_i(\omega_i, \omega_j)] - \frac{1}{2} k x_i^2. \tag{7}
\]

The Hessian matrix is negative definite when \( k > \frac{1}{4(1 - \gamma^2)} \), as is proved in appendix A1, otherwise the research would be meaningless. The supplier’s best-response wholesale price and cost reduction effort are

\[
\hat{\omega}_i(\omega_j) = \frac{(1 - \gamma)((2k(1 - \gamma^2) - 1)\alpha + 2(1 + \gamma)kc)}{4k(1 - \gamma^2) - 1} + \frac{(2k(1 - \gamma^2) - 1)\gamma E[\omega_j]}{4k(1 - \gamma^2) - 1}, \tag{8}
\]

and

\[
\hat{x}_i(\omega_j) = \frac{(1 - \gamma)\alpha - c}{4k(1 - \gamma^2) - 1} + \frac{\gamma E[\omega_j]}{4k(1 - \gamma^2) - 1}. \tag{9}
\]

When \( n = (1, 1) \), each supplier \( i \) received demand signal and maximize its profit based on the anticipation of the retailer’s order quantity

\[
(\omega_i - c_i + x_i)E[\hat{q}_i(\omega_i, \omega_j) \mid Y] - \frac{1}{2} k x_i^2. \tag{10}
\]

The supplier’s best-response wholesale price and cost reduction effort are

\[
\hat{\omega}_i(\omega_j) = \frac{(1 - \gamma)((2k(1 - \gamma^2) - 1)\alpha + 2(1 + \gamma)kc)}{4k(1 - \gamma^2) - 1} + \frac{(2k(1 - \gamma^2) - 1)\gamma Y}{(1 + s)(4k(1 - \gamma^2) - 1)}, \tag{11}
\]

and

\[
\hat{x}_i(\omega_j) = \frac{(1 - \gamma)\alpha - c}{4k(1 - \gamma^2) - 1} + \frac{\gamma \omega_j}{4k(1 - \gamma^2) - 1} + \frac{(1 - \gamma)(2k(1 - \gamma^2) - 1)Y}{(1 + s)(4k(1 - \gamma^2) - 1)}. \tag{12}
\]

When \( n = (1, 0) \), supplier 1 receives demand signal but supplier 2 does not. They choose the wholesale prices and cost reduction effort to maximize their profits
given in equation (10) and equation (7), respectively. The setting when \( n = (0,1) \) is symmetric, with the roles of the two suppliers switched.

Here we use Bayesian Nash equilibrium to solve the static games of incomplete information. When \( n = (0,0) \) or \( n = (1,1) \), suppliers are symmetric in demand signal, and therefore each supplier's conjecture about \( \omega \) is consistent with the reality, that is \( E[\omega] = \omega \). When \( n = (1,0) \), suppliers are asymmetric in demand signal \( Y \), supplier 1's conjecture about \( \omega \) is consistent with the reality, that is \( E[\omega] = \omega \); whereas supplier 2's conjecture about \( \omega \) is \( E[\omega] \), neglecting the part related to demand signal \( Y \). An equilibrium \( (\omega^*, q^*_1, q^*_2) \) can be found by solving \( \omega_i^* = \hat{\omega}_i(\omega^*) \) and \( q^*_i = \hat{q}_i(q^*) \).

Table 3 groups the optimal decisions and corresponding expected ex-ante profits of the supply chain members in system SC without information leakage.

| \( n \) | Decisions | Ex-ante profits |
|-------|-----------|----------------|
| \((0,0)\) | \( \omega_1^{(0,0)} = \omega_0 \) \( \omega_2^{(0,0)} = \omega_0 \) \( q_1^{(0,0)} = q_0 + \frac{Y}{2(1+\gamma)(1+\gamma)} \) | \( \pi_R^{(0,0)} = \pi_R^0 + \frac{\sigma^2}{2(1+\gamma)(1+\gamma)} \) \( \pi_{S_1}^{(0,0)} = \pi_S^0 \) |
| \((1,1)\) | \( \omega_1^{(1,1)} = \omega_0 + \frac{2k(1-\gamma^2-1)}{1+2s}(1+\gamma^{-1}) \) \( q_1^{(1,1)} = q_0 + \frac{Y}{2(1+\gamma)(1+\gamma)} \) \( \omega_2^{(1,1)} = \omega_0 + \frac{2k(1-\gamma^2-1)}{1+2s}(1+\gamma^{-1}) \) \( q_2^{(1,1)} = q_0 + \frac{Y}{2(1+\gamma)(1+\gamma)} \) | \( \pi_R^{(1,1)} = \pi_R^0 + \frac{2k(1-\gamma^2-1)}{1+2s}(1+\gamma^{-1}) \) \( \pi_{S_1}^{(1,1)} = \pi_S^0 + \frac{2k(1-\gamma^2-1)}{1+2s}(1+\gamma^{-1}) \) |
| \((0,0)\) | \( \omega_1^{(0,0)} = \omega_0 \) \( \omega_2^{(0,0)} = \omega_0 \) \( q_1^{(0,0)} = q_0 + \frac{Y}{2(1+\gamma)(1+\gamma)} \) \( q_2^{(0,0)} = q_0 + \frac{Y}{2(1+\gamma)(1+\gamma)} \) | \( \pi_R^{(0,0)} = \pi_R^0 + \frac{\sigma^2}{2(1+\gamma)(1+\gamma)} \) \( \pi_{S_1}^{(0,0)} = \pi_S^0 \) |

Notes. \( \omega_0 = \frac{(2k(1-\gamma^2-1)\gamma+2k(1+\gamma)\gamma)}{(2k(1-\gamma^2-1)\gamma+4k(1+\gamma)\gamma)} \) \( \omega_0 = \frac{(2k(1-\gamma^2-1)\gamma+2k(1+\gamma)\gamma)}{(2k(1-\gamma^2-1)\gamma+4k(1+\gamma)\gamma)} \) \( q_0 = \frac{k(1-\gamma^2-1)\gamma+2k(1+\gamma)\gamma}{(2k(1-\gamma^2-1)\gamma+4k(1+\gamma)\gamma)} \) \( \pi_R^{(0,0)} = \pi_R^0 + \frac{\sigma^2}{2(1+\gamma)(1+\gamma)} \) \( \pi_{S_1}^{(0,0)} = \pi_S^0 \).

Form table 3, we can see intuitively how suppliers adjust cost reduction levels and wholesale prices according to the received demand information in system SC without information leakage, as illustrated in lemma 4.1.

**Lemma 4.1.** In system SC without information leakage, (a) if supplier \( i \) is uninformed of the demand signal \( Y \), its wholesale price and cost reduction level have no concern with \( Y \); (b) if supplier \( i \) is informed of the demand signal \( Y \), its cost reduction level is increasing with \( Y \); (c) if supplier \( i \) is informed of the demand signal \( Y \), its wholesale price is increasing with \( Y \) if \( k \geq \frac{1}{2(1-\gamma^2)} \) and decreasing otherwise.

As the demand signal \( Y \) increases, an informed supplier expects the order quantity and thus the return of cost reduction to be high. Therefore, a larger \( Y \) induces
the supplier to increase its cost reduction effort. However, when the cost reduction efficiency is low \( k \geq \frac{1}{2(1-\gamma^2)} \), with a slight reduction in the unit production cost and a large amount of expense on cost reduction effort, the supplier will raise the wholesale price to increase its marginal profit. When the cost reduction efficiency is high \( k < \frac{1}{2(1-\gamma^2)} \), with a substantial reduction in the unit production cost and a small amount of expenses on cost reduction effort, the supplier will reduce the wholesale price to increase sales without sacrificing its marginal profit. It’s worth noting that the threshold of cost reduction efficiency \( k \) for the informed supplier to adjust wholesale prices according to demand signal \( Y \) differs from that in Ha et al.[8]. In Ha et al.[8], the threshold of \( k \) is \( \frac{1}{2} \), and therefore the adjustment of wholesale price according to demand signal \( Y \) has nothing to do with competition intensity. In system SC, the threshold of \( k \) is \( \frac{1}{2(1-\gamma^2)} \), which increases with \( \gamma \), and therefore an informed supplier is more likely to decrease wholesale prices with \( Y \) when competition becomes more intense.

Next, we consider how information sharing impacts the order quantity of the retailer.

**Lemma 4.2.** In system SC without information leakage, whether the retailer shares information with supplier \( j \) or not, information sharing with supplier \( i \) makes \( q_i \) more responsive to \( Y \) and \( q_j \) less responsive to \( Y \) when \( k < \frac{1}{2(1-\gamma^2)} \), and \( q_i \) less responsive to \( Y \) and \( q_j \) more responsive to \( Y \) otherwise.

See Appendix A2 for proof.

The retailer adjusts \( q_i \) in the opposite direction with the adjustment in \( \omega_i \). From lemma 4.1 we can see that when \( k < \frac{1}{2(1-\gamma^2)} \), information sharing decreases \( \omega_i \), and thus makes \( q_i \) more responsive to \( Y \); When \( k \geq \frac{1}{2(1-\gamma^2)} \), information sharing increases \( \omega_i \), and thus makes \( q_i \) less responsive to \( Y \). The adjustment of \( q_j \) with demand signal \( Y \) is contrary to \( q_i \) because the two products are strategic substitutes. The retailer maximizes its profit by buying fewer high-priced items and more low-priced ones.

Now, we consider how information sharing impacts the profits of supply chain members in system SC without information leakage.

**Proposition 1.** In system SC without information leakage, (a) information sharing always benefits the suppliers; (b) if the retailer doesn’t share information with supplier \( j \), information sharing with supplier \( i \) benefits the retailer when \( k < \frac{1}{2(1-\gamma^2)} \) and hurts it otherwise; (c) if the retailer shares information with supplier \( j \), information sharing with supplier \( i \) benefits the retailer when \( k_{SC} < k < \frac{1}{2(1-\gamma^2)} \) and hurts it otherwise.

See Appendix A3 for proof.

Whether or not the rival supplier is informed, an informed supplier adjusts cost reduction effort and wholesale price to optimize its profit based on more accurate inference about demand uncertainty and the wholesale price of its rival supplier, which always benefits the supplier.

From table 3 we can see that when \( k \geq \frac{1}{2(1-\gamma^2)} \), compared the situation when the retailer shares information with neither supplier, information sharing with one supplier increases wholesale price of the informed supplier, which hurts the retailer and prevents it from information sharing. When \( k < \frac{1}{2(1-\gamma^2)} \), compared the situation when the retailer shares information with neither supplier, information sharing
with one supplier decreases wholesale price of the informed supplier, which benefits the retailer and encourages it from information sharing.

Compared the situation when the retailer shares information with one supplier, information sharing with both suppliers decreases the wholesale price of the uninformed supplier but increases the wholesale price of the informed supplier, which leads to opposite changes in the retailer’s profit. When \( k_{SC} < k < \frac{1}{2(1-\gamma^2)} \), the increase of retailer’s profit brought by the decrease of wholesale price of the uninformed supplier is greater than the decrease of retailer’s profit brought by the increase of wholesale price of the informed supplier, that is information sharing with both suppliers overall increase the profit of the retailer, and therefore information sharing benefits the retailer and encourages it from information sharing. Otherwise, when \( \frac{1}{2(1-\gamma^2)} < k \leq k_{SC} \) or \( k \geq \frac{1}{2(1-\gamma^2)} \), information sharing hurts the retailer and prevents it from information sharing.

To illustrate supply chain members’ expected profits under different information sharing arrangements in system SC without information leakage, we conduct a numerical analysis and assume that \( \alpha = 20, \ c = 20, \ \gamma = 0.5, \ s = 1, \) and \( \sigma^2 = 10. \) The results are shown in Figure 1. From figure 1(a) we can see that when the retailer doesn’t share information with supplier \( j \), information sharing with supplier \( i \) always benefits supplier \( i \); when the retailer shares information with supplier \( j \), information sharing with supplier \( i \) still benefits supplier \( i \). Therefore, whether the retailer shares information with the rival supplier, information sharing always benefits the supplier who received demand information.

![Figure 1](image)

**Figure 1.** Supply chain members’ expected profit in system SC without information leakage

From proposition 1, the retailer’s optimal information sharing strategies without information leakage are as follows.

**Proposition 2.** In system SC without information leakage, when \( \frac{1}{2(1-\gamma^2)} < k \leq k_{SC} \), the retailer shares information with one supplier; when \( k_{SC} < k < \frac{1}{2(1-\gamma^2)} \), the retailer shares information with two suppliers; when \( k \geq \frac{1}{2(1-\gamma^2)} \), the retailer shares information with neither supplier.
Comparing proposition 2 in our study with that of proposition 7 in Ha et al. [8], we find that retailers’ information sharing strategies are different in different supply chain structures. In system SC without information leakage, the retailer chooses to share information with one, two or neither suppliers out of self-interests. However, in Ha et al. [8] with two competing supply chains, each retailer decides whether to share information with its supplier or not. Different supply chain structures lead to different information sharing strategies.

The retailer’s information sharing strategies without information leakage are illustrated in Figure 2, where competition intensity $\gamma$ varies from zero to one. Proposition 2 indicates that the retailer’s information sharing strategies depend on the relationship between cost reduction efficiency $k$ and competition intensity $\gamma$, and have nothing to do with other parameters. From figure 2 we can see that the transactions are meaningless when $k \geq \frac{1}{4(1-\gamma^2)}$ (Area I). The retailer will share information with one supplier when $\frac{1}{4(1-\gamma^2)} < k \leq k_{SC}$ (Area II), with both suppliers when $k_{SC} < k < \frac{1}{2(1-\gamma^2)}$ (Area III), and with neither retailer when $k \geq \frac{1}{2(1-\gamma^2)}$ (Area IV). Numerical analysis indicates that both $k_{SC}$ and $\frac{1}{2(1-\gamma^2)}$ increase with $\gamma$ and therefore the retailer is more likely to share information as the competition becomes more intense. This is in sharp contrast with that in Ha et al. [8], where information sharing occurs with a higher probability when either competition is less intense or information is less accurate.

![Figure 2. The retailer’s information sharing strategies in system SC without information leakage](image)

Finally, we explore the incentive for an informed supplier to leak demand information to the uninformed one and how the information leakage behavior of the supplier affects the information sharing decision of the retailer.
Proposition 3. In system SC with information leakage, (a) when \( k \geq \frac{1}{2(1-\gamma)} \), an informed supplier will leak demand information to the uninformed one; otherwise the informed supplier will keep the demand information as a secret. (b) information leakage behavior of the informed supplier won’t affect the information sharing decision of the retailer.

See Appendix A4 for proof.

Considering information leakage, from lemma 4.1 we can see that when \( k \geq \frac{1}{2(1-\gamma)} \), information leakage of an informed supplier to the uninformed one increases the wholesale price of the uninformed supplier, which in turn improves the competitiveness of the informed supplier, and thus the informed supplier will leak demand information to the uninformed one. Otherwise, the informed supplier will keep the demand information as a secret. In addition, information leakage behavior of the informed supplier won’t affect the information sharing decision of the retailer since the retailer shares information with neither supplier when \( k \geq \frac{1}{2(1-\gamma)} \).

Numerical analysis can be seen in figure 1(a). By comparing the situation when only supplier \( i \) is informed with the situation when both supplier \( i \) and \( j \) are informed, we can see that it is optimal for an informed supply to keep the demand information as a secret when \( k < \frac{1}{2(1-\gamma)} \), but leak the demand information to the uninformed supplier otherwise. Since \( \frac{1}{2(1-\gamma)} \) increase with \( \gamma \), suppliers are less likely to leak information when competition becomes more intense.

5. Information sharing in system RC. As in section 4, we assume that the two products are identical in production cost and production cost reduction efficiency, that is \( c_1 = c_2 = c \) and \( k_1 = k_2 = k \). We further assume \( k > \frac{\alpha}{2(2+\gamma)c} \) to guarantee that the optimal cost reduction level cannot exceed the original production cost \( c \), and both \( c \) and \( \sigma \) are small relative to \( \alpha \) so that the equilibrium quantity and cost reduction level are nonnegative with a probability close to one. In order to draw a distinction between cost reduction effect and information leakage effect, we first conduct equilibrium analysis under different information sharing arrangements without information leakage.

5.1. Without information leakage. Without information leakage, each retailer only knows the demand information of its own and can’t infer the rival retailer’s demand information from the wholesale price. We derive the decisions and ex-ant profits for supply chain members by means of backward induction method.

In the first stage, there are three possible information sharing arrangements: both retailers share demand information, no retailer shares demand information, and only one retailer shares demand information. Hence, in the following three information sharing arrangements, we first derive the retailer’s optimal order quantity as a function of the wholesale price, then figure out the supplier’s optimal wholesale price and cost reduction effort, and finally calculate the expected profits of supply chain members.

Each retailer can’t observe the rival retailer’s order quantity, so they make order quantity decisions based on a conjecture of the rival retailer’s order quantity. Given the wholesale price \( \omega_i \) and a conjecture of \( q_j \), the expected profit for retailer \( i \) is:

\[
(\alpha + E[\theta | Y_i] - q_i - \gamma E[q_j | Y_i])q_i.
\]

In system SC, given the wholesale price \( \omega_i \), a common retailer decides on order quantities for the two kinds of products simultaneously based on the same demand
However, in system RC, given the wholesale price \( \omega_i \), each retailer \( i \) decides on its order quantity based on its private demand signal \( Y_i \) and anticipation of the rival retailer’s order quantity. Therefore, without information leakage, the retailer \( i \)’s best-response order quantity in system RC is:

\[
\hat{q}_i(\omega_i, \omega_j) = \frac{\alpha(2 - \gamma) - 2\omega_i + \gamma \omega_j}{4 - \gamma^2} + \frac{Y_i}{2 + 2s + \gamma}.
\]

As can be seen from Equation (14), given wholesale prices of the two products, the best response order quantity of a retailer is only related to its own demand information, and has nothing to do with the demand information of the rival retailer.

Having known retailers’ best response functions on \( \omega_i \) and \( \omega_j \), the supplier decides on its optimal wholesale prices and cost reduction efforts for both products.

When both retailers share demand information, \( n = (1, 1) \), the expected profit for the supplier is:

\[
\sum_{i=1}^{2} \left( (\omega_i - c_i + x_i)E[\hat{q}_i(\omega_i, \omega_j) \mid Y_1, Y_2] - \frac{1}{2}k x_i^2 \right).
\]

(15)

When no retailer shares demand information, \( n = (1, 1) \), the expected profit for the supplier is:

\[
\sum_{i=1}^{2} \left( (\omega_i - c_i + x_i)E[\hat{q}_i(\omega_i, \omega_j)] - \frac{1}{2}k x_i^2 \right).
\]

(16)

When only one retailer shares demand information, without loss of generality, we assume that retailer 1 shares its demand information, \( n = (1, 0) \), then the expected profit for the supplier is:

\[
\sum_{i=1}^{2} \left( (\omega_i - c_i + x_i)E[\hat{q}_i(\omega_i, \omega_j) \mid Y_1] - \frac{1}{2}k x_i^2 \right).
\]

(17)

To prove the existence of the maximum value for the supplier’s expected profit function, the Hessian matrix must be negative. As is proved in Appendix A5 the Hessian matrix is negative when \( k > \frac{1}{2(2 - \gamma)^2} \), otherwise there would be no transaction between the supplier and retailers, and thus the research would be meaningless. Similarly, we omit the situation where only retailer 2 shares information due to symmetry.

The supplier’s optimal wholesale prices and cost reduction efforts under different information sharing arrangements are obtained by setting the partial derivatives of the expected profit function on \( \omega_i, x_i, \omega_j \) and \( x_j \) for the supplier to zero. Substitute the supplier’s wholesale prices without information leakage into equation (14), we obtain the retailers’ order quantities. Substitute decisions of supply chain members under different information sharing arrangements into profit functions, we can derive the ex-ante profits of them. Table 4 groups the optimal decisions and corresponding expected ex-ante profits of supply chain members in system RC without information leakage.

Form table 4, we can see that in a supply chain with one supplier and two retailers, and without information leakage, the supplier adjusts wholesale prices and cost reduction levels for both products based on the information received in complex ways, which is different from that in other supply chain structures. The different adjustments of cost reduction level in different supply chain structures are due to differences in the way that decisions are made. In system RC, the
supplier codetermines wholesale prices and cost reduction levels for both products, facing trade-off between the two products. Whereas, in system SC and among two competing supply chains, each supplier i determines the wholesale price and cost reduction level for product i independently. In system RC without information

TABLE 4. Decisions and ex-ante profits in system SC without information leakage

| n     | Decisions | Ex-ante profits |
|-------|-----------|-----------------|
| (0, 0) | \( \omega^0_i = \omega^0 \) | \( \pi^{(0,0)}_{R_i} = \pi^{0}_R + \frac{(1+s)^2}{(2+2+\gamma)^2} \) |
|       | \( x^0_i = x^0 \)          | \( \pi^{(0,0)}_S = \pi^0 \)          |
|       | \( q_i^{(0,0)} = q^0 + \frac{Y_i}{2+2+\gamma} \) |                   |
| (1, 1) | \( \omega^1_i = \omega^0 + \alpha^1_i \) | \( \pi^{(1,1)}_{R_i} = \pi^{1}_R + \xi^{(1,1)}_i \) |
|       | \( x^1_i = x^0 + \beta^1_i \)          | \( \pi^{(1,1)}_S = \pi^1_S + \eta^{(1,1)}_i \)          |
| (1, 0) | \( \omega^1_i = \omega^0 + \alpha^1_0 \) | \( \pi^{(1,0)}_{R_i} = \pi^{1}_R + \xi^{(1,0)}_i \) |
|       | \( x^1_i = x^0 + \beta^1_0 \)          | \( \pi^{(1,0)}_S = \pi^1_S + \eta^{(1,0)} \)          |
|       | \( q_i^{(1,0)} = q^0 + \delta^1_0 \)          |                   |
|       | \( q_i^{(1,0)} = q^0 + \delta^1_0 \)          |                   |

Notes. \( \omega^0 = \frac{(k(2+\gamma)-1)\alpha+k(2+\gamma)c}{2k(2+\gamma)-1}, q^0 = \frac{\kappa(\alpha-c)}{2k(2+\gamma)-1}, \pi^0_R = \frac{k^2(\alpha-c)^2}{2k(2+\gamma)-1}, \)
\( \pi^0_S = \frac{k^2(\alpha-c)^2}{(2k(2+\gamma)-1)^2}, \)
\( \begin{align*}
&\beta^{(1,0)}_1 = \frac{(2k(1+s)(4-\gamma^2)-2(2+s+\gamma))Y_i}{(1+s)(2+2+\gamma)(2k(2+\gamma)-1)}Y_i, \\
&\beta^{(1,0)}_2 = \frac{(2k(4-\gamma^2)-2(2+s+\gamma))Y_i}{(1+s)(2+2+\gamma)(2k(2+\gamma)-1)}Y_i, \\
&\beta^{(1,1)} = \frac{(2k(4-\gamma^2)-1)Y_i-Y_i}{2k(4-\gamma^2)-2(2+s+\gamma)}Y_i, \\
&\delta^{(0,0)}_1 = \frac{(k(6-\gamma^2)-2k^2(4-\gamma^2))Y_i}{(1+s)(2+2+\gamma)(2k(2+\gamma)-1)}Y_i, \\
&\delta^{(1,1)}_1 = \frac{(2k(4-\gamma^2)-1)Y_i-Y_i}{2k(4-\gamma^2)-2(2+s+\gamma)}Y_i, \\
&\eta^{(0,0)}_1 = \frac{(4k(2+\gamma)(4-\gamma^2)-2(1+s)(2+s+\gamma)^2-2(4-\gamma^2))\kappa^2}{(2k(4-\gamma^2)-2(2+s+\gamma))^2}, \\
&\eta^{(0,1)}_1 = \frac{(4k(2+\gamma)(4-\gamma^2)-2(1+s)(2+s+\gamma)^2-2(4-\gamma^2))\kappa^2}{(2k(4-\gamma^2)-2(2+s+\gamma))^2}, \\
&\eta^{(1,1)} = \frac{(2(2+2+\gamma)(4-\gamma^2)-2(2+s+\gamma)+2(4-\gamma^2)+2(4-\gamma^2))\kappa^2}{(2k(4-\gamma^2)-2(2+s+\gamma))^2}, \\
&\eta^{(1,0)} = \frac{(k(6-\gamma^2)-2k^2(4-\gamma^2)-2(2+s+\gamma)+2(4-\gamma^2))\kappa^2}{(2k(4-\gamma^2)-2(2+s+\gamma))^2}.
\end{align*} \)
leakage, the adjustments of order quantities for both products according to demand signals are also quite complex.

Next, we consider how information sharing impacts the profits of supply chain members in system RC without information leakage.

**Proposition 4.** In system RC without information leakage, (a) information sharing always benefits the supplier; (b) if retailer \( j \) doesn’t share information with the supplier, information sharing of retailer \( i \) benefits itself when
\[
\frac{6+6s-\gamma-\sqrt{4(1+s)^2-12(1+s)\gamma+(9+16s+8s^2)^2}}{2(1+s)}
\]
and hurts itself otherwise; (c) if retailer \( j \) shares information with the supplier, information sharing of retailer \( i \) benefits itself when
\[
k < \frac{1}{3-\sqrt{1+2\gamma}}
\]
and hurts itself otherwise.

See Appendix A6 for proof.

Proposition 4 indicates that the supplier’s optimal expected profit increases when more retailers share demand information. When more retailers share demand information, the information advantages are transferred from the retailers to the supplier. Therefore, the supplier can adjust cost reduction efforts and wholesale prices to increase expected profit based on more accurate inference about demand uncertainty.

To illustrate the supply chain members’ expected profits under different information sharing arrangements in system RC without information leakage, we conduct a numerical analysis and assume that \( \alpha = 20, c = 20, \gamma = 0.5, s = 1, \) and \( \sigma^2 = 10. \) From figure 3(a), when more retailers sharing information, the supplier is always better off.

![Figure 3. Supply chain members’ expected profits in system RC without information leakage](image)

Without information leakage, the effects of information sharing for retailers depend on the relationship among cost reduction efficiency, information accuracy and competition intensity. When the supplier is efficient in cost reduction, it can reduce production cost significantly with less expenses. Therefore, it is optimal for the supplier who obtained demand information to enhance cost reduction level and reduce the wholesale price. Lower wholesale price would benefit the retailer.
who shared information in turn. The opposite is true when the supply is inefficient in cost reduction. What’s more, 

\[ \frac{1}{2(1+s)} < \frac{1}{3 - \sqrt{1 + 2\gamma}}, \]

retailer \( i \) is more likely to share information if retailer \( j \) shares information. The related numerical analysis is shown in Figure 3(b), where \( k_1 = \frac{1}{2(1+s)} \) and \( k_2 = \frac{1}{3 - \sqrt{1 + 2\gamma}} \).

From proposition 4, retailers’ optimal information sharing strategies without information leakage are as follows.

**Proposition 5.** In system RC without information leakage, When \( \frac{1}{2(1-s)} < k \leq \frac{2(1+s)}{6+6s-\gamma - \sqrt{4(1+s)^2 - 12(1+s)\gamma + (9+16s+8s^2)^2}} \), both retailers share their information; when \( k \geq \frac{1}{3 - \sqrt{1 + 2\gamma}} \), neither retailer shares its information; when \( \frac{2(1+s)}{6+6s-\gamma - \sqrt{4(1+s)^2 - 12(1+s)\gamma + (9+16s+8s^2)^2}} < k < \frac{1}{3 - \sqrt{1 + 2\gamma}} \), the two retailers would adopt the same information sharing strategies.

Retailers are willing to share their information only when it is profitable to do so. From proposition 4, we can see that when the cost reduction efficiency is lower than \( \frac{1}{2(1-s)} \), both retailers are better off whether the rival retailer shares information or not, thus both retailers share information. When the cost reduction efficiency is more than \( \frac{1}{3 - \sqrt{1 + 2\gamma}} \), both retailers are worse off whether the rival retailer shares information or not, thus neither retailer shares information. When the cost reduction efficiency is more than \( \frac{2(1+s)}{6+6s-\gamma - \sqrt{4(1+s)^2 - 12(1+s)\gamma + (9+16s+8s^2)^2}} \) and less than \( \frac{1}{3 - \sqrt{1 + 2\gamma}} \), whether the retailer who shares information is better off depends on the rival retailer’s decision. If the rival retailer doesn’t share information, it is worse off for a retailer to share information. If the rival retailer shares information, it is better off for a retailer to share information. Therefore, the two retailers would adopt the same information sharing strategies.

The retailers’ information sharing strategies without information leakage are illustrated in Figure 4, where competition intensity \( \gamma \) varies from zero to one and \( s = 1 \). From figure 4 we can see that the transactions are meaningless when \( k \leq \frac{2(1+s)}{6+6s-\gamma - \sqrt{4(1+s)^2 - 12(1+s)\gamma + (9+16s+8s^2)^2}} \) (Area I). Both retailers share information with the supplier when \( \frac{1}{2(1-s)} < k \leq \frac{2(1+s)}{6+6s-\gamma - \sqrt{4(1+s)^2 - 12(1+s)\gamma + (9+16s+8s^2)^2}} \) (Area II), Neither or both retailers share information with the supplier when \( \frac{2(1+s)}{6+6s-\gamma - \sqrt{4(1+s)^2 - 12(1+s)\gamma + (9+16s+8s^2)^2}} < k < \frac{1}{3 - \sqrt{1 + 2\gamma}} \) (Area III), and neither retailer shares information with the supplier when \( k \geq \frac{1}{3 - \sqrt{1 + 2\gamma}} \) (Area IV).

### 5.2. With information leakage

In this section, we conduct equilibrium analysis under different information sharing arrangements with information leakage. With information leakage, each retailer can infer the rival retailer’s demand information from the wholesale price if the rival retailer shares information. What’s more, as is proved in Appendix A7, whether the retailers share demand information or not, a single pricing and cost reduction effort is optimal for the supplier with information leakage, that is \( \omega_1 = \omega_2 = \omega, x_1 = x_2 = x \). Given the wholesale price \( \omega \), the
Retailers’ expected profits are as follows:
\[(\alpha + E[\theta | Y_i, \omega]) - q_i - \gamma E[q_j | Y_i, \omega])q_i. \tag{18}\]

When both retailers share demand information, \( n = (1, 1) \), each retailer \( i \) can infer the demand signal of retailer \( j \). When neither retailer shares demand information, each retailer only possesses its own demand signal. When only one retailer \( i \) shares demand information, retailer \( j \) can infer the demand signal of retailer \( i \), but retailer \( i \) doesn’t know the demand signal of retailer \( j \). Consequently, retailers’ best-response order quantities in system RC with information leakage are
\[
\begin{align*}
\hat{q}_i(\omega) &= \frac{\alpha - \omega}{2 + \gamma} + \frac{Y_i}{2 + 2s + \gamma} - \gamma E[q_j | Y_i, \omega], \\
\hat{q}_j(\omega) &= \frac{\alpha - \omega}{2 + \gamma} + \frac{Y_j}{2 + 2s + \gamma}, \\
\hat{q}_1(\omega) &= \frac{\alpha - \omega}{2 + \gamma} + \frac{(1 + s)(2 + \gamma)}{2 + 2s + \gamma} - \gamma E[q_2 | Y_1, Y_2], \\
\hat{q}_2(\omega) &= \frac{\alpha - \omega}{2 + \gamma} + \frac{(2 + 2s - \gamma)Y_1}{2 + 2s + \gamma} + \frac{Y_2}{2(2 + s)}.
\end{align*}
\tag{19}\]

When both retailers share demand information, \( n = (1, 1) \), the expected profit for the supplier is:
\[
\sum_{i=1}^{2} ((\omega - c + x)E[\hat{q}_1(\omega) + \hat{q}_2(\omega) | Y_1, Y_2] - \frac{1}{2}kx^2). \tag{20}\]

When neither retailer shares demand information, \( n = (0, 0) \), the expected profit for the supplier is:
\[
\sum_{i=1}^{2} ((\omega - c + x)E[\hat{q}_1(\omega) + \hat{q}_2(\omega)] - \frac{1}{2}kx^2). \tag{21}\]
When only one retailer shares demand information, without loss of generality, we assume that retailer 1 shares its demand information, \( n = (1, 0) \), then the expected profit for the supplier is:

\[
\sum_{i=1}^{2} (\omega - c + x) E[q_1(\omega) + q_2(\omega) \mid Y_1] - \frac{1}{2} kx^2.
\]  

(22)

The Hessian matrix is negative definite when \( k > \frac{1}{2(2+\gamma)} \), otherwise the research would be meaningless. Relative proof can be seen in appendix A8. Similarly, we omit the situations where only retailer 2 shares information due to symmetry.

The supplier's optimal wholesale prices and cost reduction efforts under different information sharing arrangements are obtained by setting the partial derivatives of the expected profit function on \( \omega, x \) for the supplier to zero. Substitute decisions of supply chain members under different information sharing arrangements into profit function, we can derive the ex-ante profits of them. Table 5 groups the optimal decisions and corresponding expected ex-ante profits of the supply chain members in system RC with information leakage.

**Table 5. Decisions and ex-ante profits in system SC without information leakage**

| \( n \)  | Decisions | Ex-ante profits |
|---------|-----------|-----------------|
| (0, 0)  | \( \omega^{(0,0)} = \omega^0 \) | \( \pi_{R,0}^{(0,0)} = \pi^0_R + \frac{(1+s)s^2}{(1+2s+2\gamma)^2} \) |
|         | \( x^{(0,0)} = x^0 \) | \( \pi_{S,0}^{(0,0)} = \pi^0_S \) |
| (1, 1)  | \( \omega^{(1,1)} = \omega^0 + \frac{(2k+\gamma-1)(1+s)}{(1+s)(2k+2\gamma-1)} Y_1 + \frac{2Y_2(2k-y-1)}{(1+s)(2k+2\gamma-1)} \) | \( \pi_{R,1}^{(1,1)} = \pi^0_R + \frac{2k^2\sigma^2}{(1+s)(2k+2\gamma-1)^2} \) |
|         | \( x^{(1,1)} = x^0 + \frac{kY_1}{2k+2\gamma-1} \) | \( \pi_{S,1}^{(1,1)} = \pi^0_S + \frac{2k^2\sigma^2}{(1+s)(2k+2\gamma-1)^2} \) |
| (1, 0)  | \( \omega^{(1,0)} = \omega^0 + \frac{2y+\gamma-1}{1+s}(1+s)(2k+2\gamma-1) \) | \( \pi_{R,1}^{(1,0)} = \pi^0_R + \frac{k^2\sigma^2}{(1+s)(2k+2\gamma-1)^2} \) |
|         | \( x^{(1,0)} = x^0 + \frac{Y_1}{1+s(2k+2\gamma-1)} \) | \( \pi_{S,1}^{(1,0)} = \pi^0_S + \frac{k^2\sigma^2}{(1+s)(2k+2\gamma-1)^2} \) |
|         | \( q_1^{(1,0)} = q^0 + \frac{2Y_1}{(1+s)(2k+2\gamma-1)} \) | \( \pi_{R,2}^{(1,0)} = \pi^0_R \) |
|         | \( q_2^{(1,0)} = q^0 + \frac{1+2k+2\gamma Y_1}{2(1+s)(2k+2\gamma-1)^2} + \frac{Y_1}{2(1+s)} \) | \( \pi_{S,2}^{(1,0)} = \pi^0_S + \frac{k^2\sigma^2}{(1+s)(2k+2\gamma-1)^2} \) |

Notes. \( \omega^0 = \frac{(2k+2\gamma-1)\gamma+2k+\gamma-1}{2k+2\gamma-1} \), \( x^0 = \frac{2k+2\gamma-1}{2k+2\gamma-1} \), \( q_1^0 = \frac{2k+2\gamma-1}{2k+2\gamma-1} \), \( q_2^0 = \frac{k(\gamma-1)}{2k+2\gamma-1} \), \( \pi_R^{(0,0)} = \frac{k^2(\alpha-\gamma)^2}{(2k+2\gamma-1)^2} \), \( \pi_S^{(0,0)} = \frac{k^2(\gamma-1)}{(2k+2\gamma-1)^2} \).

Form table 5, we can see intuitively how suppliers adjust wholesale price and cost reduction effort according to the received demand information in system RC with information leakage, as illustrated in lemma 5.1.

**Lemma 5.1.** In system RC with information leakage, (a) if the supplier is uninformed of both demand signals, its wholesale price and cost reduction effort level have no concern with both demand signals; (b) if the supplier is informed of one
or both demand signal signals, its cost reduction effort level is increasing with the demand signal(s); (c) if the supplier is informed of one or both demand signals, its wholesale price is increasing with the demand signal(s) if $k \geq \frac{1}{2(1+\gamma)}$ and decreasing otherwise.

The adjustments of wholesale price and cost reduction effort based on demand signal(s) in system RC are similar to that in system SC. However, the threshold of cost reduction efficiency $k$ for suppliers to adjust wholesale prices according to demand signal(s) in system RC differs from that in system SC. In system RC, the threshold of $k$ is $\frac{1}{2(1+\gamma)}$, which decreases with $\gamma$, and therefore suppliers are more likely to increase wholesale prices with demand signal when competition becomes more intense. This result is related to the competitive structures of supply chains, where upstream competition in system SC lowers wholesale price but downstream competition in system RC increases wholesale price. Moreover, retailers adjust their order quantities in a more complex way within system RC than that in system SC. Comparing equation 6 with equation 19, the adjustments of order quantities under different information sharing arrangements in system SC depend only on the adjustments of wholesale prices, while the adjustments of order quantities under different information sharing arrangements in system RC depend on the adjustments of wholesale prices and demand signals.

Next, we consider how information sharing impacts the profits of supply chain members with information leakage in system RC. Combining cost reduction effect and information leakage effect together, the impacts of information sharing on supply chain members are as follows.

**Proposition 6.** In system RC with information leakage, (a) information sharing always benefits the supplier; (b) if retailer $j$ doesn’t share information with the supplier, information sharing of retailer $i$ benefits itself when $k < \frac{1+s}{2(1+s)+(1+2s)\gamma}$ and hurts itself otherwise; (c) if retailer $j$ shares information with the supplier, information sharing of retailer $i$ benefits itself when $k < \frac{1}{2(1+\gamma)}$ and hurts itself otherwise.

See Appendix A9 for proof. From proposition 4 and proposition 6, we can see that no matter information is leaked or not, the supplier is always better off with more demand information. The related numerical analysis is shown in Figure 5(a).

With information leakage, the effects of information sharing for retailers also depend on the relationship among cost reduction efficiency, information accuracy and competition intensity. Whether the rival retailer shares information or not, information sharing benefits the retailer if the supplier is efficient in cost reduction and hurts the retailer otherwise. What’s more, $\frac{1}{2(1+\gamma)} < \frac{1+s}{2(1+s)+(1+2s)\gamma}$, and therefore retailer $i$ is more likely to share information if retailer $j$ doesn’t share information. The related numerical analysis is shown in Figure 5(b), where $k_{1L} = \frac{1}{2(1+\gamma)}$, and $k_{2L} = \frac{1+s}{2(1+s)+(1+2s)\gamma}$.

From proposition 6, retailers’ optimal information sharing strategies with information leakage are as follows.

**Proposition 7.** In system RC with information leakage, When $\frac{1}{2+\gamma} < k \leq \frac{1}{2(1+\gamma)}$, both retailers share their information; when $k \geq \frac{1+s}{2(1+s)+(1+2s)\gamma}$, neither retailer shares its information; when $\frac{1}{2(1+\gamma)} < k < \frac{1+s}{2(1+s)+(1+2s)\gamma}$, the two retailers would adopt opposite information sharing strategies.
INFORMATION SHARING IN TWO-TIER SUPPLY CHAINS

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
Cost reduction efficiency \( k \)

The expected profit of the supplier

\[ \frac{2}{1+\gamma} \]

Both retailers share information

Only one retailer shares information

Neither retailer shares information

(a)

0.3 0.32 0.34 0.36 0.38 0.4 0.42 0.44 0.46 0.48 0.5
Cost reduction efficiency \( k \)

The expected profit of retailer \( i \)

\[ \frac{1}{2} + \frac{1}{2} \gamma \]

Both retailers share information

Only retailer \( j \) shares information

Only retailer \( i \) shares information

Neither retailer shares information

(b)

Figure 5. Supply chain members’ expected profits in system RC with information leakage

Similar to that in proposition 5, with information leakage, both retailers share information when the supplier is efficient in cost reduction, but neither retailer shares information otherwise. Since \( \frac{1}{2(1+\gamma)} \) and \( \frac{1+s}{2(1+s)+(1+2s)\gamma} \) decrease with competition intensity \( \gamma \), and \( \frac{1+s}{2(1+s)+(1+2s)\gamma} \) decrease with information accuracy \( s \), the retailers are less likely to share information when either the competition is more intense or information is less accurate.

However, with information leakage, the threshold of \( k \) is smaller than that of none information leakage, i.e. \( \frac{1}{2(1+\gamma)} < \frac{1}{2(1+s)} \) and \( \frac{1+s}{2(1+s)+(1+2s)\gamma} < \frac{1}{3\sqrt{1+2\gamma^2}} \). Therefore, retailers are less likely to share information with information leakage.

In addition, with information leakage, when the cost reduction efficiency is between the two thresholds, i.e. \( \frac{1}{2(1+\gamma)} < k \leq \frac{1}{2(1+s)} \), the two retailers adopt the opposite information sharing strategies. Whereas, without information leakage, the two retailers adopt the same information sharing strategies when cost reduction efficiency is intermediate. The reason is that with information leakage, the threshold of \( k \) when the rival retailer shares information is smaller than that when the rival retailer doesn’t share information, i.e. \( \frac{1}{2(1+\gamma)} < k \leq \frac{1}{2(1+s)} \), which means that a retailer is more likely to share information when its rival retailer doesn’t share information. The opposite is true without information leakage. Without information leakage, the threshold of \( k \) when the rival retailer shares information is larger than that when the rival retailer doesn’t share information, i.e. \( \frac{1}{2(1+\gamma)} > \frac{1}{2(1+s)} \), which means that a retailer is more likely to share information when its rival retailer shares information.

The retailers’ information sharing strategies with information leakage are illustrated in Figure 6, where competition intensity \( \gamma \) varies from zero to one and \( s = 1 \). From figure 6 we can see that the transactions are meaningless when \( k \leq \frac{1}{2(2+\gamma)} \) (Area I). Both retailers share information with the supplier when \( \frac{1}{2(2+\gamma)} < k \leq \frac{1}{2(1+\gamma)} \) (Area II, only one retailer shares information with the supplier.
when \[ \frac{1}{2(1+\gamma)} < k \leq \frac{1+s}{2(1+s)+(1+2s)\gamma} \] (AreaIII), and neither retailer shares information with the supplier when \[ k \geq \frac{1+s}{2(1+s)+(1+2s)\gamma} \] (AreaIV).

\[ \begin{align*}
0 &\quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.7 \quad 0.8 \quad 0.9 \quad 1 \\
0 &\quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \\
\end{align*} \]

Figure 6. Retailers’ information sharing strategies in system RC without information leakage

6. **Concluding remarks.** This study investigates information sharing in two-tier supply chains considering production cost reduction effort and information leakage, with either upstream or downstream competition. To explore the different effects of cost reduction and information leakage on the supply chain members, we conduct equilibrium analysis without and with information leakage. Results show that in system SC, without information leakage, the retailer shares information with one supplier when cost reduction efficiency is high, with neither supplier when cost reduction efficiency is low, and with both suppliers when cost reduction efficiency is intermediate. What’s more, the retailer is more likely to share information when competition is more intense. Considering information leakage, an informed supplier leaks the demand information to an uninformed supplier when cost reduction efficiency is low and the supplier is less likely to leak information when competition is more intense. However, the information leakage of the informed supplier doesn’t affect the information sharing strategies of the retailer since the retailer shares information with neither supplier when cost reduction efficiency is low. In system RC, with or without information leakage, both retailers share information with the supplier when cost reduction efficiency is high and neither retailer shares information with the supplier when cost reduction efficiency is low. However, the threshold of cost reduction efficiency without information leakage is always lower than that with information leakage, which demonstrates that it is less likely for retailers to share information with information leakage. What’s more, retailers are
more likely to share information when either competition is less intense or information is more accurate with information leakage. In addition, the two retailers choose the same information sharing strategies without information leakage but the opposite information sharing strategies with information leakage when the cost reduction efficiency is intermediate.

The contributions of this paper are twofold. Firstly, we extend the research of demand information sharing in different supply chain structures. On the one hand, Jiang and Hao[11] demonstrated that retailer competition is necessary for information sharing, whereas supplier competition precludes information sharing. Considering cost reduction effort and information leakage in different supply chain structures, our study shows that with either retailer competition or supplier competition, information sharing depends on cost reduction efficiency, competition intensity and information accuracy. On the other hand, Ha et al.[8] revealed that when two supply chains compete in quantity, information sharing occurs when suppliers are efficient in cost reduction and it is more likely to occur when either information is less accurate or competition is less intense. However, we prove that in system SC and RC, the variations of information sharing strategies with parameters are different from that of Ha et al.[8]. For instance, information sharing is more likely to occur when competition is more intense in system SC. Secondly, we supplement the research of information leakage in supply chains. Previous studies[8, 18, 34] believed that information leakage always prevents information sharing, whereas we find that the impacts of information leakage on information sharing incentives are quite complex when considering cost reduction effort and information leakage simultaneously. In system SC, information leakage doesn’t affect the information sharing incentive for the retailer since the requirements of information leakage and information sharing on the cost reduction efficiency are on the contrary. While in system RC, information leakage doesn’t change the trend of information sharing, and just enhances the requirements of information sharing on the supplier’s cost reduction efficiency.

There are several directions for future research. It would be interesting to investigate information sharing problems under different contracts (other than wholesale price) with cost reduction effort and information leakage, since transaction contracts affect the information sharing decision of retailers by influencing the profit distribution among supply chain members, such as revenue sharing contract. Another extension of this work is to investigate the effect of player’s risk preference on information sharing strategies. Our research assumes that supply chain members are risk neutral, that is, they all seek to maximize the expected profit. In reality, supply chain members’ risk preferences are different, where risk seeking members seek to maximize profits while risk averse members seek to minimize risks. Risk preference affect the information sharing decisions of retailers by influencing objective function. The other interesting extension is to study how the collusion among the retailers affects the players’ decisions. We leave the situation when the retailers may collude to exaggerate market demand for future research.

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Appendix.

A1.

Proof. In system SC without information leakage, the Hessian matrix for the supplier’s expected profit function without information leakage is:

$$
\begin{pmatrix}
\frac{-1}{2(1-\gamma^2)} & \frac{-1}{2(1-\gamma^2)} \\
\frac{-1}{2(1-\gamma^2)} & -k
\end{pmatrix}.
$$

The value of the determinant is $\frac{4k(1-\gamma^2)-1}{4(1-\gamma^2)^2}$, and the necessary condition for the supplier’s expected profit function to have extreme value is that the determinant value is greater than zero. Therefore, $k > \frac{1}{4(1-\gamma^2)}$. Otherwise, there exists no extreme value for the suppliers’ expected profit function, the supplier would set the wholesale price to zero or infinite, which is meaningless.

A2.

Proof. In system SC without information leakage,

1. when the retailer doesn’t share information with supplier $j$, information sharing with supplier $i$ leads to the adjustment of order quantity for product $i$:

$$
(1-\gamma)\frac{k}{1+s[\frac{(2k(1-\gamma^2)-1)}{2(1+s)(4k(1-\gamma^2)-1)} - \frac{Y}{2(1+s)(1+\gamma)}]}
$$

and the adjustment of order quantity for product $j$:

$$
(2k(1-\gamma^2)-1)\frac{Y}{2(1+s)(4k(1-\gamma^2)-1)}
$$

2. when the retailer shares information with supplier $j$, information sharing with supplier $i$ leads to the adjustment of order quantity for product $i$:

$$
\frac{kY}{1+s[\frac{(2k(2+\gamma)(1-\gamma^2)-1)}{2(1+s)(4k(1-\gamma^2)-1)} - \frac{Y}{2(1+s)(1+\gamma)}]}
$$

and the adjustment of order quantity for product $j$:

$$
\frac{(1-\gamma)Y}{1+s[\frac{(2k(2+\gamma)(1-\gamma^2)-1)}{2(1+s)(4k(1-\gamma^2)-1)} - \frac{Y}{2(1+s)(1+\gamma)}]}
$$

3. Known that $k > \frac{1}{2(1-\gamma^2)}$, $2k(2-\gamma^2) - 1 > \frac{\gamma^2}{2(1-\gamma^2)} > 0$. Therefore, whether the retailer shares information with supplier $j$ or not, information sharing with supplier $i$ makes $q_i$ more responsive to $Y$ and $q_j$ less responsive to $Y$ when $k < \frac{1}{2(1-\gamma^2)}$, and $q_i$ less responsive to $Y$ and $q_j$ more responsive to $Y$ otherwise.

A3.

Proof. Proof of part (a): In system SC without information leakage,

1. when the retailer doesn’t share information with supplier $j$, information sharing with supplier $i$ leads to the change in the profit of supplier $i$:

$$
\frac{k(1-\gamma)^2\sigma^2}{2(1+s)(4k(1-\gamma^2)-1)} > 0.
$$

2. when the retailer shares information with supplier $j$, information sharing with supplier $i$ leads to the change in the profit of supplier $i$:

$$
\frac{k(4k(1-\gamma^2)-1)^2\sigma^2}{2(1+s)[2k(2+\gamma)(1+\gamma)-1]^2} > 0.
$$

Therefore, in system SC without information leakage, information sharing always benefit the suppliers.

Proof of part (b): In system SC without information leakage, when the retailer doesn’t share information with supplier $j$, information sharing with supplier $i$ leads to the change in the profit of the retailer:

$$
\frac{(4k^2(1-\gamma^2)(1+\gamma)(5+\gamma)-8k(1-\gamma^2)+1)\sigma^2}{4(1+s)(4k(1-\gamma^2)-1)^2} - \frac{\sigma^2}{2(1+s)(1+\gamma)} = \frac{-4k(1-\gamma^2)-1}{4(1+s)(4k(1-\gamma^2)-1)^2}.
$$
Information sharing with supplier $i$ benefits the retailer when $k < \frac{1}{2(1-\gamma^2)}$ and hurts the retailer otherwise.

Proof of part (c): In system SC without information leakage, when the retailer shares information with supplier $j$, information sharing with supplier $i$ leads to the change in the profit of the retailer:

$$\frac{2k^2(1+\gamma)\sigma^2}{(1+s)(2k(2-\gamma)(1+\gamma)-1)^2} - \frac{(4k^2(1-\gamma)^2(1+\gamma)(5+3\gamma)-8k(1-\gamma^2)+1)\sigma^2}{4(1+s)(2k(2-\gamma)(1+\gamma)-1)^2},$$

where $f(k) = 8(1-\gamma^2)^2(12+4\gamma-3\gamma^2)k^2 - 4(2-\gamma)(1-\gamma^2)(8+7\gamma)k^2 + 2(1+\gamma)(7-5\gamma)k - 1$.

(1) $f'(k) = 2(1+\gamma)(12(1-\gamma)^2(1+\gamma)(12+4\gamma-3\gamma^2)k^2 - 4(2-\gamma)(1-\gamma^2)(8+7\gamma)k^2 + 7-5\gamma)$, and $\Delta = (4(2-\gamma)(1-\gamma^2)(8+7\gamma))^{-2} - 48(1-\gamma^2)^2(1+\gamma)(12+4\gamma-3\gamma^2)(7-5\gamma) = 16(1-\gamma^2)^2(4+36\gamma+31\gamma^2-6\gamma^3+4\gamma^4) > 0$. So $f(k)$ has two extreme points: $k_1 = \frac{16+6\gamma-7\gamma^2+\sqrt{(4+36\gamma+31\gamma^2-6\gamma^3+4\gamma^4)}}{6(1-\gamma^2)(12+4\gamma-3\gamma^2)}$, and $k_2 = \frac{16+6\gamma-7\gamma^2-\sqrt{(4+36\gamma+31\gamma^2-6\gamma^3+4\gamma^4)}}{6(1-\gamma^2)(12+4\gamma-3\gamma^2)}$.

(2) Since $k_1 \geq \frac{1}{4(1-\gamma^2)}$ and $k_2 \leq \frac{1}{4(1-\gamma^2)}$, we have $f(k)$ decreases when $\frac{1}{4(1-\gamma^2)} < k < k_1$ and increases when $k > k_1$.

Since $f\left(\frac{1}{4(1-\gamma^2)}\right) = \frac{\sigma^2}{4(1-\gamma^2)(12+4\gamma-3\gamma^2)} < 0$ and $f\left(\frac{1}{2(1-\gamma^2)}\right) = \frac{\sigma^2}{2(1-\gamma^2)(4(2-\gamma)(1+\gamma)-1)^2} > 0$, there exists a root $k_{SC}$ within the interval $\frac{1}{4(1-\gamma^2)} < k < \frac{1}{2(1-\gamma^2)}$ that makes $f(k_{SC}) = 0$.

(4) Combining (1), (2) and (3), $f(k) < 0$ when $\frac{1}{4(1-\gamma^2)} < k \leq k_{SC}$, and $f(k) > 0$ when $k > k_{SC}$. Thus, $\frac{(1-2k(1-\gamma^2))f(k)\sigma^2}{(1+s)(2k(2-\gamma)(1+\gamma)-1)^2(4k(1-\gamma^2)-1)^2} > 0$ when $k_{SC} < k \leq \frac{1}{1-\gamma^2}$ and $\frac{(1-2k(1-\gamma^2))f(k)\sigma^2}{(1+s)(2k(2-\gamma)(1+\gamma)-1)^2(4k(1-\gamma^2)-1)^2} \leq 0$ otherwise. In a word, information sharing with supplier $i$ benefits the retailer when $k_{SC} < k < \frac{1}{2(1-\gamma^2)}$ and hurts the retailer otherwise.

A4.

Proof. In system SC with information leakage, the profit change of an informed supplier when the informed supplier leaks the demand information to the uninformed one is:

$$\frac{k(4k(1-\gamma^2)-1)\sigma^2}{2(1+s)(2k(2-\gamma)(1+\gamma)-1)^2} - \frac{(k(1-\gamma)^2)\sigma^2}{2(1+s)(4k(1-\gamma^2)-1)^2} = \frac{(2k(1-\gamma^2)-1)(32(1-\gamma)^2-2k(1-\gamma^2)(8-4\gamma+\gamma^2)+2-2\gamma+\gamma^2)\sigma^2}{2(1+s)(2k(2-\gamma)(1+\gamma)-1)^2(4k(1-\gamma^2)-1)^2}. $$

Since $\Delta = (2(1-\gamma^2)(8-4\gamma+\gamma^2))^2 - 4 \times 32(1-\gamma^2)(2-2\gamma+\gamma^2) = 4(8-\gamma)^3(1-\gamma^2)^2 < 0$ and $32(1-\gamma^2)^2 - 2k(1-\gamma^2)(8-4\gamma+\gamma^2)+2-2\gamma+\gamma^2 > 0$, Consequently, an informed supplier will leak demand information to the uninformed one when $k \geq \frac{1}{2(1-\gamma^2)}$; otherwise the informed supplier will keep the demand information as a secret.

From proposition 2, the retailer shares information with neither supplier when $k \geq \frac{1}{2(1-\gamma^2)}$. Therefore, information leakage behaviors of suppliers won’t affect the information sharing decision of the retailer.
A5.

Proof. In system RC without information leakage, the Hessian matrix for the supplier’s expected profit function without information leakage is:

\[
\begin{pmatrix}
\frac{24}{4 - \gamma} & \frac{2 \gamma}{4 - \gamma} & \frac{-2}{4 - \gamma} & \frac{2}{4 - \gamma} \\
\frac{2 \gamma}{4 - \gamma} & \frac{24}{4 - \gamma} & \frac{2}{4 - \gamma} & \frac{-2}{4 - \gamma} \\
\frac{-2}{4 - \gamma} & \frac{2}{4 - \gamma} & \frac{24}{4 - \gamma} & \frac{2 \gamma}{4 - \gamma} \\
\frac{2}{4 - \gamma} & \frac{-2}{4 - \gamma} & \frac{2 \gamma}{4 - \gamma} & \frac{24}{4 - \gamma}
\end{pmatrix}
\]

The value of the determinant is \(\frac{(2(2+\gamma)k-1)(2(2+\gamma)k-1)}{(4-\gamma)^2}\). The necessary condition for the supplier’s expected profit function to have extreme value is that the determinant value is greater than zero. Therefore, \(k > \frac{1}{2(2+\gamma)}\) or \(k < \frac{1}{2(2+\gamma)}\gamma\). Having known that \(k > \frac{a}{2(2+\gamma)}\) and \(a > c\), we have \(k > \frac{1}{2(2+\gamma)}\). Otherwise, there exists no extreme value for the supplier’s expected profit function, the supplier would set the wholesale price to zero or infinite, which is meaningless. □

A6.

Proof. Proof of part (a):

(1) In system RC without information leakage, when retailer \(j\) doesn’t share information with the supplier, information sharing of retailer \(i\) leads to the change in the profit of the supplier:

\[
\frac{(4k(2+\gamma+s(2+s+\gamma))(4-\gamma)^2-2(1+s)(2+\gamma)^2-s^2(4+\gamma)^2)k\sigma^2}{2(1+s)(2+2s+\gamma)^2(2k(2+\gamma)-1)(2k(2+\gamma)-1)}
\]

Knew that \(k > \frac{1}{2(2+\gamma)}\gamma\), \(4k(2+\gamma+s(2+s+\gamma))(4-\gamma)^2-2(1+s)(2+\gamma)^2-s^2(4+\gamma)^2\) > \(s^2(2-\gamma)\gamma > 0\), and thus \(\frac{(4k(2+\gamma+s(2+s+\gamma))(4-\gamma)^2-2(1+s)(2+\gamma)^2-s^2(4+\gamma)^2)k\sigma^2}{2(1+s)(2+2s+\gamma)^2(2k(2+\gamma)-1)(2k(2+\gamma)-1)}\) > 0. Therefore, in system RC without information leakage, information sharing always benefits the supplier.

Proof of part (b): In system RC without information leakage, when retailer \(j\) doesn’t share information with the supplier, information sharing of retailer \(i\) leads to the change in its own profit:

\[
\frac{(2k(1+s)(4-\gamma)^2-(2+2s+\gamma)^2k^2\sigma^2)}{(2k^2(1+s)(4-\gamma)^2-6+6s-\gamma)k+1+s} = \frac{(1+s)\sigma^2}{(2k^2(1+s)(4-\gamma)^2-6+6s-\gamma)k+1+s}\]

(1) Let \(g(k) = 2(1+s)(4-\gamma)^2-(6+6s-\gamma)k+1+s = 0\), there are two roots

\[
k_1 = \frac{6+6s-\gamma-\sqrt{4(1+s)^2-12(1+s)\gamma+9+16s+8\gamma^2}}{4(1+s)(4-\gamma)^2}
\]

and

\[
k_2 = \frac{6+6s-\gamma+\sqrt{4(1+s)^2-12(1+s)\gamma+9+16s+8\gamma^2}}{4(1+s)(4-\gamma)^2}
\]

\(k_1 = \frac{1}{2(2-\gamma)}\), \(k_2 = \frac{1}{2(2-\gamma)}\gamma\). Having known that \(k > \frac{a}{2(2+\gamma)}\) and \(a > c\), we have \(k > \frac{1}{2(2+\gamma)}\). Otherwise, there exists no extreme value for the supplier’s expected profit function, the supplier would set the wholesale price to zero or infinite, which is meaningless. □

Thus, \(g(k) \geq 0\) when \(k \geq k_1\) and \(g(k) < 0\) otherwise.
(2) Let \( g(k) = 6(1+s)(4-\gamma^2)k^2 - (10 + 10s + \gamma)k + 1 + s = 0 \), there are two roots
\[
k_3 = \frac{10+10s+\gamma+\sqrt{(1+s)^2-20(1+s)\gamma+(25+48s+24s^2)\gamma^2}}{2(1+s)} \quad \text{and} \quad k_4 = \frac{10+10s+\gamma-\sqrt{(1+s)^2-20(1+s)\gamma+(25+48s+24s^2)\gamma^2}}{2(1+s)}.
\]
Therefore \( k_4 < k_3 < \frac{1}{2(2-\gamma)} \) and \( h(k) > 0 \).

(3) Combining (1) and (2),
\[
- \frac{(2k^2(1+s)(4-\gamma^2))}{2(2+5s)(1+s)}(4-\gamma^2) - (10+10s+\gamma)k + 1 + s \sigma^2 > 0 \quad \text{when} \quad k < \frac{1}{2(1+s)}
\]
and
\[
6+6s-\gamma-\sqrt{4(1+s)^2-12(1+s)\gamma+(9+16s+8s^2)\gamma^2} < 0.
\]
That is to say information sharing of retailer \( i \) benefits itself when \( k < \frac{1}{2(1+s)} \) and hurts itself otherwise.

Proof of part (c): In system RC without information leakage, when retailer \( j \) shares information with the supplier, information sharing of retailer \( i \) leads to the change in its own profit:
\[
\left(4k^2(1+s)(4-\gamma^2)^2 + 2k^2(1+s)(4-\gamma^2)(s\sigma^2-12(1+s)\gamma+(9+16s+8s^2)\gamma^2) \right) = \frac{(2k^2(2+5s)(1+s)(4-\gamma^2) - (10+10s+\gamma)k + 1 + s \sigma^2}{(1+s)(2+2s+2\gamma)^2(2k(2+5s)(1+s)(4-\gamma^2) - (10+10s+\gamma)k + 1 + s \sigma^2)}
\]
and
\[
- \frac{(2k^2(1+s)(4-\gamma^2)^2 - (10+10s+\gamma)k + 1 + s \sigma^2}{(1+s)(2+2s+2\gamma)^2(2k(2+5s)(1+s)(4-\gamma^2) - (10+10s+\gamma)k + 1 + s \sigma^2) \leq 0 \quad \text{otherwise}.
\]
(1) Let \( l(k) = 2k^2(4-\gamma^2) - 6k + 1 = 0 \), there are two roots \( k_1 = \frac{1}{3+\sqrt{1+2\gamma}} \) and
\[
k_2 = -\frac{1}{2(2-\gamma)} = \frac{1-\gamma-\sqrt{1+2\gamma^2}}{2(4-\gamma^2)} > 0 \quad \text{and} \quad k_3 < \frac{1}{2(2-\gamma)}.
\]
(2) Let \( m(k) = 2k^2(2+3s+\gamma^2)(4-\gamma^2) - (4+10s+8\gamma)k + s + \gamma = 0 \), there are two roots \( k_3 = \frac{2+5s+4\gamma+\sqrt{(2+5s)^2+2s(2+5s)\gamma^2+2(2+5s)\gamma^3+4\gamma^4}}{s+\gamma} \) and
\[
k_4 = \frac{2+5s+4\gamma-\sqrt{(2+5s)^2+2s(2+5s)\gamma^2+2(2+5s)\gamma^3+4\gamma^4}}{s+\gamma}.
\]
(3) Combining (1) and (2),
\[
- \frac{(2k^2(4-\gamma^2)-6k+1)(2k^2(2+3s+\gamma^2)(4-\gamma^2)-(4+10s+8\gamma)k + s + \gamma)\sigma^2}{(1+s)(2+2s+2\gamma)(2k(2+5s)(1+s)(4-\gamma^2) - (10+10s+\gamma)k + 1 + s \sigma^2) \leq 0 \quad \text{otherwise}.
\]
A7. Proof. In system RC with information leakage, assuming that the supplier has an incentive to set different wholesale price and cost reduction effort for the two retailers with different information sharing decisions. Without loss of generality, we assume that retailer 1 shares information but retailer 2 doesn’t. The wholesale price and cost reduction effort are $\omega_1$ and $x_1$ for retailer 1, and $\omega_2$ and $x_1$ for retailer 2, respectively. The retailers’ expected profits are:

$$(\alpha + E[\theta \mid Y_i, \omega_i, \omega_j] - q_i - \gamma E[q_j \mid Y_i, \omega_i, \omega_j])q_i.$$  

Since retailer 2 knows $Y_1$ after $\omega_1$ and $\omega_2$ are announced, but retailer 1 has no idea of $Y_2$, the corresponding order quantities of the retailers are as follow:

$$\hat{q}_1(\omega_i, \omega_j) = \frac{\alpha(2 - \gamma) - 2\omega_1 + \gamma \omega_2}{4 - \gamma^2} + \frac{Y_1}{(1 + s)(2 + \gamma)},$$

$$\hat{q}_2(\omega_i, \omega_j) = \frac{\alpha(2 - \gamma) - 2\omega_2 + \gamma \omega_1}{4 - \gamma^2} + \frac{(2 + 2s - \gamma)Y_1 + Y_2}{2 + 2s + \gamma}.$$  

The supplier’s expected profit, which is dependent on $Y_1$ equals

$$\sum_{i=1}^{2}((\omega_i - c_i + x_i)E[\hat{q}_i(\omega_i, \omega_j) \mid Y_1] - \frac{1}{2}kx_i^2).$$

Therefore, the supplier’s optimal wholesale price and production cost reduction effort are as follows:

$$\omega_1^* = \omega_2^* = \frac{(2k + k\gamma - 1)\alpha + (2 + \gamma)kc}{4k + 2k\gamma - 1} + \frac{(2k + k\gamma - 1)Y_1}{(1 + s)(4k + 2k\gamma - 1)},$$

$$x_1^* = x_2^* = \frac{\alpha - c}{4k + 2k\gamma - 1} + \frac{Y_1}{(1 + s)(4k + 2k\gamma - 1)}.$$  

Thus, whether the retailers share demand information or not, a single pricing and cost reduction effort is optimal for the supplier. \(\square\)

A8. Proof. In system RC with information leakage, the Hessian matrix for the supplier’s expected profit function is:

$$\begin{bmatrix} -\frac{4k}{(2 + \gamma)^2} & 2 \frac{k}{2 + \gamma} \\ 2 \frac{k}{2 + \gamma} & -\frac{2}{2 + \gamma} - 2k \end{bmatrix}.$$  

The value of the determinant is $\frac{8k(2 + \gamma) - 4}{(2 + \gamma)^2}$. The necessary condition for the supplier’s expected profit function to have extreme value is that the determinant value is greater than zero. Therefore, $k > \frac{1}{4(2 + \gamma)}$. Otherwise, there exists no extreme value for the supplier’s expected profit function, the supplier would set the wholesale price to zero or infinite, which is meaningless. \(\square\)

A9. Proof. Proof of part (a):

(1) In system RC with information leakage, when retailer $j$ doesn’t share information with the supplier, information sharing of retailer $i$ leads to the change in the profit of the supplier: $\frac{k\sigma^2}{(1 + s)(2k(2 + \gamma) - 1)}$. Known that $k > \frac{1}{2(2 + \gamma)}$, and thus $\frac{k\sigma^2}{(1 + s)(2k(2 + \gamma) - 1)} > 0$. \(\square\)
(2) In system RC with information leakage, when retailer $j$ shares information with the supplier, information sharing of retailer $i$ leads to the change in the profit of the supplier:

\[
\frac{2k\alpha^2}{k^2\sigma^2} - \frac{1}{(1+s)(2k(2+\gamma)-1)} - \frac{1}{(1+s)(2k(2+\gamma)-1)} = \frac{2k\alpha^2}{k^2\sigma^2} > 0.
\]

Therefore, in system RC with information leakage, information sharing always benefits the supplier.

Proof of part (b): In system RC with information leakage, when retailer $j$ doesn’t share information with the supplier, information sharing of retailer $i$ leads to the change in its own profit:

\[
\frac{k^2\sigma^2}{(1+s)(2k(2+\gamma)-1)^2} - \frac{1}{(1+s)(2k(2+\gamma)-1)} - \frac{1}{(1+s)(2k(2+\gamma)-1)} = \frac{k^2\sigma^2}{(1+s)(2k(2+\gamma)-1)^2} > 0.
\]

Let \(-((1+s)+(3+2s\gamma)k-1-s)((2(1+s)+(1+2s\gamma)k-1-s)\sigma^2) = 0\), there are two roots $k_1 = \frac{1+s}{2(2+\gamma)+2s\gamma}$ and $k_2 = \frac{1}{2(2+\gamma)+2s\gamma}$. $k_1 - \frac{1}{2(2+\gamma)+2s\gamma} > 0$, and therefore $k_1 > 0$, $k_2 = \frac{1}{2(2+\gamma)+2s\gamma} < 0$, and therefore $k_2 < 0$. Thus, information sharing benefits itself when $k < 0$ and hurts itself otherwise.

Proof of part (c): In system RC with information leakage, when retailer $j$ shares information with the supplier, information sharing of retailer $i$ leads to the change in its own profit:

\[
\frac{k^2\sigma^2}{(2k(2+\gamma)-1)^2} - \frac{4k^2(2+8s\gamma+4k\gamma+6k-1)-8k-1)s\sigma^2}{4k^2(2+8s\gamma+4k\gamma+6k-1)-8k-1)s\sigma^2} = \frac{2k(1+s)+1)(2k(3+\gamma)+1)s\sigma^2}{4(1+s)(2k(2+\gamma)-1)^2} > 0.
\]

Let \(-((2(1+s)-(3+2s\gamma)k-1-s)((2(1+s)+(1+2s\gamma)k-1-s)\sigma^2) = 0\), there are two roots $k_1 = \frac{1}{2(2+\gamma)+2s\gamma}$ and $k_2 = \frac{1}{2(2+\gamma)+2s\gamma}$. $k_1 > 0$, $k_2 = \frac{1}{2(2+\gamma)+2s\gamma} < 0$, and therefore $k_1 > 0$, $k_2 = \frac{1}{2(2+\gamma)+2s\gamma} < 0$. Thus, information sharing benefits itself when $k < 0$ and hurts itself otherwise.

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