Pricing Strategy and Product Quality Design with Platform-Investment

Xiujing Dang
IIF, School of Management
University of Science and Technology of China
Hefei 230026, China

Yang Xu
School of Finance
Anhui University of Finance and Economics
Bengbu 233030, China

Gongbing Bi∗
IIF, School of Management
University of Science and Technology of China
Hefei 230026, China

Lei Qin
Faculty of Management and Economics
Kunming University of Science and Technology
Kunming 650093, China

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Abstract. With the development of business, more consumers are quality sensitive and improving the product quality becomes particularly important. We mainly discuss two investment strategies: retailer-investment and platform-investment. Compared with non-investment case, only if consumer sensitivity is not too high, it is profitable for the retailer to select retailer-investment. When both retailer-investment and platform-investment are viable, the choice of investment mechanism depends on the profit-sharing ratio. Particularly, if the ratio is within a certain range, the optimal investment strategy is platform-investment, achieving a triple-win outcome. Besides, to effectively alleviate the contradiction between the retailer’s moral hazard problem and the sustainable value-added effect of platform-investment, we further research the contract term. These results give us some meaningful management inspirations in investment mechanism.

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∗ Corresponding author: Gongbing Bi.
1. Introduction. With the rapid development of business models, platforms are playing an increasing important role in the real world. And, consumers have more requirements for high quality products. When retailers realize that consumers are quality sensitive, they make efforts to improve the product quality. They can improve quality by themselves, especially in the hotel service industry. Alternatively, they can also cooperate with specialized platforms. Various platforms emerge one after another, for instance, OYO Hotel, a multinational hotel company. It can help some small and medium-sized private hotels achieve higher quality services. In China, there are tens of thousands of fragmented individual hotels, but most of them face the dilemma of limited resources, such as unknown brands, high cost and lack of professional management. Under the premise of consumers’ pursuit of living quality, the occupancy rate of such hotels is not high. Therefore, these hotels have the motivation to improve the product quality. Once those hotels decide to join the platform (OYO Hotel), she conducts strict screening and remodeling of rooms to enforce high quality living environment and considerate service, helping them improve operational efficiency and increase revenue. Correspondingly, the platform charges free-to-join fee, and only charges a certain percentage of profit from individual hotels (called retailers). In short, retailers face two options, retailer-investment or platform-investment. For retailers, thanks to the product’s demand is price-dependent, they can obtain more revenue by improving the product quality. Besides, consumers can get more consumer surplus through purchasing higher quality products, due to better user experience, fierce competition or more alternatives. In the presence of retailer-investment and platform-investment, which investment scheme makes retailers get more profit? And under different investment strategies, how should retailers price? These are the issues that retailers are most concerned about.

To better study the investment mechanism of the product quality, this paper aims to address the following research questions. First, is the well-funded retailer profitable under retailer-investment case? Second, which is the optimal strategy when both retailer-investment and platform-investment are feasible? Third, how do different parametric variables affect the profitability of each party, the supply chain performance, and consumer surplus?

To solve the above research problems, we examine a stylized supply chain consisting of one retailer and one platform, where the retailer sells quality-improvement products to consumers. In the paper, the unit cost is given exogenously. In addition to being risk-neutral, both the retailer and the platform maximize their profit. We regard non-investment case as the benchmark model. We mainly analyze two investment strategies, namely, retailer-investment and platform-investment, then we discuss the retailer’s optimal retail price and the optimal quality-improvement level under different situations. Compared with non-investment case, only if consumer sensitivity is within a certain range, it is profitable for the retailer to select retailer-investment. When both retailer-investment and platform-investment are feasible, the choice of investment mechanism depends on the profit-sharing ratio. If the profit-sharing ratio is relatively low, the optimal strategy is retailer-investment; if the ratio is limited to a certain range, the retailer prefers to cooperate with the platform to obtain higher quality products and more benefits, then platform-investment is the optimal strategy. And we analyze the impact of different parametric variables on the profitability of each party, the supply chain performance, and consumer surplus.
Furthermore, when platform-investment is chosen, the moral hazard problem arises, which mainly relates to the contract term. If the platform only offers a one-year contract to the retailer, the retailer will refuse to continue cooperation next year. In order to continuously stimulate the value-added effect of platform-investment, the platform provides a one-year with a two-part tariff contract or a two-year contract to mitigate the moral hazard problem. We also discuss the impact of the pricing power on the optimal retail price when it belongs to the platform.

Our contributions to the literature are summarized in four aspects. Above all, our paper enriches the research on investment mechanism, especially considering the product quality improvement. Second, when consumers are quality sensitive, it is always beneficial for the retailer to opt retailer-investment to enhance the product quality, compared with non-investment case. The result provides a managerial insight that the retailer should adjust his marketing strategy based on consumer orientation. Third, when both retailer-investment and platform-investment are viable, the choice of investment mechanism relies on the profit-sharing ratio, filling up the literature gap in this field. If and only if the profit-sharing ratio is limited to a certain scope, platform-investment is the optimal investment strategy, and a triple-win situation among the retailer, the platform and consumers can be achieved. This provides a theoretical basis for these small and medium-sized enterprises to improve the product quality. Fourth, there is a conflict situation in reality that the retailer tends to terminate the contract after getting more profit due to his moral hazard problem, while the platform wants to keep the continuous valued-added effect of investment. This provides a managerial implication for the platform’s managers, that is, the platform should adjust the contract duration to effectively deal with the moral hazard problem.

The remainder of this paper is organized as follows. In section 2, the relevant existing literature is reviewed. In section 3, the model is presented in detail. In section 4, optimal decisions under retailer-investment and platform-investment cases are derived, and insights on why the retailer prefers platform-investment are offered. Section 5 performs numerical analysis to validate these results. Section 6 researches the contract duration when the moral hazard problem arises. Finally, main conclusions and future directions are summarized in section 7. All proofs are presented in the Appendix.

2. Literature review. Our research is related to the literature on operation and investment decisions, which is of importance to incorporate investment strategy into operational decisions. In recent years, most of the operation management literature ignored the impact of investment efforts on operation decision, especially from platforms’ investment efforts. To be brief, there are two streams of literature closely related to this paper. The first stream of literature studies the product pricing and the quality improvement strategy based on the platform. The second stream focuses on contract design.

We review the product pricing and the product quality improvement issues. With the rapid development of technology, retailers are enable to sell quality-improvement products to consumers. Firstly, some scholars held that these platforms had pricing power and they looked into the pricing mechanism of online car hailing platform ([27],[30]). Similarly, [5] addressed application developer’s platform selection and price decisions in a two-platform market. Moreover, the platform’s pricing issue was also analyzed in [19] and [25]. [23] studied retailers’ pricing strategies when
they provided different versions of an agricultural product, organic and nonorganic versions. [7] explored competitive products’ pricing between an innovator and an imitator. Different from the above literature, the platform in this paper is not an e-commerce platform, but an off-line entity platform. And the paper assumes that the retailer possesses pricing power under retailer-investment or platform-investment case. Especially, the retailer considers the pricing and the quality improvement simultaneously. Besides, we give some interesting extensions of our research, that is, if the pricing power belongs to the platform, whether it has a substantial impact on our main conclusions. Secondly, we also take the product quality improvement into consideration. Some scholars focused on quality differentiation between substitutable products to increase their competitiveness. [21], [39], [42] focused on the impact of the environmental quality product on the supply chain in the centralized model and the decentralized model, in which the environmental quality was exogenous. Besides, they explored the optimal abatement level with cap-and-trade regulation under bank financing and trade credit financing, respectively ([2], [29]). They regarded the abatement level as a decision variable, namely, endogenously decided. [10] studied the supplier’s investment in the manufacturer’s quality improvement under three competition models by equity holding. They thought the supplier’s investment value came from the quality improvement and the profit sharing in supplier Stackelberg and manufacturer Stackelberg models. In [40], when a manufacturer’s product quality was exogenously given or endogenously decided in a distribution channel, the platform adopted different contracts. Different from those articles, the paper assumes that the product quality-improvement level is determined endogenously, especially depending on the retailer or the platform. Importantly, the influence of different investors on the product quality improvement is a key index for the retailer’s strategy choice. And the retailer’s quality-improvement investment decision is based on consumer preference.

Our paper also relates to contract design. Some literature emphasized the supply chain coordination. [39] thought that a return policy could effectively achieve supply chain coordination. [32] examined whether revenue-sharing, buyback, and all-unit quantity discount contracts could coordinate a financially constrained supply chain. Analogously, [41] and [36] treated a buyback contract as a type of coordination. In addition, they all believed that a revenue-sharing contract could coordinate the supply chain ([15], [28], [11], [36], [24], [8]). Besides, [4] analyzed the risk-sharing mechanism and an inventory subsidizing scheme. A revenue with subsidy incentive scheme and a wholesale-price scheme with buybacks were discussed to coordinate the supply chain by [11]. Another stream focuses on contract selection to promote inter-firm cooperation. In cooperation with the platform, retailers were usually given two types of contracts, the revenue-sharing contract ([26],[1],[20], [18] and [12]), and the fixed fee contract ([17],[22],[14], [40] and [35]). In [38], the platform provided two contracts mentioned above to manufacturers to strengthen their cooperation. Similarly, the retailer offered revenue-sharing scheme or cost-sharing scheme to spur the manufacturer for cooperation ([36], [6]). [15] studied several contracts to enhance cooperation level in light of environmental sustainability, including price-only, green-marketing cost-sharing, and a two-part tariff contract. Their work shed light on it and showed that environmental improvements could be achieved by cooperations among partners. Besides, [31] explored the impact of the cost-sharing strategy on carbon emission reduction and sales effort under a Nash game. Their results showed that it was advantageous for the manufacturer and the retailer to
Table 1. Notations

| Variables | Description |
|-----------|-------------|
| $U$       | The utility that a consumer derives from the product |
| $V$       | The consumer’s utility from the product functional attributes |
| $p_i$     | The unit retail price of the product under different scenarios, which is a decision variable of the retailer, where $i = NI, RI, PI$ |
| $c$       | The unit cost of the product |
| $\lambda$ | Consumer sensitivity to the quality-improvement product |
| $e_i$     | The product quality-improvement level, which is a decision variable of the retailer or platform, where $i = RI, PI$ |
| $k$       | The product quality-improvement cost parameter of the retailer |
| $\beta$  | The product quality-improvement cost parameter of the platform |
| $\theta$ | The profit-sharing ratio given by the platform |
| $\pi_i$  | The retailer’s profit, where $i = NI, RI, PI$ |
| $\Pi_i$  | The platform’s profit, where $i = PI$ |

adopt the cost-sharing contract. Unlike those articles, we take the profit-sharing contract into account to strengthen inter-firm cooperation. And this contract is put into practice, which provides the theoretical support for practical application. What’s more, our work shows that cooperation between firms by the profit-sharing contract does improve the product quality-improvement level.

3. Model. In this section, we consider a supply chain system which consists of a well-funded retailer, a platform and consumers, where the retailer sells quality-improvement products to consumers. In particular, consumers are quality conscious and derive utility from purchasing products. We assume that consumers are heterogeneous in their evaluation of the product’s functional attributes but homogeneous in terms of their evaluation of the quality attributes ([15],[13]). That is, consumers gain utility from both the functional and quality attributes of the product. We mainly consider two investment strategies: the first scenario that the retailer invests the product quality with his own capital (retailer-investment), the second scenario that the platform is willing to improve the product quality (platform-investment). And we regard non-investment case as the benchmark model, in which the retailer doesn’t make any changes.

We firstly formulate the problem and analyze the benchmark model. Then, we study retailer-investment and platform-investment scenarios respectively. For notational convenience, ‘NI’ is used to stand for non-investment, ‘RI’ for retailer-investment, and ‘PI’ for platform-investment. To avoid trivial cases, we assume $u > p_i > c > 0$. Major notations are summarized in Table 1.

3.1. Benchmark model -- non-investment. The benchmark model -- non-investment means that the retailer doesn’t make investment efforts. In this case, the retailer sells products to consumers at the retail price $p_{NI}$. We denote $V$ as consumer’ utility from the functional attributes of the product. We assume that $V$ is a nonnegative random value with a cumulative distribution function $F(x)$ on $x \in [0,\hat{V}]$, where $\hat{V}$ is maximal utility of the product. Specially, the product quality-improvement level $e_{NI}$ is supposed to be 0 in this case. And the unit cost of the retailer $c$ is exogenous.
The total utility is expressed as a linear utility function, which is widely used in the existing literature ([3], [34], [15]). The total utility is

\[ U = V - p_{NI} \]

For consumers, they purchase the product if and only if \( U > 0 \), (i.e., \( V - p_{NI} > 0 \)). Let \( q_{NI}(p_{NI}) \) be the product demand, which depends on consumers’ decision. Then, the product demand is

\[ q_{NI}(p_{NI}) = P\{V > p_{NI}\} = u - F(p_{NI}) \]

Because consumers are heterogeneous in the evaluation of the product’s functional attributes, the functional utility \( V \) is assumed to satisfy uniform distribution in \([0,u]\) in our model([9], [15], [37]), where \( u \) is the maximal functional utility. Then demand function is rewritten as function (3).

\[ q_{NI}(p_{NI}) = u - p_{NI} \]

Given consumer utility \( U > 0 \), the retailer’s expected profit as a function of the retail price is

\[ \pi_{NI} = (u - p_{NI})(p_{NI} - c) \]

The retailer’s objective is to maximize his expected profit. Through a series of calculations, we obtain the optimal retail price and the optimal expected profit.

\[ p_{NI}^* = \frac{c + u}{2} \]

\[ \pi_{NI}^* = \frac{1}{4}(u - c)^2 \]

The proof of optimal solutions are detailed in Appendix 1.

Our results imply that when the retailer makes no change, the optimal retail price and the optimal profit are only influenced by the functional utility \( u \) and the unit cost \( c \).

3.2. Retailer-investment. When a well-endowed retailer realizes that consumers are quality sensitive, he wants to improve the product quality by his own capital to attract more consumers. However, the retailer might fall into two categories, the success probability of the investment \( \rho_i \in (0,1) \) or the failure probability \( 1 - \rho_i \). The product quality improvement primarily relies on investment efforts, and the cost function is presented as a convex function regarding \( e_i \). We denote \( k \) as the cost parameter of the quality-improvement product and correspondingly investment cost is \( ke_{RI}^2 \). In this section, consumers derive the quality utility from buying the quality-improvement product, and the quality utility is assumed to be a linear function \( \lambda e_{RI} \), where \( e_{RI} \) is the product quality-improvement level \( (e_{RI} > 0) \) and the coefficient \( \lambda \) is consumer sensitivity to the quality-improvement product, similarly to [15, 16, 33, 3]. Then, the total utility is

\[ U = \begin{cases} V - p_{RI} + \lambda e_{RI} & \rho_i \\ V - p_{RI} & 1 - \rho_i \end{cases} \]

Similarly, consumers purchase the quality-improvement product if and only if \( U > 0 \). When the retailer invests successfully, a consumer’s total utility is \( U = V - p_{RI} + \lambda e_{RI} \). Otherwise, the consumer’s total utility is \( V - p_{RI} \). Given a consumer’s total utility, we obtain the retailer’s expected profit which is a function of
the retail price and the quality-improvement level. Then, we formulate the retailer’s expected profit as function (6).

\[ \pi_{RI} = E[p_l(u + \lambda e - p_{RI})(p_{RI} - c) + (1 - p_l)(u - p_{RI})(p_{RI} - c)] - ke^2_{RI} \tag{6} \]

**Proposition 1.** Under retailer-investment case, if and only if \( 0 < \lambda < \frac{2\sqrt{k}}{p_l} \),

(i) the optimal retail price is \( p^*_R = c + \frac{2k(u-c)}{4k-\lambda^2\rho_l^2} \).

(ii) the optimal quality-improvement level is \( e^*_R = \frac{(u-c)\lambda\rho_l}{4k-\lambda^2\rho_l^2} \).

The proof of Proposition 1 is detailed in Appendix 2.

Under retailer-investment case, both the optimal retail price and the optimal quality-improvement level are related to the functional utility \( u \), the unit cost \( c \), the cost coefficient \( k \), the success probability \( \rho_l \), and consumer sensitivity \( \lambda \). Therefore, business managers must fully consider all relevant factors when making decisions. Especially, with regard to consumer sensitivity, we obtain a management enlightenment that the appropriate and reasonable consumer sensitivity can stimulate the retailer to improve the product quality. That is, the rational consumer preference is the driving force of the retailer in investment.

**Corollary 1.** When \( 0 < \lambda < \frac{2\sqrt{k}}{p_l} \), optimal decisions have the following properties:

(i) \( \frac{\partial p_{RI}}{\partial u} > 0, \frac{\partial p_{RI}}{\partial \lambda} > 0, \text{ and } \frac{\partial p_{RI}}{\partial p_l} > 0. \)

(ii) \( \frac{\partial e_{RI}}{\partial \lambda} > 0, \frac{\partial e_{RI}}{\partial p_l} > 0, \text{ and } \frac{\partial e_{RI}}{\partial k} < 0. \)

Corollary 1 characterizes basic properties with respect to optimal decisions. In retailer-investment case, Corollary 1(i) explains that the retailer’s optimal price is positively influenced by the functional utility \( u \), consumer sensitivity \( \lambda \) and the success probability \( p_l \). That is, the higher functional utility, the greater consumer sensitivity and the higher success probability induce the retailer to increase the retail price. Corollary 1(ii) shows that consumer sensitivity \( \lambda \) and the success probability \( p_l \) have positive impact on the optimal quality-improvement level. When facing quality-sensitive consumers, who are willing to pay a premium for quality-improvement products, it is favorable for the retailer to improve the product quality to obtain higher price. Correspondingly, higher quality products also increase consumers’ utility. Obviously, the success probability has a positive incentive effect on the quality-improvement level. Because of greater success probability, the retailer is more likely to get better outcomes. However, the optimal quality-improvement level is negatively affected by the cost coefficient. Namely, when the investment cost is very high, the marginal revenue is less than its’ marginal cost from improving an additional unit quality level. Thence, the retailer will reduce quality-improvement investment.

By substituting the \( p^*_R \) and \( e^*_R \) into the objective function (6), we obtain the retailer’s profit.

\[ \pi_{RI} = \frac{k(u-c)^2}{4k-\lambda^2\rho_l^2}, \quad \text{(s.t. } 0 < \lambda < \frac{2\sqrt{k}}{p_l}) \]

When facing quality-conscious consumers, is the retailer motivated to improve the product quality? From the perspective of the retailer’s profit, non-investment (NI) and retailer-investment (RI) are compared, and the balance (\( \Delta \pi_1 \)) is

\[ \Delta \pi_1 = \pi_{RI} - \pi_{NI} = \frac{(u-c)^2\lambda^2\rho_l^2}{4(4k-\lambda^2\rho_l^2)}, \quad \text{(s.t. } 0 < \lambda < \frac{2\sqrt{k}}{p_l}) \tag{7} \]
Proposition 2. There exists a threshold $\hat{\lambda} = \frac{2\sqrt{k}}{\rho_l}$, when $0 < \lambda < \hat{\lambda}$, then $\pi_{RI} > \pi_{NI}$.

For the retailer, which is the optimal strategy, non-investment or retailer-investment case? As shown in Proposition 2, if and only if $0 < \lambda < \hat{\lambda}$, the retailer’s profit under retailer-investment case is more than that of non-investment case. That is, it is profitable for the retailer to make investment decision. Thence, business managers should commit to investing in the product quality. In other words, for corporate managers, making an appropriate change can enhance their competitive advantage.

Corollary 2. Under retailer-investment case, the retailer’s profit has the following properties:

$$\frac{\partial \pi_{RI}}{\partial u} > 0, \quad \frac{\partial \pi_{RI}}{\partial \lambda} > 0, \quad \frac{\partial \pi_{RI}}{\partial \rho_l} > 0, \quad \text{and} \quad \frac{\partial \pi_{RI}}{\partial k} < 0.$$ 

Obviously, the functional utility $u$, consumer sensitivity $\lambda$ and the success probability $\rho_l$ play an active role in the retailer’s profit by influencing the retail price. However, the retailer’s profit is negatively influenced by the cost parameter $k$. The larger the cost parameter of the quality-improvement product is, the stronger the opposite effect on his profit is.

3.3. Platform-investment. In practice, the retailer may seek cooperation with the professional platform to enhance the product quality. In this section, we model their strategic interaction as a Stackelberg game between one platform (she) and one retailer (he) in terms of the product quality-improvement level, with the platform as the leader and the retailer as the follower in the supply chain. And the platform is committed to improving the product quality, known as platform-investment. Different from retailer-investment case, the cooperation between enterprises in improving quality indicates that the retailer needs to give a certain profit to the platform. The profit-sharing contract is widely adopted in the real world. This contract prompts the platform to make investment efforts. We assume that the success probability of the platform is higher and the cost coefficient is lower than those of the retailer ($0 < \rho_l < \rho_h \leq 1$ and $\beta < k$), due to her professional expertise, standardized management and first-class design team. The profit-sharing ratio $\theta$ is assumed to be exogenous.

The sequence of events is as follows. First of all, the platform and the retailer reach a cooperation about the profit-sharing ratio $\theta$. Then the platform decides the quality-improvement level $e_{PI}$. After observing the platform’s decision and $\theta$, the retailer decides the retail price $p_{PI}$. Thus, our model examines the optimal retail price and the optimal quality-improvement level under the profit-sharing contract.

Without loss of generality, we proceed backwards to derive optimal decisions. For given $e_{PI}$ and $\theta$, the retailer’s problem is

$$\pi_{PI}(p_{PI}, e_{PI}) = E[(1 - \theta)(1 - \rho_h)(u + \lambda e_{PI} - p_{PI})(p_{PI} - c)]$$

The platform’s choice of $e_{PI}$: under the profit-sharing contract, the platform’s problem is to maximize her total expected profit.

$$\Pi_{PI}(p_{PI}, e_{PI}) = E[\theta \rho_h (u + \lambda e_{PI} - p_{PI})(p_{PI} - c)]$$

By analyzing the first-order derivatives of $\pi_{PI}(p_{PI}, e_{PI})$ in terms of $p_{PI}$ and $\Pi_{PI}(p_{PI}, e_{PI})$ in terms of $e_{PI}$, separately. The following result shows that the
optimal retail price and the optimal quality-improvement level under platform-investment case.

**Proposition 3.** When $0 < \theta < \frac{4\beta}{\lambda^2 p_h^2}$, the Stackelberg equilibrium under profit-sharing contract are $p_{PI}^* = c + \frac{2\beta(u-c)}{4\beta - \theta \lambda^2 p_h^2}$, $\epsilon_{PI}^* = \frac{\theta \lambda p_h (u-c)}{4\beta - \theta \lambda^2 p_h^2}$.

The proof of Proposition 3 is detailed in Appendix 3.

Different from retailer-investment case, with the profit-sharing contract, the optimal retail price and the optimal quality-improvement level are also influenced by the cost coefficient of the platform $\beta$, the success probability $p_h$, and the profit-sharing ratio $\theta$. At this time, the profit-sharing ratio is a very important parameter. It tells us that as long as the profit-sharing ratio is controlled within a certain range, the cooperation between enterprises can appear, improving the product quality and getting considerable pricing.

**Corollary 3.** (i) $\frac{\partial \pi_{PI}}{\partial \alpha} > 0$, $\frac{\partial \pi_{PI}}{\partial \lambda} > 0$, $\frac{\partial \pi_{PI}}{\partial p_h} > 0$, and $\frac{\partial \pi_{PI}}{\partial \beta} < 0$.

(ii) $\frac{\partial \pi_{PI}}{\partial \alpha} > 0$, $\frac{\partial \pi_{PI}}{\partial p_h} > 0$, and $\frac{\partial \pi_{PI}}{\partial \beta} < 0$.

According to Corollary 3(i), the higher functional utility, the greater consumer awareness and the bigger success probability promote the retailer to raise the retail price. However, the greater cost parameter is, the lower retail price is. Because when the investment cost is high, the platform reduces investment efforts, thus she cuts down the quality-improvement level. In turn, it affects the retail price. From Corollary 3(ii), it is clear that consumers with higher quality awareness encourage the retailer to reach a cooperation with the platform. In general, the platform with professional ability not only has a greater success chance, but also has an advantage in cost, i.e., the smaller cost parameter motivates her to further improve the product quality.

By substituting optimal decision variables $p_{PI}^*$ and $\epsilon_{PI}^*$ into the objective function (8) and (9), when $0 < \theta < \frac{4\beta}{\lambda^2 p_h^2}$, we can obtain the retailer’s profit and the platform’s profit.

\[
\pi_{PI} = \frac{4\beta^2(1-\theta)(u-c)^2}{(4\beta-\theta \lambda^2 p_h^2)^2}, \quad \Pi_{PI} = \frac{\theta \beta (u-c)^2}{4\beta - \theta \lambda^2 p_h^2}.
\]

**Corollary 4.** (a) For the retailer, (1) $\frac{\partial \pi_{PI}}{\partial u} > 0$, $\frac{\partial \pi_{PI}}{\partial \lambda} > 0$, $\frac{\partial \pi_{PI}}{\partial p_h} > 0$, and $\frac{\partial \pi_{PI}}{\partial \beta} < 0$.

(2) when $0 < \theta < \tilde{\theta}$, then $\frac{\partial \pi_{PI}}{\partial \lambda} > 0$; when $\theta > \tilde{\theta}$, then $\frac{\partial \pi_{PI}}{\partial \lambda} < 0$, where $\tilde{\theta} = 2 - \frac{4\beta}{\lambda^2 p_h^2}$.

(b) For the platform, $\frac{\partial \Pi_{PI}}{\partial u} > 0$, $\frac{\partial \Pi_{PI}}{\partial \lambda} > 0$, $\frac{\partial \Pi_{PI}}{\partial p_h} > 0$, and $\frac{\partial \Pi_{PI}}{\partial \beta} < 0$.

Corollary 4(a) shows that the retailer’s profit increases with the functional utility $u$, consumer sensitivity $\lambda$ and the success probability $p_h$, while his profit decreases with the cost parameter $\beta$, which lowers the retail price. Moreover, there is a significant result that the profit-sharing ratio $\theta$ is very critical. That is, when $\theta$ is confined to a certain range ($0 < \theta < \tilde{\theta}$), his profit increases with $\theta$. Thence, it is profitable for the retailer as long as most profit belongs to him; Once $\theta$ exceeds a threshold ($\tilde{\theta} < \theta < 1$), the retailer’s profit decreases with $\theta$, and his profit is quickly captured by the platform.

From Corollary 4(b), after observing consumer sensitivity, the platform is ready to make efforts regarding the quality improvement, which conduces the retailer to raise the retail price. In return, she can get more benefits. An intuitive explanation is that the cost parameter $\beta$ is closely related to her investment cost. Further, if the cost coefficient is high, the total cost outweighs her benefits. Consequently, it is
unfavorable for both the platform and the retailer. There is no doubt that the larger the profit-sharing ratio \( \theta \) is, the larger the platform’s profit is. And, the greater success probability not only strengthens the retailer’s confidence in cooperation, but it also impels the platform to increase her investment budgets.

4. Analysis and discussions. In previous sections, we explicitly discuss two cases, namely, retailer-investment and platform-investment. To understand our idea and contributions, we regard non-investment case as the basic model, and mainly analyze participants’ decisions in different cases. In section 3, we compare non-investment with retailer-investment case, and the result shows that it is worthy for the retailer to improve the product quality. Furthermore, when both retailer-investment and platform-investment are feasible, which is the optimal strategy for the retailer? The answer is as follows.

\[
\Delta \pi_2 = \pi_{PI} - \pi_{NI} = \frac{1}{4} (u-c)^2 \left[ \frac{16 \beta^2 (1-\theta)}{(4 \beta^2 - \theta \lambda^2 \rho_k^2)^2} - 1 \right] \quad (10)
\]

\[
\Delta \pi_3 = \pi_{PI} - \pi_{RI} = (u-c)^2 \left[ \frac{4 \beta^2 (1-\theta)}{(4 \beta^2 - \theta \lambda^2 \rho_k^2)^2} - \frac{k}{4k - \lambda^2 \rho_l^2} \right] \quad (11)
\]

By comparison, the following Proposition 4 shows properties of investment decisions.

**Proposition 4.** (1) Compared with non-investment case, there is a threshold \( \tilde{\theta} \). If \( 0 < \theta < \tilde{\theta} \), then \( \pi_{PI} > \pi_{NI} \), where \( \tilde{\theta} = \frac{8 \beta^2 (1-\theta) \lambda^2 \rho_k^2}{\lambda^2 \rho_k^2} \), \( 0 < \lambda < \frac{2 \sqrt{2} \beta}{\kappa^2} \). Otherwise, if \( \tilde{\theta} < \theta < 1 \), then \( \pi_{PI} < \pi_{NI} \).

(2) Compared with retailer-investment case, if \( 0 < \theta < \tilde{\theta} \), then \( \pi_{PI} < \pi_{RI} \); if \( \tilde{\theta} < \theta < 1 \), then \( \pi_{PI} > \pi_{RI} \). And \( \Pi_{PI} = \frac{\theta^2 (u-c)^2}{8 \beta^2 - \lambda^2 \rho_k^2} > 0 \). where

\[
\hat{\theta} = \frac{2}{k^2 \lambda^2 \rho_k^2} (-4k \beta^2 + \lambda^2 (2k \rho_k^2 + \beta \rho_l^2) + \sqrt{\beta^2 (4k - \lambda^2 \rho_k^2)(k - 2 \beta + \lambda^2 \rho_k^2)^2 - \beta^2 \lambda^2 \rho_l^2})
\]

\[
\hat{\lambda} = \frac{2}{k^2 \lambda^2 \rho_k^2} (-4k \beta^2 + \lambda^2 (2k \rho_k^2 + \beta \rho_l^2) - \sqrt{\beta^2 (4k - \lambda^2 \rho_k^2)(k - 2 \beta + \lambda^2 \rho_k^2)^2 - \beta^2 \lambda^2 \rho_l^2})
\]

As shown in Proposition 4(1), compared with non-investment case, when \( 0 < \theta < \hat{\theta} \), the retailer’s profit under platform-investment case is more than that of non-investment case. At this time, the retailer is motivated to collaborate with the platform. When the profit-sharing ratio \( \theta \) is not high, it is profitable for the retailer to reach cooperation. However, once the threshold is exceeded \( (\theta > \hat{\theta}) \), the retailer gives up cooperating with the platform, and non-investment is the optimal strategy.

From Proposition 4(2), when both retailer-investment and platform-investment are viable, if \( 0 < \hat{\theta} < \theta < \tilde{\theta} < 1 \), the retailer can get more profit by partnering with the platform, and platform-investment is the optimal strategy. It also shows that the cooperation between enterprises requires conditions, namely, the platform is willing to invest on the product quality only if she can obtain certain income. However, when the retailer’s profit is excessively squeezed by the platform \( (\theta > \hat{\theta}) \), the retailer gives up the cooperation. In addition, cooperation between companies can make the platform obtain more profit. Thence, there is a win-win outcome among the retailer and the platform. The platform managers should be willing to facilitate cooperation.
So far, we study the retailer’s optimal investment strategy under different cases. Then, we characterize properties with respect to the optimal retail price $p_i$ in Proposition 5.

**Proposition 5.** The optimal retail price $p_i^*$ in different cases satisfies the following relationships:

1. If and only if $0 < \lambda < \frac{2\sqrt{k}}{\rho_l}$, then $p_{RI}^* > p_{NI}^*$.
2. If and only if $0 < \lambda < \frac{2\sqrt{\beta \theta}}{\rho_h}$, then $p_{PI}^* > p_{NI}^*$.
3. When $0 < \beta \rho_l^2 / k \rho_l < \theta < 1$, $0 < \lambda < \frac{2\sqrt{k}}{\rho_l}$, and $0 < \lambda < \frac{2\sqrt{\beta \theta}}{\rho_h}$, then $p_{PI}^* > p_{RI}^* > p_{NI}^*$.

When consumers are quality sensitive, improving one unit quality level either by retailer-investment or platform-investment can make the retailer get higher the retail price, as demonstrated by Corollary 1(i) and Corollary 3(i). Moreover, when both retailer-investment and platform-investment are viable, selecting the latter with certain condition is the optimal solution. Because the platform has professional knowledge and outstanding design team, she enables the retailer get more added value. In other words, as long as the profit-sharing ratio exceeds a certain threshold ($\frac{\beta \rho_l^2}{k \rho_l} < \theta < 1$), it is wise for the retailer to partner with the platform to get higher retail price.

**Proposition 6.** There is a threshold $\tilde{\theta}$, if $0 < \theta < \tilde{\theta}$, then $e_{PI}^* < e_{RI}^*$; if $\tilde{\theta} < \theta < 1$, then $e_{PI}^* > e_{RI}^*$, where $\tilde{\theta} = \frac{4\beta \rho_l}{\rho_h (4k - \lambda^2 \rho_l^2 + \lambda \rho_l \rho_h)}$.

Proposition 6 compares the quality-improvement level in two cases. When both retailer-investment and platform-investment are feasible, the quality-improvement level depends on the profit-sharing ratio $\theta$. When the ratio $\theta$ is not too small, the quality-improvement level is higher under platform-investment situation ($e_{PI}^* > e_{RI}^*$). It signifies that if the platform gets more profit, correspondingly, she also makes more investment efforts to improve the product quality. When $\theta$ is relatively low, the quality-improvement level is higher under retailer-investment case.

For consumers, if they can get more consumer surplus, they are more willing to buy higher quality products. And consumers are the major driving force in improving the product quality. Therefore, we compare consumer surplus in different cases.

**Proposition 7.** The consumer surplus in different situations satisfies the following relationships:

1. when $\lambda > \hat{\lambda}$, then $CS_{RI} > CS_{NI}$; when $0 < \lambda < \hat{\lambda}$, then $CS_{RI} < CS_{NI}$.
2. when $\lambda > 0$, then $CS_{PI} > CS_{NI}$; when $\lambda = 0$, then $CS_{PI} = CS_{NI}$.
3. when $\tilde{\theta} < \theta < 1$, then $CS_{PI} > CS_{RI}$; when $0 < \theta < \tilde{\theta}$, then $CS_{PI} < CS_{RI}$.

The proof of Proposition 7 is detailed in Appendix 4.

When consumers are quality sensitive, it is favorable for consumers to purchase quality-improvement products. Compared with non-investment case, when consumer sensitivity exceeds a certain threshold $\hat{\lambda}$, consumer surplus is bigger under retailer-investment case. As long as consumers have positive consumer sensitivity in platform-investment case, it always motivates the platform to help the retailer
enhance the product quality. The reason behind is that the platform has a good reputation and reliable quality assurance, this is why consumers prefer brand products in real life.

When both retailer-investment and platform-investment are feasible, only if the platform gets more benefits ($\theta > \theta$), she endeavors to improve the product quality. In turn, it also enables consumers to obtain more consumer surplus. Therefore, there is a meaningful result, a triple-win situation among three parties.

5. Numerical analysis. In this section, we perform numerical analysis to verify our results and to examine impacts of different parametric variables on the retailer’s decisions. Examples are provided to illustrate how consumer sensitivity $\lambda$ and the profit-sharing ratio $\theta$ affect the retail price, the product quality-improvement level as well as the supply chain performance respectively. Our numerical analysis is consistent with the following benchmark parameter values: $c = 0.05$, $k = 3.5$, $\beta = 1.0$, $\rho_l = 0.6$, $\rho_h = 0.8$, and the functional utility $V$ follows a normal distribution with a mean of 1.5.

![Figure 1](image_url)

**Figure 1.** The impact of $\lambda$ on decision variables

We first examine how consumer sensitivity $\lambda$ affects the quality-improvement level $e_i$ and the optimal retail price $p_i$ under two situations, which is consistent with Corollary 1 and 3. In Figure 1(a), the product quality-improvement level increases with consumer sensitivity. Specifically, there is a meaningful result that when consumer sensitivity is relatively low ($1 < \lambda < 1.87$), it has a relatively large effect on the quality-improvement level under retailer-investment case. When consumer sensitivity is relatively high, it effectively promotes the quality-improvement level (blue curve). It is wise for the retailer to adopt platform-investment to greatly improve the product quality as consumer sensitivity increases. Figure 1(b) shows that the optimal retail price is positively affected by consumer sensitivity. Obviously, it has a greater impact on the price under platform-investment scenario (blue curve).

Which is the optimal investment strategy for the retailer? We conduct relevant numerical analysis to test the robustness of our results. From the retailer’s perspective, Figure 2 shows that compared with non-investment case, the retailer should take actions to improve the product quality because of higher profit. The balance profit $\Delta \pi_1$ increases with consumer sensitivity in Figure 2(a), and the increment is gradual. In contrast to non-investment case, Figure 2(b) demonstrates that the
retailer’s profit is larger in platform-investment case as long as the profit-sharing ratio $\theta$ is within a certain range $[0, 0.97]$. To further clarify the retailer’s choice, Figure 2(c) shows that only if the ratio $\theta$ is within $[0.2, 0.96]$, platform-investment is the optimal strategy. This also verifies that the platform makes more efforts to improve the product quality only if she obtains certain benefits. Otherwise, the retailer should opt retailer-investment.

![Graphs](a) The impact of $\lambda$ on $\Delta_1$  
(b) The impact of $\theta$ on $\Delta_2$  
(c) The impact of $\theta$ on $\Delta_3$

**Figure 2.** The impact of $\lambda$ and $\theta$ on balance profit

For consumers, they are concerned about higher quality products and consumer surplus. In Figure 3, we present effects of the profit-sharing ratio $\theta$ on the product quality-improvement level, consumer surplus, and the supply chain performance under two scenarios. We find that when the ratio $\theta$ exceeds 0.2, consumers acquire higher quality products (blue curve) and obtain larger consumer surplus (green curve) in platform-investment case. In addition, it is more conducive to the overall supply chain in platform-investment case (red curve), which implies that the professional platform can reduce various risks to a certain extent and cooperation between companies enhances supply chain performance. The impact of the ratio on the entire supply chain performance is further analyzed in Appendix 8.

6. **Extension.** In previous sections, the contract term is not taken into consideration. In this section, to effectively alleviate the contradiction between the retailer’s moral hazard problem and the sustainable value-added effect of platform-investment, we further research the contract term. In general, the retailer is required to sign a contract with the platform regarding the contract period, for instance, $T = 1$, $T = 2$, or $T = n$. To avoid trivial cases, we mainly discuss two situations,
$T = 1$ or $T = 2$. Assuming $T = 1$, the retailer agrees to sign a one-year contract with the platform. After gaining revenues, the retailer always tends to terminate the cooperation to avoid sharing profit in the next year. Hence, we consider a two-part tariff contract to resolve above problem. Assuming $T = 2$, the platform signs a two-year contract with the retailer to ensure the value-added effect of the quality investment.

Firstly, we study a one-year with a two-part tariff contract. Without considering the retailer’s moral hazard problem, his profit is bigger within certain condition under platform-investment case. If the retailer continues to cooperate with the platform, he always has to share profit with the latter. Therefore, the retailer tends to make a rejective choice in the next year. Because the moral hazard problem is more prominent under platform-investment situation, thence the retailer’s total profit in the first and second year is

$$
\pi_{T=1} = E[\rho_h((1 - \theta)(u + \lambda e - p_{T=1})(p_{T=1} - c) + \pi_{\text{ph}}) + (1 - \rho_h)((u + \lambda e - p_{T=1})(p_{T=1} - c) + \pi_{\text{ph}})]
$$

Since the platform only invests in the first year, so the product quality-improvement level $e_{T=1}$ is given. Then, the retailer’s optimal retail price in the second year is as follows.

$$p^*_T = \frac{1}{2}(c + u + \frac{\theta_{\text{ph}}}{4\beta - \theta \lambda^2 \rho_h^2})$$

In the second year, the retailer rejects the cooperation, harming the platform’s profit. Next, we consider the second situation $T = 2$. The retailer can adjust his pricing strategy in a timely manner according to the first year’s earnings. The retailer’s profit is

$$
\pi_{T=2} = E[\rho_h((1 - \theta)(u + \lambda e - p_{T=2})(p_{T=2} - c) + \pi_{\text{ph}}) + (1 - \rho_h)((1 - \theta)(u - p_{T=2})(p - c) + \pi_{\text{ph}})]
$$

After a series of calculations, the retailer’s optimal retail price $p_{T=2}$ in the second year, is

$$p^*_T = c + \frac{2\beta(u - c)}{4\beta - \theta \lambda^2 \rho_h^2}$$

**Proposition 8.** With a two-year contract, the retailer’s optimal retail price in the second year is the same as that without considering moral hazard problem. Similarly, his profit is twice as big as that without considering moral hazard problem.
The proof of Proposition 8 is detailed in Appendix 5. Proposition 8 summarizes an interesting result. Under a two-year contract, the retailer’s pricing strategy remains unchanged as that without moral hazard problem, namely, \( p_{T=2}^* = p_{T=1}^* \). This occurs when the retailer lacks management experience, or many retailers form tacit agreement in the same market. Analogously, the retailer’s profit also maintains changeless as before.

In order to continue the value-added effect of platform-investment and to mitigate the retailer’s moral hazard problem, the platform implements a one-year with a two-part tariff contract or a two-year contract. Let \( T \) be a fixed transfer payment.

\[
T = \pi_{T=2} - \pi_{T=1} = \frac{\theta(u-c)^2(1-\rho h)(16\beta^2 + \lambda^2 \rho h(1-\theta \rho h)(\theta \lambda^2 (1-\theta \rho h)\rho h + 8\beta))}{4(4\beta - \theta \lambda^2 \rho h)^2}
\]

**Proposition 9.** Compared to a two-year contract, the platform adopts a one-year with a two-part tariff contract to respond to the retailer’s moral hazard problem. After refusing to continue cooperation, the retailer is required to pay a fixed transfer payment \( T \) to the platform.

The proof of Proposition 9 is detailed in Appendix 6. Proposition 9 summarizes the platform’s decision about the contract term when faced with the retailer’s moral hazard problem. After the retailer refuses to continue cooperation, the platform requires him to pay a certain fee to terminate the contract, achieving the same performance as a two-year contract. The implementation of this contract has two advantages. On the one hand, the retailer’s moral hazard problem can be alleviated, promoting the sincere cooperation between the retailer and the platform, and it also can warn other retailers. On the other hand, it effectively avoids the platform’s losses, making the platform more confident in improving the product quality.

We further analyze the situation that the platform possesses the pricing power. Proposition 10 shows that no matter who owns the pricing power, there is no substantial change to our results.

**Proposition 10.** When the platform possesses the pricing power, the optimal retail price and the optimal quality-improvement level are the same as the situation that the pricing power belongs to the retailer.

The proof of Proposition 10 is detailed in Appendix 7. Proposition 10 provides us with a significant management enlightenment that in cooperation, no matter which party has the pricing power, the interests of both parties can be maximized. And it not only improves the product quality to capture more consumers, but it also gets the same optimal retail price. In other words, the platform managers don’t need to fight for the pricing power.

7. **Conclusions and future research.** In this paper, we present a two-tier supply chain to study the interaction between operation and investment decisions. When the retailer realizes that consumers are quality sensitive, he makes efforts to improve the product quality. The retailer faces two investment choices, retailer-investment and platform-investment. In the strategic interaction between the retailer and the platform, we obtain the Stackelberg equilibrium. Moreover, we compare optimal decisions and participants’ profit under two cases from the perspectives of the retailer, the platform, consumers and the supply chain performance.

We regard non-investment case as the basic model. Our analysis reveals that compared with non-investment case, it is favorable for the retailer to enhance the
product quality, as it gives incentives to him to obtain more benefits. When both retailer-investment and platform-investment are viable, the optimal strategy depends on the profit-sharing ratio $\theta$. This gives us a meaningful management enlightenment, that is, the relationship between retailer-investment and platform-investment is alternative within a certain condition.

If the profit-sharing ratio $\theta$ is very low, the retailer is willing to devote to the quality improvement by cooperation because the retailer can get more benefits. However, the platform doesn’t agree to cooperation. Only if the profit-sharing ratio $\theta$ is confined to a certain range $[\tilde{\theta}, \hat{\theta}]$, the platform is more inclined to cooperate with the retailer, and the platform does her best to enhance the quality. Not only does it help the retailer get higher yields and higher quality products, but it also helps the platform get a good return on her investment, and consumers also prefer to buy higher quality products. The management inspirations behind are as follows: first, the platform invests to improve the product quality only if she obtains a certain amount of revenues by the cooperation, due to the fact the platform pursues profit maximization; second, these retailers are consumer-oriented, and they have a strong sensitivity to the market demand. In short, the most important thing is that cooperation between enterprises can indeed improve the product quality, achieving a triple-win outcome for three parties involved.

Then, we discuss some interesting extensions of our model. First of all, in order to maintain the value-added effect of platform-investment and avoid the retailer’s moral hazard problem, the platform provides two contracts, a two-year contract or a one-year with a two-part tariff contract. The result shows that considering the retailer’s moral hazard problem, the platform requires the retailer to pay a fixed transfer payment $T$ to terminate the contract. Second, when the platform possesses the pricing power, the optimal retail price and the optimal quality-improvement level hold unchanged.

Various research directions can be explored to further our current model. Firstly, our paper assumes that the retailer is well-funded. We can further explore the financing and operation decisions when the retailer is capital constraints. Secondly, we intend to discuss information asymmetry among the retailer and the platform in terms of the product quality-improvement level, market imperfections as well as demand information. Thirdly, we assume that the retailer and the platform are risk-neutral in this paper, we can explore the impact of the risk averse attitude on the retailer’s operation decision. Finally, according to our theoretical analysis, cooperation can indeed achieve a triple-win situation; however, there is no relevant empirical research. Hence, collecting relevant industry data for the empirical research is also a meaningful research direction.

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Appendix.

Appendix 1. Proof of non-investment case. From Eq.(4), we get the first-order derivative and the second-order derivative of \( \pi_{NI} \) in terms of \( p_{NI} \), separately.

\[
\frac{\partial \pi_{NI}}{\partial p_{NI}} = u - 2p_{NI} + c, \quad \frac{\partial^2 \pi_{NI}}{\partial p_{NI}^2} = -2 < 0.
\]

Therefore, we get that the retailer’s expected profit is a concave function of the retail price \( p_{NI} \). Then, we obtain the optimal retail price \( p_{NI}^* = u - 2p_{NI} + c = 0 \), namely, \( p_{NI}^* = \frac{u + c}{2} \). Correspondingly, we substitute the optimal retail price into the retailer’s expected profit function, that is, maximize his profit, \( \pi_{NI}^* = \frac{1}{4}(u - c)^2 \).

Appendix 2. Proof of Proposition 1. From Eq.(6), when the well-capitalized retailer chooses to improve the product quality by himself, he decides the product quality-improvement level \( e_{RI} \) and the retail price \( p_{RI} \) at the same time. To prove the joint concavity on \( e_{RI} \) and \( p_{RI} \), we need to show that the Hessian matrix of \( \pi_{RI}(e_{RI}, p_{RI}) \) is negative semi-definite, i.e., \( \frac{\partial^2 \pi_{RI}}{\partial e_{RI}^2} \leq 0 \), \( \frac{\partial^2 \pi_{RI}}{\partial p_{RI}^2} \leq 0 \), and the determinant of the Hessian matrix is non-negative. After some algebra work, we have,

\[
H(e_{RI}, p_{RI}) = \begin{bmatrix}
-2k & \lambda \rho_l \\
\lambda \rho_l & -2
\end{bmatrix}
\]

Thence, \( \frac{\partial^2 \pi_{RI}}{\partial e_{RI}^2} \leq 0 \), \( \frac{\partial^2 \pi_{RI}}{\partial p_{RI}^2} \leq 0 \). The determinant of the Hessian can be found to be, \( |H(e_{RI}, p_{RI})| = 4k - \lambda^2 \rho_l^2 \). The following condition is needed to guarantee \( |H(e_{RI}, p_{RI})| \geq 0 \), which is \( 0 < \lambda < \frac{2\sqrt{k}}{\rho_l} \). The condition puts restriction on the product quality-improvement level \( e_{RI} \), the retail price \( p_{RI} \) as well as the retailer’s profit.

Appendix 3. Proof of Proposition 3. From Eq.(8) and Eq.(9), when the retailer chooses to cooperate with the platform in order to higher quality products, the platform decides the product quality-improvement level \( e_{PI} \) and the retailer decides retail price \( p_{PI} \). Obviously, \( \frac{\partial^2 \pi_{PI}}{\partial e_{PI}^2} = -2(1 - \theta) < 0 \), then we get the optimal retail price. To prove the concavity on \( e_{PI} \), we analyze the first-order derivative and the second-order derivative of \( \Pi_{PI}(e_{PI}) \) in terms of \( e_{PI} \), separately.

\[
\frac{\partial \Pi_{PI}}{\partial e_{PI}} = \frac{1}{2} [\theta \lambda(u - c)\rho_h - 4\beta + e\theta \lambda^2 \rho_h^2]
\]

\[
\frac{\partial^2 \Pi_{PI}}{\partial e_{PI}^2} = \frac{1}{4} [2\theta \lambda^2 \rho_h^2 - 8\beta]
\]

We assume \( \frac{\partial^2 \Pi_{PI}}{\partial e_{PI}^2} \leq 0 \), then the following condition is needed to satisfy \( 0 < \lambda < \frac{4\beta}{(2\theta \lambda^2 \rho_h^2 - 8\beta)} \). Then, we bring the condition into the first-order derivative, \( \frac{\partial \Pi_{PI}}{\partial e_{PI}} > 0 \), so we get the optimal quality-improvement level \( e_{PI}^* \).

Appendix 4. Proof of Proposition 7. Consumer surplus refers to the difference between the maximal retail price that consumers are willing to pay for a product and the actual price, namely, a remnant utility. Let \( \hat{p}_i \) be the maximum retail price, \( \hat{p}_i = u + \lambda e_{PI}^* \), similarly to Hong and Guo (2019). Thence, consumer surplus of the supply chain is as follows.

\[
CS_i = \frac{1}{2} [(\hat{p}_i - p_{NI}^*)q_i^*].
\]

We get consumer surplus in different scenarios. In Proposition 7, we compare consumer surplus under different scenarios and summarize their relationship. Besides, we do not repeat results here.

\[
CS_{NI} = \frac{1}{4}(u - c)^2
\]
\[ CS_{RI} = \frac{(u-c)^2(4k^2 + \lambda^4(1-\rho_1)p_1^2)}{2(4k-\lambda^2p_1^2)^2} \]
\[ CS_{PI} = \frac{(u-c)^2(\beta^2 + \theta^4\lambda^4(1-\rho_h)p_h^2)}{2(4\beta^2 - \theta\lambda^2\rho_h^2)^2} \]
\[ \hat{\lambda} = \frac{\sqrt{8k}}{\sqrt{5p_1^2 - 4p_i}} \]
\[ \bar{\rho} = \frac{4\beta^2(4k^2 - \lambda^4(\rho_1 - 1)p_1^2)}{\lambda^2\rho_h^2(-4k - \lambda^2p_1^2)^2 + \rho_h(20k^2 - 8k\lambda^2p_1^2 + \lambda^4p_1^2)} + \frac{2\sqrt{\beta^2\rho_h^2(\lambda^2p_1^2 - 4k)^2(4k^2\rho_h - 8k\lambda^2(\rho_h - 1)p_1^2 + \lambda^4(4 - 3\rho_h)p_h^2 + \lambda^4(4\rho_h - 5)p_1^2)}{\lambda^2\rho_h^2(-4k - \lambda^2p_1^2)^2 + \rho_h(20k^2 - 8k\lambda^2p_1^2 + \lambda^4p_1^2)} \]

**Appendix 5.** Proof of Proposition 8. In order to get continuously value-added effect of platform investment, we assume that the platform provides a two-year contract with profit-sharing to the retailer. Generally speaking, retailers can adjust their retail price in a timely manner in the second year to obtain more profits. From function (13), we obtain the retail price in the second year and the retailer’s total profit.

\[ p_{T=2}^* = c + \frac{2\beta(u-c)}{4\beta^2(1-\theta)(u-c)^2} \]
\[ \Pi_{T=2} = \frac{2\beta(1-\theta)(u-c)^2(2\beta - \theta\lambda^2(\rho_h - 1)p_h)}{4\beta^2(1-\theta)(u-c)^2(2\beta - \theta\lambda^2p_h^2)} \]
\[ \pi_{p_h} = \frac{2\beta(1-\theta)(u-c)^2(2\beta - \theta\lambda^2p_h^2)}{4\beta^2(1-\theta)(u-c)^2(2\beta - \theta\lambda^2p_h^2)} \]
\[ \pi_{p(1-h)} = \frac{2\beta(1-\theta)(u-c)^2(2\beta - \theta\lambda^2p_h^2)}{4\beta^2(1-\theta)(u-c)^2(2\beta - \theta\lambda^2p_h^2)} \]

**Appendix 6.** Proof of Proposition 9. Assuming \( T = 1 \), when the retailer’s moral hazard problem exists, and if the platform wants to get the same value-added effect, the retailer is asked to pay a fixed transfer payment \( \Pi \). After some calculations, we get the retailer’s total profit (\( T = 1 \)).

\[ \pi_{T=1} = \frac{(u-c)^2\theta p_h^2\lambda^2(-8\beta(\theta + 1) + \theta\lambda^2)}{4(4\beta - \theta\lambda^2p_h^2)^2} + \frac{8(u-c)^2\theta p_h\beta(\lambda^2 - 2\beta)}{4(4\beta - \theta\lambda^2p_h^2)^2} \]
\[ + \frac{(u-c)^2\theta p_h^2\lambda^2(\theta p_h(8\beta + \lambda^2(1 + 2\theta - \theta p_h) - (\theta + 2)\lambda^2))}{4(4\beta - \theta\lambda^2p_h^2)^2} \]
\[ + \frac{16(u-c)^2\beta^2(2 - \theta)}{4(4\beta - \theta\lambda^2p_h^2)^2} \]

**Appendix 7.** Proof of Proposition 10. When the platform possesses the pricing power, her decision variables are the product quality-improvement level and the retail price. The platform’s profit is

\[ \Pi_{PI}(p_{PI}, e_{PI}) = E[\theta p_h(u + \lambda e_{PI} - p_{PI})(p_{PI} - c)] + \theta(1 - \rho_h)(u - p_{PI})(p_{PI} - c)] - \beta e_{PI}^2 \]

To prove the joint concavity on \( e_{PI} \) and \( p_{PI} \), we need to show that the Hessian matrix of \( \Pi_{PI}(e_{PI}, p_{PI}) \) is negative semi-definite, i.e., \( \frac{\partial^2 \Pi_{PI}}{\partial e_{PI}^2} \leq 0 \), \( \frac{\partial^2 \Pi_{PI}}{\partial p_{PI}^2} \leq 0 \), and the determinant of the Hessian matrix is non-negative. After some algebra work, we have,

\[ H(e_{PI}, p_{PI}) = \begin{bmatrix} -2\beta & \theta \lambda p_h \\ \theta \lambda p_h & -2\theta \end{bmatrix} \]
Thence, $\frac{\partial^2 \Pi}{\partial e^2} < 0$, $\frac{\partial^2 \Pi}{\partial p^2} < 0$. The determinant of the Hessian can be found to be, $|H(e_{PI}, p_{PI})| = \theta(4 \beta - \theta \lambda^2 \rho^2)$. The following condition is needed to guarantee $|H(e_{PI}, p_{PI})| \geq 0$, which is $0 < \lambda < \frac{2 \sqrt{\beta / \theta}}{\rho h}$.

Then, the optimal quality-improvement level $e_{PI}^*$ and the optimal retail price $p_{PI}^*$ are as follows.

$$e_{PI}^* = \frac{\theta \lambda (u - c) \rho h}{4k - \theta \lambda^2 \rho^2 h}$$

$$p_{PI}^* = c + \frac{2 \beta (u - c)}{4k - \theta \lambda^2 \rho^2 h}$$

Specially, no matter who has the pricing power, the optimal quality-improvement level and the retail price remain unchanged.

Appendix 8. In our paper, the overall supply chain performance consists of the retailer’s profit, the platform’s profit and consumer surplus. We compare the supply chain performance under different scenarios when the profit-sharing ratio $\theta = 0.1$ or $\theta = 0.2$.

![Graphs](a) $\theta = 0.1$ (b) $\theta = 0.2$

**Figure 4. The impact of $\theta$ on supply chain performance**

From Figure 4, we further verify the importance of the profit-sharing ratio. From the supply chain perspective, only if the ratio $\theta$ exceeds a certain threshold, platform-investment is the optimal strategy (red curve); otherwise, retailer-investment is the optimal strategy (green curve).

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E-mail address: dang2018@mail.ustc.edu.cn
E-mail address: ustcxy@mail.ustc.edu.cn
E-mail address: bigb@ustc.edu.cn
E-mail address: qinleichristine7@126.com