POMS PRODUCTION AND OPERATIONS MANAGEMENT

PRODUCTION AND OPERATIONS MANAGEMENT POMS

Vol. 0, No. 0, xxxx–xxxx 2015, pp. 1–17
ISSN 1059-1478 | EISSN 1937-5956 | 15 | 00 | 0001
DOI 10.1111/poms.12315

Requirement or Promise? An Analysis of the First-Mover Advantage in Quality Contracting

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Quality contracting is critical and challenging due to the many unique issues related to quality. In this study, we analyze the first-mover right in quality contracting by considering two different strategies for the buyer: the quality requirement strategy (QR) where buyer moves first by posting quality requirement to suppliers and quality promise strategy (QP) where buyer voluntarily gives up the first-mover right to suppliers to ask them to promise quality. We study which strategy (1) better encourages suppliers' quality improvement efforts and (2) leads to a higher expected profit for the buyer. To analyze the drivers behind the buyer's choice between QR and QP, we start with the basic model where buyer faces only one supplier who has the opportunity to make quality improvements. We then gradually add other business features such as information asymmetry and supplier competition, analyzing how each feature adds/changes the driving forces and how they interact in the buyer's decision between QR and QP. We consider both the case where the wholesale price is fixed (when the buyer has the power to dictate price or price is set by the market) and the case where the wholesale price is included as a variable (when price is part of the negotiation). We find that QP always leads to the first-best quality efforts from the supplier(s) while QR limits their efforts. However, this does not guarantee higher expected profit for the buyer under QP. We provide insightful guidelines in buyer's choice between QP and QR. This research enriches the limited literature on quality contracting with quality improvement opportunity and asymmetric information.

Key words: Quality contracting; first-mover right; quality improvement; information asymmetry; supplier competition
History: Received: July 2010; Accepted: August 2014 by Panos Kouvelis, after 4 revisions.

1. Introduction

With the global economy, there is great sensitivity to product quality as quality issues permeate media reports. Companies look for effective strategies in quality contracting since their reputation is significantly affected by the quality of goods and services provided by their suppliers.

In quality contracting, one prevalent strategy a buyer uses is to provide quality requirements to potential suppliers and select a supplier based on their reactions to these quality requirements. With this strategy, buyer moves first in quality contracting and her suppliers respond accordingly. We call this quality requirement strategy (QR). QR is commonly used in practice. For example, IBM uses a Product Quality Addendum, which includes expected Shipped Product Quality Level (SPQL) and reliability requirements. However, is QR always the best strategy for the buyer, especially when suppliers have better information and also usually have the ability to exert efforts to improve quality? An alternative strategy is for the buyer to solicit quality promises from potential suppliers, based on which the buyer selects her supplier with a quality contract as well. With this strategy, buyer gives up her first-mover right to allow suppliers to assume a more proactive role and she will respond accordingly. We call this quality promise strategy (QP). For example, a big electronics company outsourcing in Taiwan (name concealed for confidentiality) contacts suppliers with fixed price and requests for quality promises to decide which supplier to contract with. The focus of this study is to compare these two strategies—QR and QP—and investigate which strategy may induce more quality improvement efforts and be more profitable for the buyer.

In dealing with quality contracting, a few unique aspects related to quality complicate the decisions.

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First, although suppliers may be responsible for quality problems, buyer usually bears the penalty cost and the potentially long-term negative effect of them. For example, a brand manufacturer (buyer) who outsources product or parts of the product to a supplier suffers from bad quality of its supplier. Hence, it is critical to establish quality penalty cost sharing plan in quality contracting. Under QR, this means the buyer *requires* a proportion of the quality-related penalty cost shared by the supplier, whereas under QP, the suppliers may be asked to promise such proportion. Obviously, a supplier's willingness to take a higher proportion of such penalty cost is often a signal of higher quality. Quality-related penalty cost sharing is also considered in previous literature. In Zhu et al. (2007), quality-related penalty cost sharing plan (proportion) was considered as a contract parameter between buyer and supplier and quality improvement performances were compared under different setups of this parameter.

The second unique issue of quality contracting is the potential of quality improvement conducted by the suppliers (and sometimes by the buyer as well to encourage more improvement in quality, for example, Chrysler, Motorola, Intel, TTI). As a result, buyer must consider these opportunities in her quality contracting decision since (1) suppliers may use these improvements to increase their competition leverage and (2) buyer may use different quality contracting strategies and penalty cost sharing plans to induce more quality improvement. To include this important aspect in the study, we consider quality improvement as part of the suppliers' decisions under either strategy. Specifically, under QR, when buyer sets quality requirement (the proportion of quality penalty cost the supplier shares), a supplier may respond by whether to accept the offer and if yes, how much (if any) quality improvement to commit. Under QP, potential suppliers promise the quality penalty cost sharing plan as well as their quality improvement plan. In addition, while we focus on the case where only suppliers improve quality, we also analyze and briefly discuss the case where only buyer may improve quality and the case where both supplier and buyer may exert quality improvement efforts under either strategy (it remains their individual decisions regarding whether they choose to improve quality or not).

Finally, the third complicating factor is the possible information asymmetry between a buyer and the suppliers regarding the suppliers' cost in quality improvement. Specifically, a supplier's quality improvement cost is usually his private information, although buyer and other suppliers may have some estimation of it. As we will show, in a decentralized system, buyer's and suppliers' decisions are closely related to suppliers' quality improvement cost. Hence, under asymmetric information, buyer will try to infer the suppliers' quality improvement cost from their actions before making decisions.

When there is asymmetric information in the supply chain, the less informed party may try to provide incentives for the more informed party to reveal his private information, that is, screening, or the more informed party may want to reveal his information to gain cooperation from the less informed, that is, signaling (Cakanyildirim et al. 2012, Chen 2003, Riley 2001). The challenge is that before the buyer chooses between the two strategies (QP and QR), she needs to find out how she tackles asymmetric information to make a better decision under these two strategies. It is interesting to see that while QP corresponds to a signaling game, QR corresponds to a screening game. We characterize the equilibrium solutions under either strategy before comparing them from the buyer's perspective in her choice between QP and QR.

To study the unique issues discussed above and find the key drivers of the buyer's choice between QR and QP in terms of her expected profit, we study the quality-contracting context where buyer designs the product and the contracted supplier produces the product for the buyer. Quality is defined as the supplier's conforming rate, that is, the proportion of units that satisfy product specifications, the most widely used quality measure. Given the many production uncertainties, conforming rate is a random variable. Hence, quality is defined as the average conforming rate, which supplier can exert efforts to improve with a cost. A higher quality level corresponds to a lower expected penalty cost, shared by the buyer and the supplier according to the penalty cost sharing proportion. This proportion, also called as the penalty sharing plan, is required by the buyer under QR and promised by the supplier(s) under QP. We start with the basic model where there is one buyer and one supplier who has the ability to make quality improvement. Buyer decides whether and how to contract with this supplier. We then gradually add in other business features, that is, asymmetric information on suppliers' quality improvement effort cost and supplier competition, each of which either adds or changes the driving forces of the buyer's choice between QP and QR. We also look at the combined effects of these factors. We also consider both the case where the wholesale price is fixed (when the buyer has the power to dictate prices or price is set by the market) and the case where wholesale price is included as a variable (when price is also part of the negotiation). We analyze how adding wholesale price as a variable affects QR and QP and the comparison of them.

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The rest of the paper is organized as follows. In section 2, we briefly review the related literature. In section 3, we introduce the basic model with single supplier, who can make quality efforts. At the end of this section, we briefly discuss the case when both the supplier and the buyer can make quality efforts. In section 4, we add information asymmetry to the basic model. In section 5, we add supplier competition to the basic model, but without information asymmetry. In section 6, we consider the hybrid model with both information asymmetry and supplier competition. In section 7, we consider the extension where wholesale price is included as another negotiation variable between the players. We conclude the paper in section 8 with a summary of managerial insights obtained from the analysis.

2. Literature Review

This work is related to three areas of literature: first-mover advantage, quality-based supplier selection, and quality improvement. In the following, we review the literature in these three areas.

The issue of first-mover advantage has been mainly studied in economics and marketing literature where the first mover is modelled as the leader in a Stackelberg game, for example, Gal-Or (1985), Dowrick (1986), Choi (1991), Kerin et al. (1992), and Kopel and Löffler (2008). However, our model and our perspective *on quality and quality improvement* decisions is very different from these models that are mostly focused *on price and/or quantity* decisions: (1) Not only the decisions are different, but decision structure is also different: In our model, when the first-mover right is switched between the supplier(s) and the buyer, the penalty cost sharing decision (one of the main contracting decisions) and the wholesale price decision (when it is a variable) are also switched between the players, while in the models in the economic and marketing literature, players' decisions do not switch; (2) we also analyze the impact of information asymmetry on the first-mover advantage, which was not considered in models in the economics and marketing literature; and (3) players' participation constraints, which make significant impact on their decisions are included in our model but are not in the economic and marketing literature. These differences lead to significantly different results of the first-mover advantage. Specifically, while the literature in economics and marketing concludes that whether there is first-mover advantage depends on the slopes of firms' reaction functions, we find the primary driver of the first-mover advantage is related to who makes quality improvement and who is more efficient in making quality improvement (which cannot be expressed through the slopes of firms' reaction functions). Furthermore, information asymmetry and supplier competition each bring about complicated driving forces as detailed in the paper. We believe our analysis of the first-mover advantage in quality contracting enriches the literature in first-mover advantage and contributes new managerial insights on quality contracting as well.

This study mainly considers quality-based sourcing/supplier selection. Literature in this area can be divided into two categories. The first category deals with one supplier and one buyer, hence does not involve quality competition. For example, Reyniers and Tapiero (1995) study the impact of price rebates and warranty costs on supplier's quality choice. Lim (2001) extends Reyniers and Tapiero (1995) by considering asymmetric quality information and the manufacturer's design of inspection and warranty policies in the contract to screen the supplier's private quality information. Baiman et al. (2000) study the contracting based on available quality information. Atasu and Souza (2013) study the impact of product recovery on a firm's product quality choice. The other category deals with quality competition among suppliers, for example, Tagaras and Lee (1996), Li (1992), Ha and Li (2003), Cachon and Zhang (2006), Benjaafar et al. (2007). Most of this literature does not consider quality improvement and none of them deals with first-mover advantage. Our study considers both single-supplier and supplier-competition cases in the presence of quality improvement and our focus is on the first-mover advantage.

Although there has been lots of operations literature on quality, much less considers the potential of quality improvement although it is one of the unique features of quality issues. In the literature that does model quality improvement, most defines quality as non-conforming rate or defective rate, the most widely used quality measure. One stream of this work follows the classic paper of Porteus (1986), which specifically models the production batch process to obtain quality (the non-conforming rate) and quality-related costs. For example, Lee and Rosenblatt (1987), Porteus (1990), Lee (1992), and Zhu et al. (2007) all take this approach to study various quality issues. Similar to this literature, we consider conforming rate as the quality measure but use general functions for quality improvement cost, like in Starbird (1997), Chao et al. (2009), Dai et al. (2012), and Hsiao and Chen (2012), in order to obtain insights of strategies QP and QR which do not rely on specific function forms. We do, however, provide a special case in Appendix S1 where we follow Porteus (1986) to obtain specific functions for conforming rate and quality-related costs through modeling of the production processes. This special case allows us to generate more detailed results presentable in figure forms for

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products that can be modeled with the specific functions of the production processes. Compared to the literature that considers quality improvement (all cited above), we study both supplier competition and information asymmetry, which were not considered in the literature (Chao et al. 2009 considered information asymmetry but not supplier competition). Our perspective of first-mover advantage in quality contracting is unique.

To summarize, in this study, we investigate (1) how the two different strategies (QR and QP) affect players' quality improvement efforts and buyer's profit; (2) whether keeping the first-mover right (QR) is always beneficial to the buyer and conditions under which either strategy is more beneficial; and (3) the key drivers of the buyer's choice between QR and QP under different business features, for example, information asymmetry and/or supplier competition. We believe this paper not only addresses a pertinent question in practice, but also enriches the limited literature on quality competition with the consideration of quality improvement and asymmetric information. Its perspective on the first-mover advantage in quality contracting is unique and provide important managerial insights.

3. Basic Model With Single Supplier

In the basic model, we consider one buyer (she) who places an order D at a wholesale price w from a supplier (he) who then sells the products to market at price r. Given the big pressure on low prices, we assume w and r are fixed. This model setup is similar to Reyniers and Tapiero (1995), Lim (2001), Benjaafar et al. (2007), etc. In section 7, we relax w to be an additional decision variable in the contract to capture the case when firms use both quality and wholesale price as tools for negotiation.

Define quality as the supplier's conforming rate, that is, the proportion of units that satisfy product specifications, the widely used quality measure. Given the many production uncertainties, supplier's conforming rate of the produced units is a random variable. Thus, quality q is defined as the supplier's *average* conforming rate, which can be improved by the supplier with an associated cost. Specifically, let the supplier's initial quality be q_0 which is common knowledge to both parties. In attracting the buyer, supplier may improve quality to q, with an associated cost of $C(q) - C(q_0)$, where $C(q_0)$ is normalized to 0. Therefore, supplier's cost to improve product quality from q_0 to q is $C(q)$. We assume $C(q)$ is convex increasing in q, as commonly used in the literature, for example, Banker et al. (1998), Benjaafar et al. (2007), and Zhu et al. (2007). The supplier's improved quality q may not be observable to the buyer, but the buyer may verify it with a fixed cost of K^1, if needed. Similar assumptions of verification and fixed verification cost were also used in much operations literature, for example, Wan and Beil (2009), and Nikoofal and Gumus (2014). Assume each defective product is found from usage and returned, which incurs a penalty cost s. The expected quality penalty cost for the demand D is given by $sD(1 - q)$. Let λ represent the proportion of quality penalty cost the supplier shares, specified in the contract.

To focus on quality and quality-related costs, we omit other costs (e.g., production cost), which are constant values and do not have impacts on the analytical results. Based on the above notations, we can write the system profit, Ψ, the supplier's profit π, and the buyer's profit Π as follows,

$$\Psi = Dr - sD(1 - q) - C(q),$$
$$\pi = Dw - \lambda sD(1 - q) - C(q),$$
$$\Pi = D(r - w) - (1 - \lambda)sD(1 - q).$$

If buyer verifies supplier's improved quality q, she needs to pay the associated cost K, that is, the buyer's cost is then $\Pi = D(r - w) - (1-\lambda)sD(1-q) - K$. Since $C(q)$ is convex increasing in q, both Ψ and π are concave in q. We assume that buyer (supplier) has a bottom-line profit $(\underline{\pi})$, that is, buyer (supplier) will participate only if she (he) obtains a profit no lower than $(\underline{\pi})$.

Next, we formally introduce the two quality contracting strategies considered by the *buyer:*

- Under the *quality requirement* strategy (QR), buyer is the first-mover. Buyer offers supplier the quality penalty cost sharing plan, λ. Then, supplier decides whether to accept the contract or not and if yes, he also offers his quality improvement plan $q \geq q_0$ (i.e., to what level he will improve his quality, $q = q_0$ if he decides not to make further improvement). Supplier will accept the buyer's offer if his profit is at least his bottom-line $\underline{\pi}$.
- Under the *quality promise* strategy (QP), buyer gives up the first-mover right to the supplier. Buyer invites the supplier to offer the penalty cost sharing plan λ and his quality improvement plan, q, only conveying expectation of her bottom-line profit, $\underline{\Pi}$. Buyer then accepts the supplier's offer if her profit is at least her bottom-line $\underline{\Pi}$.

As will be shown, under QR, since buyer controls supplier's quality improvement decision by his proposal of the penalty sharing proportion, λ, there is no need to verify supplier's quality level, q. On the other hand, under QP, buyer needs to verify supplier's improved quality with the fixed cost K. This is an

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advantage of QR over QP. In addition, notice that at the time when buyer makes a requirement of λ under QR or decides whether to accept the supplier's offer of λ under QP, the actual penalty cost has not been realized yet. Thus, buyer makes her decisions according to the *expected* penalty cost $sD(1-q)$ which depends on the supplier's improved quality, q, that is, the *average* conforming rate, instead of the random conforming rate.

Next, we first analyze the first-best solution in the centralized system, which serves as a benchmark. We then investigate the decentralized system of the basic model under the two different strategies (QR and QP) and then compare them.

3.1. Centralized System

In the centralized system, there is only one decision, the quality improvement plan, q, and the objective is to maximize the system profit. Define $\hat{q}$ as the $q \geq q_0$ which solves $\frac{d\Psi}{dq} = sD - C'(q) = 0$; $\hat{q} = q_0$ if no such solution exists. We know $\hat{q}$ is well-defined since Ψ is concave in q.

Proposition 1. *q^c exists and is unique. Specifically, when $q_0 < \hat{q}$, supplier improves quality to $q^c = \hat{q}$; Otherwise, no quality improvement is necessary, that is, $q^c = q_0$.*

All proofs are in the Appendix. Proposition 1 shows that quality improvement is beneficial only when the initial quality level q_0 is sufficiently low. The optimal solution is to improve quality to a threshold $\hat{q}$ to ensure every unit of quality improvement effort is beneficial. In addition, since $\hat{q}$ solves $C'(q) = sD$, $\hat{q}$ is higher when $C'(q)$ is lower, that is, supplier is more likely to exert quality effort and will exert more effort if he is more efficient in quality improvement.

Denote buyer's *first-best* profit as $V^c = \Psi^c - \underline{\pi}$. This is also the maximal profit buyer can possibly obtain in a decentralized system by maximizing system profit and pushing the supplier's profit to his bottom-line $\underline{\pi}$.

3.2. Decentralized System Under QR

In the decentralized system when buyer takes the requirement strategy (QR), buyer first announces the penalty cost sharing plan, λ, as a tool to induce the supplier to exert sufficient quality effort. Then the supplier decides the quality improvement plan, q, and accepts the buyer's offer only if his profit is at least his bottom-line $\underline{\pi}$.

Given the buyer's decision, λ, supplier's profit, $\pi^R(q|\lambda)$, can be written as

$$\pi^R(q|\lambda) = Dw - \lambda sD(1-q) - C(q).$$

Maximizing the supplier's profit, we obtain the supplier's best response to the buyer's offer, $q^{R*}(\lambda)$. Since buyer can use λ to control supplier's incentive for quality improvement, she does not need to verify supplier's quality. Anticipating supplier's best response, buyer's profit, $\Pi^R(\lambda)$ can be written as follows,

$$\Pi^R(\lambda) = D(r - w) - (1-\lambda)sD(1 - q^{R*}(\lambda)).$$

Buyer's objective is to maximize her own profit $\Pi^R(\lambda)$ while ensuring the supplier's participation, that is, buyer solves the optimal decision λ^{R*} based on the following optimization problem:

$$\begin{aligned} &\max_{\lambda} \Pi^R(\lambda) \\ &s.t.\ q^{R*}(\lambda) = Argmax\,\pi^R(q|\lambda), \\ &\pi^R(q^{R*}(\lambda)|\lambda) \geq \underline{\pi}. \end{aligned} \tag{1}$$

To avoid trivial solution, we assume $\underline{\pi} \geq Dw - sD(1-q^c) - C(q^c)$. Otherwise buyer can simply require supplier to bear all penalty cost, that is, $\lambda = 1$.

Similar to the centralized system, define $\hat{q}^R(\lambda)$ as the *threshold* of q under QR, which solves $\frac{d\pi^R(q|\lambda)}{dq} = \lambda sD - C'(q) = 0$; let $\hat{q}^R(\lambda) = q_0$ if there is no solution. Buyer's optimal choice of λ^{R*} is to squeeze the supplier's profit to his bottom-line, that is, λ^{R*} solves $\pi^R(q^{R*}(\lambda)|\lambda) = \underline{\pi}$. To find the supplier's decision on quality improvement, it is sufficient to look at $\hat{q}^R(\lambda^{R*})$ (refer to Appendix S3 for more details). Denote the buyer's maximal profit under QR as Π^{R*}, obtained under the equilibrium solution to problem (1).

Proposition 2. *Under QR, $\hat{q}^R(\lambda^{R*}) \leq \hat{q}$ and a unique equilibrium solution $\{\lambda^{R*}, q^{R*}\}$ exists. Specifically, if $q_0 < \hat{q}^R(\lambda^{R*})$, supplier will improve the quality to $q^{R*} = \hat{q}^R(\lambda^{R*})$; Otherwise, supplier will not make any quality improvement, that is, $q^{R*} = q_0$. In either case, $q^{R*} \leq q^c$ and buyer will require a penalty cost sharing plan λ^{R*} that solves $\pi(q^{R*}|\lambda) = \underline{\pi}$. In addition, $\Pi^{R*} \leq V^c$.*

Proposition 2 indicates that in the decentralized system under QR, similar to the centralized system, supplier makes quality improvement only if the initial quality q_0 is sufficiently low (i.e., $q_0 < \hat{q}^R(\lambda^{R*})$). However, differently, since under QR, supplier (the second mover), only responds to the buyer's required penalty cost sharing λ, he only shares partial penalty cost. This limits his incentive for quality improvement and results in a lower optimal quality level compared to that in the centralized system (i.e., $\hat{q}^R(\lambda^{R*}) \leq \hat{q}$). Thus, supplier is less likely to make quality efforts and also make less efforts even if he does ($q^{R*} \leq q^c$). As a result,

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buyer cannot obtain the *first-best* profit, that is, $\Pi^{R*} \leq V^c$.

3.3. Decentralized System Under QP

In the decentralized system when buyer takes QP strategy, supplier first promises to the buyer his penalty cost sharing plan and his quality improvement plan $\{\lambda, q\}$. Buyer, who will later verify supplier's improved quality, accepts supplier's offer only if her profit is at least her bottom-line . Hence, given supplier's decisions $\{\lambda, q\}$, his profit is $\pi^P(q,\lambda) = Dw - \lambda sD(1-q) - C(q)$, and buyer's profit is $\Pi^P = D(r-w) - (1-\lambda)sD(1-q) - K$.

Supplier solves his optimal decisions $\{\lambda^{P*}, q^{P*}\}$ based on the following optimization problem

$$\begin{aligned} &\max_{\{q,\lambda\}} \pi^P(q,\lambda) \\ &s.t.\ \Pi^P \geq \underline{\Pi}. \end{aligned} \tag{2}$$

To avoid trivial cases again, we assume $\underline{\Pi} \geq D(r-w) - sD(1-q^c) - K$. Otherwise the supplier can simply push the buyer to bear all penalty cost, that is, $\lambda = 0$. Based on the solution to (2), we know that buyer will obtain her bottom-line profit $\underline{\Pi}$. Therefore, the higher is, the higher profit buyer can obtain, as long as that leaves the supplier a profit no lower than his bottom-line, $\underline{\pi}$. Let Π^{P*} denote the highest profit buyer can obtain under QP. We know that is obtained when supplier obtains $\underline{\pi}$ only.

Similar to QR, define the quality threshold under QP as $\hat{q}^P(\lambda^*(q))$ which solves $\frac{d\pi^R(q,\lambda^*(q))}{dq} = 0$ (if there is no solution, let $\hat{q}^P(\lambda^*(q)) = q_0$). $\lambda^*(q)$ denotes the supplier's optimal choice of penalty cost sharing plan, solved from problem (2) given the supplier's quality improvement decision q. The following proposition presents the equilibrium solution.

Proposition 3. *Under QP, $\hat{q}^P(\lambda^*(q)) = \hat{q}$ and a unique equilibrium solution $\{\lambda^{P*}, q^{P*}\}$ exists. Specifically, $q^{P*} = q^c$ and λ^{P*} solves $\Pi^P = \underline{\Pi}$. Further, $\Pi^{P*} = V^c - K$.*

Proposition 3 indicates that under QP, the equilibrium quality level is the same as that under the centralized system, that is, supplier has the full incentive to improve quality to the first-best level! This is because as the first mover, supplier's optimal strategy is to maximize system profit (by improving quality), and then give the buyer her bottom-line profit. By conveying a higher expectation of bottom-line profit, buyer can obtain a higher profit. Thus, buyer's highest profit under QP is $\Pi^{P*} = V^c - K$ (the first-best profit less the quality verification cost), obtained when the system profit is maximized and buyer provides a bottom-line profit that leaves the supplier with $\underline{\pi}$ only. In short, a higher system profit allows buyer to achieve a higher profit as well.

3.4. Which Strategy to Choose: QR or QP?

In this section, we compare QR and QP to find out (1) which strategy better stimulates the supplier to improve quality and (2) driver(s) of the buyer's choice between QR and QP, given that buyer makes her choice based on her expected profit. The following analytical result directly follows the analysis in sections 2 and 3.

Corollary 1. *Comparing QR and QP:*

- *In terms of the quality improvement effort, supplier is more likely to exert quality improvement effort under QP and $q^{P*} = q^c \geq q^{R*}$.*
- *In terms of buyer's profit, buyer prefers QR if $K \geq V^c - \Pi^{R*}$ and QP otherwise.*

From the analysis in the previous sections, we see that while QR limits the supplier's efforts in quality improvement, QP gives the supplier the same incentive for quality improvement as in the centralized system. Why is this and what essentially makes the difference? The importance of the first-mover right is that the first mover has the opportunity to obtain the highest profit for himself/herself. This means two things: to maximize the system profit (the whole pie) and to push the other player to his/her bottom-line profit. The way to maximize the whole pie in our context is to increase the quality. Therefore, if the first mover is also the one who makes quality improvement (i.e., QP), quality will be improved to first-best level. On the other hand, under QR, since buyer can only induce supplier to make quality improvement through the proportion of penalty cost sharing, supplier does not have the incentive to improve quality to first-best. This reveals the primary driver in the buyer's choice between QR and QP: give first-mover right to the quality improving party, which leads to higher system profit and hence higher profit for the buyer. This shows an advantage of QP over QR. On the other hand, compared to QR, where buyer controls the supplier's incentive for quality improvement effort through requiring the penalty cost sharing plan λ, under QP, buyer loses direct control of quality and has to pay K to verify supplier's quality improvement efforts. The second bullet of Proposition 1 gives the tradeoff between the primary driver and the cost of verification.

Above, we see that the primary driver for the buyer's choice between QR and QP is who makes quality improvement. When supplier is the party making quality improvement (the main case we study in this paper), giving up the first-mover right to the supplier (QP) can potentially provide the buyer more benefits if the quality verification cost is not too high. When conducting similar analysis, we find similar results hold when only buyer herself can make quality improvement and when both parties can improve quality (dual-effort): the primary driver of the buyer's choice between QR and QP is who improves quality in the single-effort scenario and who is more efficient in quality improvement in the dual-effort scenario. Considering also the required quality verification cost, the following proposition summarizes the results:

Proposition 4. *In the model consisting of one supplier and one buyer:*

- *if the supplier improves quality alone (single-effort) or if the supplier is more efficient (dual-effort), then when $K \geq V^c - \Pi^{R*}$, QR is preferred; otherwise, QP is preferred.*
- *if the buyer improves quality alone (single-effort) or if the buyer is more efficient (dual-effort), then QR is always preferred.*

For easy of exposition, in the rest of the paper, we still focus on the case when only supplier can improve quality.

4. Basic Model with Asymmetric Information

In the previous section, we have found that the primary driver of the buyer's choice between QR and QP is who can make quality efforts and/or the efficiency in doing so. However, in reality, players' efficiency in quality improvement is often their private information. Therefore, in this section, we consider the basic model with information asymmetry where the supplier's quality improvement efficiency is his private information. We investigate how information asymmetry affects the buyer's choice between QR and QP.

Let supplier's cost for improving quality to q be either high or low ($C_H(q)$ or $C_L(q)$). Accordingly, define the supplier to be low-cost type (or L-type, i.e., more efficient) when he pays a lower cost for the same amount of quality improvement, for example, from q_1 to $q_2 > q_1$, that is, $C_L(q_2) - C_L(q_1) < C_H(q_2) - C_H(q_1)$. While supplier knows his type, buyer only has a prior estimation that the supplier has a probability of p to be H-type and a probability of $1-p$ to be L-type. The assumption that the information is of two types is widely used in the extant literature in analyzing systems with asymmetric information (e.g., Baiman et al 2000, Chao et al. 2009, Lim 2001). Similar but more involved analysis can be extended to n levels.

Naturally, as the less-informed party, the buyer's profit will be hurt by information asymmetry. However, it is not clear which strategy (QR or QP) may lead to a lower loss in the buyer's profit.

Similar to the basic model (section 3), we start from the centralized system where there is no information asymmetry. According to the supplier's two improvement cost types, we have two sets of the first-best solutions: q_H^c and q_L^c, respectively. Denote the buyer's *first-best* profits under the two types as V_H^c and V_L^c, respectively. Since the L-type supplier pays less effort cost, he can improve quality to a higher level with the same cost which results in a higher *first-best* profit, that is, $q_H^c < q_L^c$ and $V_H^c < V_L^c$. Define the buyer's *first-best expected* profit as $\tilde{V}^c = pV_H^c + (1-p)V_L^c$ under information asymmetry. We use $\tilde{}$ to indicate the scenario with asymmetric information.

4.1. Decentralized System Under QR – A Screening Game

Under QR, since supplier has private information of his own cost type, buyer would expect to infer more information regarding his cost type from the supplier's actions. In fact, buyer may want to use a menu of penalty cost sharing plans $\{\lambda_T, T = H, L\}$ to screen the supplier's cost type based on the supplier's response. However, if the cost of screening the true information is too high, the buyer may choose not to screen the information (by offering a single plan $\lambda_H = \lambda_L = \lambda$). For the rest of the paper, we use T to indicate the supplier's type when it is a random variable, and t as his true type, which is only known to the supplier himself.

Given the buyer's offer, $\{\lambda_T, T = H, L\}$, the t-type supplier's profit when he chooses the offer intended for a type-T supplier (λ_T), $\tilde{\pi}_t^R(q|\lambda_T)$, can be written as

$$\tilde{\pi}_t^R(q|\lambda_T) = Dw - \lambda_T sD(1-q) - C_t(q).$$

The t-type supplier solves his best response to the buyer's offer, $\tilde{q}_t^{R*}(\lambda_T)$, to maximize his profit $\tilde{\pi}_t^R(q|\lambda_T)$. For brevity, we denote $\tilde{\pi}_t^{R*}(T)$ as the supplier's optimal profit when he is a t-type but has taken a contract intended for a T-type. Accordingly, anticipating the supplier's best response, the buyer's profit, $\tilde{\Pi}_t^R(T)$, is given as follows,

$$\tilde{\Pi}_t^R(T) = D(r-w) - (1-\lambda_T)sD\big(1-\tilde{q}_t^{R*}(\lambda_T)\big).$$

Finally, the buyer will design her menu by making sure she can screen the true cost types, that is, a T-type supplier will only choose the contract intended for a T-type supplier. Hence, she solves the following optimization problem for her decision $\{\tilde{\lambda}_T^{R*}, T = H, L\}$ to maximize her expected profit

$E[\tilde{\Pi}_T^R(T)]$ with the incentive compatibility constraints:

$$\begin{aligned} &Max_{\{\lambda_H,\lambda_L\}} E[\tilde{\Pi}_T^R(T)] \\ &s.t.\ \tilde{q}_t^{R*}(\lambda_T) = Argmax \tilde{\pi}_t^R(q|\lambda_T), \\ &\tilde{\pi}_T^{R*}(T) \geq \underline{\pi}, T = H, L, \\ &\tilde{\pi}_H^{R*}(H) \geq \tilde{\pi}_H^{R*}(L), \\ &\tilde{\pi}_L^{R*}(L) \geq \tilde{\pi}_L^{R*}(H). \end{aligned} \tag{3}$$

The last two constraints are the incentive compatibility constraints, which ensure the supplier chooses the cost sharing plan according to his true type.

Denote the buyer's optimal expected profit obtained from problem (3) as $\tilde{\Pi}^{R*}$. Also denote λ_T^{R*}, Π_T^{R*}, and q_T^{R*} as buyer's optimal cost sharing proportion, buyer's optimal profit, and supplier's optimal quality improvement plan for a T-type supplier, respectively, which are solved from problem (1) in the basic model when the supplier is T-type. Denote $\tilde{\Pi}_L^{R*}(H)$ as the buyer's profit when the L-type supplier accepts the H-type cost sharing plan λ_H^{R*}. The following theorem presents the results.

PROPOSITION 5. *Under QR with information asymmetry, there exists a unique equilibrium solution,* $\{\tilde{\lambda}_t^{R*}, \tilde{q}_t^{R*}, t = H, L\}$. *Specifically,*

- $\tilde{\lambda}_t^{R*} = \lambda_H^{R*}, t = H, L.$
- $\tilde{q}_H^{R*} = q_H^{R*}$ *and* $\tilde{q}_L^{R*} = Argmax_q \tilde{\pi}_L^R(q|\lambda_H^{R*})$.
- $\tilde{\Pi}^{R*} = p\Pi_H^{R*} + (1-p)\tilde{\Pi}_L^{R*}(H) < p\Pi_H^{R*} + (1-p)\Pi_L^{R*} \leq \tilde{V}^c$.

Proposition 5 indicates that with information asymmetry, the buyer's optimal strategy is to not screen the supplier's types and offer a single cost sharing plan λ_H^{R*} (bullet 1). This is because when buyer offers multiple λ, the supplier will always choose the lowest one. Thus, to ensure participation from supplier of either type, she can only require the optimal λ intended for the H-type supplier (λ_H^{R*}), which is lower than that for the L-type supplier, that is, $\lambda_H^{R*} < \lambda_L^{R*}$. This causes an extra loss in the buyer's profit due to information asymmetry: the buyer's expected profit with information asymmetry is less than what she can obtain with common knowledge, which is already less than the first-best expected profit (the last bullet of Proposition 5).

4.2. Decentralized System Under QP – A Signalling Game

Under QP, the supplier of either type, t, announces his optimal offer $\{\lambda_t, q_t\}$. Since supplier knows his type, t, the buyer expects to infer more information about the supplier's cost type from his offer. In other words, by viewing supplier's offer, $\{\lambda_t, q_t\}$, buyer expects to update her belief of the supplier's cost type. Hence, under asymmetric information, QP is analyzed as a signalling game.

Define $\tilde{p}(\lambda_t, q_t)$ as the buyer's updated belief of the probability that the supplier is H-type after she observes his offer, $\{\lambda_t, q_t\}$. This updated belief $\tilde{p}$ must be consistent with the supplier's equilibrium decisions. Specifically, If the supplier makes different offers when he is H-type and L-type, that is, $\{\lambda_L, q_L\} \neq \{\lambda_H, q_H\}$, then by observing what the supplier offers, the buyer is able to infer the supplier's cost type. Hence, we must have $\tilde{p} = 1$ when the buyer observes $\{\lambda_H, q_H\}$ and $\tilde{p} = 0$ otherwise. This is referred to as a separating equilibrium. If, however, the supplier makes the same offers regardless of his quality improvement cost type, that is, $\{\lambda_L, q_L\} = \{\lambda_H, q_H\}$, then the buyer cannot infer any information from his offer about his type. In this case, consistency calls for no change in the buyer's belief in the supplier's cost type, that is, $\tilde{p} = p$. This is referred to as a pooling equilibrium. A belief structure that is consistent is referred to as an equilibrium belief. The equilibrium of the signaling game consists of the supplier's offer $\{\lambda_t, q_t, t = H, L\}$ and the equilibrium belief in the suppliers' cost types. To read more on pooling and separating equilibrium, refer to Kreps (1990), Fudenburg and Tirole (1992), and Chen (2003).

Given t-type supplier's offer $\{\lambda_t, q_t\}$, buyer's profit is given by $\tilde{\Pi}^P(t) = D(r-w) - (1-\lambda_t) \times sD(1-q_t) - K$. The t-type supplier's profit is $\tilde{\pi}^P(\lambda_t, q_t) = Dw - \lambda_t sD(1-q_t) - C_t(q_t)$. The supplier aims to solve his optimal decision $\{\tilde{\lambda}_t^{P*}, \tilde{q}_t^{P*}, t = H, L\}$ for each cost type from the following optimization problem:

$$\begin{aligned} &\max_{\{\lambda_t, q_t\}} \tilde{\pi}^P(\lambda_t, q_t) \\ &s.t.\ \tilde{\Pi}^P(t) \geq \underline{\Pi}. \end{aligned} \tag{4}$$

Define the buyer's optimal expected profit as $\tilde{\Pi}^{P*} \triangleq p\tilde{\Pi}^{P*}(H) + (1-p)\tilde{\Pi}^{P*}(L)$, where $\tilde{\Pi}^{P*}(t)$ indicates buyer's profit under t-type supplier's optimal decision $\{\tilde{\lambda}_t^{P*}, \tilde{q}_t^{P*}\}$ which is solved from problem (4).

PROPOSITION 6. *Under QP with information asymmetry, there exists a unique separating equilibrium solution* $\{\tilde{\lambda}_t^{P*}, \tilde{q}_t^{P*}\}$. *Specifically,* $\tilde{q}_t^{P*} = q_t^c$ *and* $\tilde{\lambda}_t^{P*}$ *solves* $\tilde{\Pi}^P(t) = \underline{\Pi}$, $\forall t = H, L$. *Further,* $\tilde{\Pi}^{P*} = V_H^c - K < \tilde{V}^c - K$.

Proposition 6 indicates that a separating equilibrium exists and under this equilibrium, similar to the common knowledge case, supplier of each cost type still has full incentive to improve quality to the first-best level even under asymmetric information. However, to ensure participation, there is a loss in the

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buyer's expected profit due to information asymmetry: her highest expected profit is bounded by the optimal profit obtained from a high-cost type (H-type) supplier, $V_H^c - K$, which is lower than that from a L-type supplier.

4.3 Which Strategy to Choose: QR or QP?

From the analysis in the previous sections, we already know that with information asymmetry, buyer cannot screen supplier's cost types under QR, but can infer this information under QP (because of the separating equilibrium). So, from information acquisition point of view, QP is better. Next, we compare QR and QP to see which strategy encourages more quality improvement effort and is better for the buyer from the expected profit perspective.

COROLLARY 2. *Comparing QR and QP with information asymmetry:*

- *In terms of the quality improvement effort, the supplier is more likely to exert quality improvement under QP and* $\tilde{q}_t^{P*} = q_t^c > \tilde{q}_t^{R*}$.
- *In terms of the buyer's profit, buyer prefers QR if* $(1-p)\big(\tilde{\Pi}_L^{R*}(H) - (V_H^c - K)\big) \geq p(V_H^c - K - \Pi_H^{R*})$, *QP otherwise.*

The above corollary shows that under information asymmetry, the primary driver is still in effect: QP still better motivates the supplier for quality improvement. However, information asymmetry works in the opposite direction from the primary driver: Although buyer may acquire supplier's information under QP (but not under QR), the loss due to information asymmetry under QP is larger than that under QR. This is because under QP, the buyer's highest profit is always restricted by the *first-best* profit obtained from a H-type supplier less the verification cost, that is, $\tilde{\Pi}^{P*} = V_H^c - K$ (Proposition 6). Therefore, the L-type supplier's higher efficiency does not benefit the buyer at all. On the other hand, under QR, although the buyer can only require λ_H^{R*} (in order to ensure participation from both types of supplier), when the supplier is a L-type, buyer still benefits from the higher improved quality resulted from the supplier's higher efficiency. This leads to a profit higher than what she can obtain from the H-type supplier under QR with common knowledge, that is, $\tilde{\Pi}_L^{R*}(H) > \Pi_H^{R*}$. This profit may be even higher than the *first-best* profit obtained from a H-type supplier, that is, $\tilde{\Pi}_L^{R*}(H) > V_H^c$.

Hence, the final conclusion of which strategy brings higher expected profit for the buyer depends on the combination of these two forces, captured in the condition (5) $(1-p)\big(\tilde{\Pi}_L^{R*}(H) - (V_H^c - K)\big) \geq p(V_H^c - K - \Pi_H^{R*})$ in Corollary 2. The left hand side represents the expected saving in the loss under QR due to information asymmetry, which equals the savings (the buyer's maximal profit obtained under QR, $\tilde{\Pi}_L^{R*}(H)$, less her highest profit under QP, $V_H^c - K$) multiplied by the probability when these savings happen (i.e., when the supplier is L-type). The right hand side is the buyer's expected benefit obtained under QP due to the primary driver (which equals the buyer's highest profit obtained from the H-type supplier under QP, $V_H^c - K$, less her maximal profit under QR, Π_H^{R*}) multiplied by the probability when this happens (i.e., when the supplier is H-type). So, when the expected saving in loss under QR (due to information asymmetry) is higher than the expected benefit under QP (due to the primary driver), QR is preferred; Otherwise, QP is preferred.

5. Basic Model with Supplier Competition

In section 4, we analyzed how the driving forces in buyer's choice between QR and QP change when there is asymmetric information between the supplier and the buyer. In this section, we consider how another business feature—supplier competition—can change/add the drivers of such decision. In this case, competition forces the suppliers to provide the *best affordable* offer to the buyer. To separate the effect of asymmetric information, we consider supplier competition with common knowledge in this section and will combine with the impact of asymmetric information to analyze their interactions in the next section.

All cost parameters remain the same. Two suppliers, denoted as i, i = 1, 2, compete for the demand D. The two suppliers have the same initial quality level q_0 but may be different in quality improvement cost efficiencies. Denote supplier i's cost of quality improvement as $C_i(q_i)$, if supplier i improves his quality to q_i. For simple exposition, we assume that both suppliers' have the same bottom-line profits ($\underline{\pi}$). Similar results can be derived in the case where the two suppliers' bottom-line profits are different.

Note that in the decentralized system, each supplier deals with the buyer separately, anticipating what the other supplier will do. Hence, the corresponding benchmark is the centralized system consisting of the buyer and one supplier, which is already analyzed in section 1. However, since the two suppliers may have different quality improvement costs, there are two centralized systems, each corresponding to a supplier. Denote the first-best system profit and buyer's profit with supplier i as Ψ_i^c and $V_i^c = \Psi_i^c - \underline{\pi}$, respectively. Comparing the *first-best* profits obtained from the two suppliers, buyer's potential maximal profit is $\bar{V}^c = \max\{V_i^c, i = 1, 2\}$. We use $^-$ to indicate the

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scenario with supplier competition. It is easy to see that the buyer can obtain a higher potential profit from the more efficient supplier.

5.1. Decentralized System Under QR

Under QR, the buyer first offers the penalty cost sharing plan λ_i to each supplier i. Each supplier i then decides his quality improvement plan q_i and whether to accept the offer, based on which the buyer selects a supplier.

Denote supplier i's profit as $\bar{\pi}_i^R(q_i|\lambda_i)$ if he is selected and buyer's corresponding profit as $\bar{\Pi}^R(\lambda_i)$. These profit functions are the same as those in the basic model. The equilibrium solution is denoted as $\{\bar{\lambda}_i^{R*}, \bar{q}_i^{R*}, i = 1, 2\}$. The buyer chooses the supplier who can give her a higher profit. Hence, the buyer's optimal profit is $\bar{\Pi}^{R*} = \max\{\bar{\Pi}^R(\bar{\lambda}_i^{R*}), i = 1, 2\}$. Using λ_i^{R*}, q_i^{R*} and Π_i^{R*} to denote the equilibrium solution and the buyer's corresponding optimal profit with supplier i in the basic model (obtained in section 2), the following proposition summarizes the results.

PROPOSITION 7. *Under QR with supplier competition, there exists a unique equilibrium solution* $\{\bar{\lambda}_i^{R*}, \bar{q}_i^{R*}, i = 1, 2\}$. *Specifically,* $\bar{\lambda}_i^{R*} = \lambda_i^{R*}$ *and* $\bar{q}_i^{R*} = q_i^{R*}$. *The buyer's optimal profit* $\bar{\Pi}^{R*} = \max\{\Pi_i^{R*}, i = 1, 2\}$. *Buyer chooses the more efficient supplier in quality improvement, say i, and* $\bar{\Pi}^{R*} = \Pi_i^{R*} \leq V_i^c = \bar{V}^c$.

Proposition 7 indicates that supplier competition under common knowledge does not impact each player's decision or the buyer's optimal profit under QR. The equilibrium solution for each supplier i is the same as that in the basic model. Based on each supplier's cost type, buyer requires the same λ as in the basic model and each supplier responds with the same quality improvement plan according to his cost type. The buyer chooses the more efficient supplier, say i, and obtains a profit Π_i^{R*} that is lower than the buyer's *first-best* profit V_i^c with supplier i since QR limits the supplier's quality improvement incentives as we discussed.

5.2. Decentralized System Under QP

Under QP, buyer gives up the first-mover right, expecting suppliers to provide good offers to her due to competition. Specifically, each supplier i announces λ_i and his quality improvement plan q_i, then buyer selects a supplier based on their offers and later verifies the selected supplier's quality improvement plan q_i with an associated cost K. Denote supplier i's profit as $\bar{\pi}_i^P(\lambda_i, q_i)$ if he is selected and the buyer's corresponding profit as $\bar{\Pi}^P(i)$. The buyer's optimal profit is $\bar{\Pi}^{P*} = \max\{\bar{\Pi}^P(i), i = 1, 2\}$ under the equilibrium solution $\{\bar{\lambda}_i^{P*}, \bar{q}_i^{P*}, i = 1, 2\}$.

PROPOSITION 8. *Under QP, there exists a unique equilibrium solution* $\{\bar{\lambda}_i^{P*}, \bar{q}_i^{P*}\}$. *Specifically,* $\bar{q}_i^{P*} = q_i^c$, $\forall i$. *Further, if supplier i is more efficient (hence* $V_i^c \geq V_j^c$*),* $\bar{\lambda}_j^{P*}$ *solves* $\bar{\pi}_j(q_j^c, \bar{\lambda}_j^{P*}) = \underline{\pi}$ *and* $\bar{\lambda}_i^{P*}$ *solves* $\bar{\Pi}^P(i) = V_j^c - K$. *Buyer chooses the more efficient supplier, say i. In that case,* $\bar{\Pi}^{P*} = V_j^c - K \leq V_i^c - K = \bar{V}^c - K$.

From Proposition 8, we see that both suppliers still have full incentives to improve quality to their first-best level, but due to different reasons. For the less efficient supplier, say j, to get a chance to win the competition, he has to give the buyer the best affordable offer. Therefore, he makes his offer to maximize the buyer's profit while only obtaining bottom-line profit ($\underline{\pi}$) himself, a fixed amount. This makes his objective aligned with the system profit. For the more efficient supplier i, however, anticipating the competitor's (supplier j's) offer, he only needs to make an offer ensuring buyer a profit slightly higher than what she would achieve from supplier j. Hence, knowing supplier j's best offer (due to common knowledge), i's objective is to maximize his own profit (by maximizing the system profit and guaranteeing a *fixed* profit for the buyer that is ε higher than the other supplier's best offer), which is also aligned with the system profit.

From the above analysis, we see that different from QR, supplier competition leads to both a benefit and a loss in the buyer's profit under QP. On the one hand, competition forces the less efficient supplier (say j) to provide his best affordable offer, which means the buyer can obtain the *first-best* profit from him less the verification cost, that is, $V_j^c - K$ (a benefit); on the other hand, the more efficient supplier i will not provide his best affordable offer, but an offer slightly better than supplier j's to win the competition. Hence, although the more efficient supplier is chosen, the buyer will only obtain a profit that is ε higher than what she obtains from the less efficient supplier (a loss).

5.3 Which Strategy to Choose: QR or QP?

Based on the analysis, we see that when there is competition, the primary driver in the basic model still exists, that is, suppliers have full incentives for quality improvement under QP, but not under QR. However, supplier competition also provides an opposite driving force: competition leads to a loss under QP: a L-type supplier will only provide an offer that is ε better than the best affordable offer from a H-type supplier. Thus, whether the buyer should choose QR or QP depends on the combination of these two forces. The following corollary presents the results.

COROLLARY 3. *Under supplier competition, without loss of generality, assuming supplier i is more efficient in quality improvement:*

- *In terms of the final quality level, the suppliers are more likely to improve quality under QP and* $\bar{q}_i^{R*} \leq \bar{q}_i^{P*} = q_i^c, \bar{q}_j^{R*} \leq \bar{q}_j^{P*} = q_j^c$.
- *In terms of the buyer's profit, buyer prefers QR when* $\Pi_i^{R*} \geq V_j^c - K$ *and QP otherwise.*

As mentioned before, each supplier has full incentive under QP but not under QR to improve quality to the fist-best level. Hence, the final quality improved by each supplier under QP is always higher than that under QR.

In terms of the buyer's profit, condition $\Pi_i^{R*} \geq V_j^c - K$ means $V_i^c - \Pi_i^{R*} \leq V_i^c - (V_j^c - K)$, which captures the aforementioned two opposite forces under competition. Specifically, the left hand side is the loss under QR due to the primary driver, which equals buyer's *first-best* profit obtained from the more efficient supplier i, V_i^c, less what the buyer obtains from him under QR, Π_i^{R*}. The right hand side is the loss under QP due to competition, which equals the first-best profit obtained from supplier i, V_i^c, less what the buyer obtains from him under QP, $V_j^c - K$. Therefore, buyer chooses QR if and only if the loss is less than that under QP.

Note that the loss under QP depends largely on the difference between the suppliers. So, when the two suppliers are similar in quality improvement efficiency, the additional driver of competition has little negative impact. Hence, QP is likely better for buyer in that case.

6. Hybrid Model with Information Asymmetry and Supplier Competition

In the previous two sections, we separately analyzed the impact of asymmetric information and supplier competition on the buyer's choice between QR and QP. In this section, we analyze their interactions by considering the *hybrid* case where there are both information asymmetry and supplier competition.

We assume each supplier i has a probability of p_i for being a H-type and $1 - p_i$ for being a L-type, which is common knowledge to all players. But only the supplier himself knows his true cost type. p_i may be different for different suppliers, with a higher p_i indicating a higher expected quality improvement cost or lower expected quality improvement efficiency.

Again, the two types of quality improvement costs correspond to two sets of centralized cases. Define the buyer's *first-best expected* profit under the hybrid case as $\bar{\bar{V}}^c$ (Note that $\bar{\bar{\ }}$ indicates the case with both supplier competition and asymmetric information), which equals V_H^c when both suppliers are H-type and equals V_L^c otherwise. Hence, $\bar{\bar{V}}^c = p_1 p_2 V_H^c + (1 - p_1 p_2) V_L^c$.

6.1. Decentralized System Under QR

Recall that in the single-supplier case with information asymmetry, buyer cannot use a menu of cost sharing plans to screen the supplier's cost types under QR. The question is: Can buyer use a menu to screen suppliers' information under supplier competition? We explore this next.

In order to screen suppliers' cost types, let's assume buyer may offer a menu of cost sharing proportions intended for each supplier (i) of different cost types: $\{\lambda_{iT}, T = H, L\}$. Each supplier i of either cost type t decides (1) whether and which contract (cost sharing proportion) in the menu to choose, and (2) potential quality improvement in order to maximize his expected profit. Denote t-type supplier i's profit as $\bar{\bar{\pi}}_{it}^R(q_i|\lambda_{iT})$ when he chooses the contract intended for type T, λ_{iT}. The buyer's profit in this case is $\bar{\bar{\Pi}}_t^R(T)$. Further, denote $\bar{\bar{q}}_{it}^{R*}(\lambda_{iT})$ as t-type supplier i's best response to λ_{iT}. The buyer's optimal expected profit under QR is denoted as $\bar{\bar{\Pi}}^{R*}$.

Recall $\{\lambda_t^{R*}, q_t^{R*}, t = H, L\}$ and Π_t^{R*} are the equilibrium solution and the buyer's optimal profit in the basic model when supplier is t-type. We suppress the subscript i for supplier i since both suppliers have the same equilibrium strategies for each cost type. Similar to the single-supplier model with information asymmetry, we denote $\bar{\bar{\pi}}_t^{R*}(T)$ ($\bar{\bar{\Pi}}_t^{R*}(T)$) as the t-type supplier's (buyer's) optimal profit under the cost sharing plan λ_T^{R*} intended for a T-type supplier. The following theorem demonstrates the buyer's strategy under QR in the hybrid model.

THEOREM 1. *Under QR in the hybrid model:*

- *If condition (5) is satisfied,*

$$\bar{\bar{\pi}}_L^{R*}(H) \leq (1 + \frac{1}{p_i})\underline{\pi}, i = 1, 2, \tag{5}$$

then buyer can use menu $A = \{\lambda_H^{R*}, \lambda_L^{R*}\}$ *to completely screen both suppliers' cost types with no cost, where* $\lambda_T^{R*}, T = H, L$ *correspond to the equilibrium cost sharing proportions in the basic model. In this case, when two suppliers' choices are different, buyer selects the L-type supplier; in case of a tie, buyer randomly chooses a supplier.*

- *If condition (5) is not satisfied, buyer can still use different menus to screen the suppliers' quality improvement cost type, but has to pay a cost (information rent). Specifically, suppose* $p_i \leq p_j$ *(i.e., on average supplier i is more efficient in quality improvement):*

- *If condition (6) is satisfied,*

$$p_i(1-p_j)\Big(\bar{\bar{\Pi}}_L^{R*}(\bar{\bar{\lambda}}_L^R) - \bar{\bar{\Pi}}_L^{R*}(H)\Big) \geq (1-p_i)\Big(\bar{\bar{\Pi}}_L^{R*}(L) - \bar{\bar{\Pi}}_L^{R*}(\bar{\bar{\lambda}}_L^R)\Big), \quad (6)$$

then buyer offers menu $B = \{\lambda_H^{R*}, \bar{\bar{\lambda}}_L^R\}$, *where* $\bar{\bar{\lambda}}_L^R \leq \lambda_L^{R*}$ *solves* $\bar{\bar{\pi}}_{iL}^R(\bar{\bar{q}}_{it}^{R*}(\bar{\bar{\lambda}}_L^R)|\bar{\bar{\lambda}}_L^R) = \frac{p_j}{1+p_j}\bar{\bar{\pi}}_L^{R*}(H)$. *In this case, when two suppliers' choices are different, buyer selects the L-type supplier; in case of a tie, buyer randomly chooses a supplier.*

- *If Equation (6) is not satisfied, then buyer should offer menu A to supplier i and offer a single-contract menu* $C = \{\lambda_H^{R*}\}$ *to supplier j. In this case, buyer selects supplier i if he chooses L-type cost sharing plan and selects supplier j otherwise.*
- *Finally,* $\bar{\bar{\Pi}}^{R*} \leq \bar{\bar{V}}^c$.

Interestingly, buyer can screen the suppliers' cost types without any cost under condition (5). If condition (5) is not satisfied, buyer has to pay information rent when screening the suppliers' types, that is, $\bar{\bar{\Pi}}_L^{R*}(\bar{\bar{\lambda}}_L^R) < \Pi_L^{R*}$. Specifically, when information screening is too expensive (i.e., when *condition* (6) is not satisfied), it is more beneficial for the buyer not to completely but partially screen suppliers' types by offering a two-plan menu to the supplier who is more likely to be a *L*-type (i.e., supplier *i* with $p_i \leq p_j$) and only one plan to the other supplier with no intention to screen his type. This "partial screening" strategy helps the buyer to avoid the exorbitant information screening cost. In addition, condition (5) is more easily satisfied when $\frac{\bar{\bar{\pi}}_L^{R*}(H)}{\underline{\pi}}$ is small (a *L*-type supplier does not gain much by pretending to be a *H*-type) or p_i (i = 1,2) is low (both suppliers' quality improvement costs are more likely to be low), both of which result in more intense competition. Finally, the last bullet of Theorem 1 indicates that even with no information rent, buyer still obtains an expected profit lower than the *first-best expected* profit, since again, QR limits the supplier's incentive for quality improvement.

Compared with the basic model with supplier competition only (where buyer's profit is not impacted), under QR, information asymmetry leads to a potential loss to the buyer (i.e., information rent when condition (5) is not satisfied). On the other hand, compared with the basic model with asymmetric information only (where no screening can be achieved), under QR, supplier competition helps the buyer to screen the suppliers' cost types.

6.2. Decentralized System Under QP

Recall that under QP with asymmetric information but no supplier competition, there is always a separating equilibrium and information asymmetry always leads to a loss to the buyer's profit. In this section, we see how supplier competition may affect the results.

Denote supplier *i*'s offer as $\{\lambda_{it}, q_{it}\}$ when he is *t*-type. We use $\bar{\bar{\pi}}_{it}^P(\lambda_{it}, q_{it})$ and $\bar{\bar{\Pi}}^P(t)$ to denote *t*-type supplier *i*'s profit and the buyer's corresponding profit when she selects *t*-type supplier *i*. Buyer selects the supplier who is more beneficial to her and verifies the selected supplier's improved quality q_{it}.

Let $\bar{\bar{\pi}}_L^{P*}(H)$ be the *L*-type supplier's optimal profit when he chooses not to compete with a *L*-type supplier (hence he makes an offer that only wins if facing a *H*-type competitor who would offer $\{\lambda_H^{P*}, q_H^c\}$, where λ_H^{P*} solves $\bar{\bar{\pi}}_{iH}^P(\lambda_{iH}, q_H^c) = \underline{\pi}$ (see appendix S14 for more details)). Let $\bar{\bar{\Pi}}^{P*}$ be the buyer's optimal expected profit under QP in the hybrid model.

Theorem 2. *Under QP in the hybrid model, there exists a unique separating equilibrium of players' strategy if and only if condition* (7) *is satisfied:*

$$\bar{\bar{\pi}}_L^{P*}(H) \leq \frac{1}{2}(1+\frac{1}{p_i})\underline{\pi}, i = 1,2. \quad (7)$$

At this equilibrium, each supplier makes an offer of $\{\lambda_t^{P*}, q_t^c, t = H, L\}$ *according to his true cost type, where* λ_t^{P*} *solves* $\bar{\bar{\pi}}_{it}^P(\lambda_{it}, q_t^c) = \underline{\pi}$. *Hence, buyer obtains the suppliers' information without any cost. After receiving suppliers' offers, buyer chooses the supplier with an offer for a lower cost type. In case of a tie, buyer randomly chooses a supplier. Buyer obtains the first-best expected profit, that is,* $\bar{\bar{\Pi}}^{P*} = \bar{\bar{V}}^c - K$.

Theorem 2 indicates that under QP, players' only possible equilibrium strategy is a separating equilibrium, obtained under condition (7). At this equilibrium, each supplier voluntarily makes his best affordable offer according to his true cost type. Therefore, due to competition, buyer finds suppliers' private cost type information with *no cost* and also obtains the *first-best expected* profit less the verification cost $\bar{\bar{V}}^c - K$. Suppliers also have the same full incentive for quality improvement as under centralized case. On the other hand, when condition (7) is not satisfied, there does not exist any equilibrium strategy, that is, suppliers' actions are unpredictable. We say QP is not applicable in that case.

Rewrite condition (7) as $\frac{\bar{\bar{\pi}}_L^{P*}(H)}{\underline{\pi}} \leq \frac{1}{2}(1+\frac{1}{p_i}), i = 1,2$. We can see that condition (7) is more easily satisfied when $\frac{\bar{\bar{\pi}}_L^{P*}(H)}{\underline{\pi}}$ is small (a *L*-type supplier does not gain much by pretending to be a *H*-type) or p_i (i = 1,2) is low (suppliers' quality improvement costs are more likely to be low), both of which result in more intense competition.

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Compared with the basic model with information asymmetry only, similar to QR, supplier competition benefits buyer, who can successfully separate the suppliers' cost types with no cost and obtain the optimal profit (*first-best expected* profit less the verification cost) when competition is sufficiently intense (i.e., condition (7) is satisfied). Supplier competition drives out pooling equilibrium, but also leads to an unpredictable situation when competition is not sufficiently intense.

Compared with the basic model with supplier competition only, we notice a very interesting phenomenon: information asymmetry can benefit the buyer under QP when competition is sufficiently intense! This is in contrast to the QR case where information asymmetry always leads to a loss to the buyer. This is caused by the switch of first-mover right: keeping the first-mover right (QR) forces the buyer to make quality requirement decision facing information asymmetry (which hurts the buyer), while giving up the first-mover right (QP) forces the suppliers (instead of the buyer) to deal with information asymmetry between the suppliers when they have to make offers of their promises anticipate what the other supplier will do (which benefits the buyer).

6.3. Which Strategy to Choose: QR or QP?

In this section, we compare final quality levels and buyer's profits under QR and QP in the hybrid model. Specifically, in terms of final quality levels, whenever QP is applicable, it better motivates suppliers (of either cost type) to improve quality to the first-best levels. In terms of buyer's profit, we summarize the following three key drivers for the buyer's choice between QR and QP in the hybrid model.

- The primary driver, that is, who makes the quality improvement, is the common driver across all models we have considered: under QP the supplier has full incentive for quality improvement, hence the system profit is maximized. This driver gives the buyer the potential to obtain higher profit under QP.
- Information asymmetry: In the presence of competition, this driver hurts the buyer under QR but benefits the buyer under QP when competition is sufficiently intense. Interestingly, this is different from the case where there is no competition, where information asymmetry always leads to loss in the buyer's profit under both QR and QP. This difference is due to supplier competition: when there is sufficiently intense competition, giving up first-mover right (adopting QP) allows the buyer to shift her responsibility of dealing with information asymmetry to suppliers as they have to estimate what their competitor will do in making their offers to the buyer (note buyer does not have to make a decision until receiving these offers). Thus, giving the first-mover right to suppliers (QP) changes the structure of information asymmetry hence changes the impacts of the driver.
- Supplier competition: In the presence of information asymmetry, this driver benefits the buyer under both QR and QP when competition is sufficiently intense. When competition is not intense, however, buyer's benefits from supplier competition under both strategies are limited: buyer has to pay information rent under QR and players' actions are unpredictable under QP (no equilibrium). The impact of supplier competition in the presence of information asymmetry is different from that without information asymmetry, where competition has no impact under QR but leads to a loss in buyer's profit under QP (the more efficient supplier only makes an offer that is slightly better than that from the less efficient supplier).

Buyer's final choice between QR and QP depends on the combined impacts of the three drivers. Interestingly, although the three drivers intermingle with each other, buyer's choice between QR and QP in the hybrid model turns out to be simple: When competition is sufficiently intense, that is, condition (7) is satisfied, buyer pays no information rent and obtains the first-best expected profit less the verification cost under QP, $\bar{\bar{V}}^c - K$. Therefore, as long as K is sufficiently small, that is, $K \le \bar{\bar{V}}^c - \bar{\bar{\Pi}}^{R*}$, QP is preferred; otherwise, QR is preferred. However, when competition is not sufficiently intense, that is, condition (7) is not satisfied, QR is the only applicable strategy left for the buyer.

7. Extension: Including Wholesale Price as a Decision

In the previous sections, we consider the case where wholesale price is fixed (dictated by the buyer or set by the market) and players use the penalty cost sharing in negotiation. In reality, it is also possible that players negotiate on both the penalty cost sharing and the wholesale price, for example, supplier bearing a higher proportion of penalty cost may justify a higher wholesale price w. This is what we study in this section. In this case, under QP, supplier(s) offer the pair of wholesale price and the penalty cost sharing plan $\{w, \lambda\}$ and under QR, buyer require $\{w, \lambda\}$. Without loss of generality, we assume there is a range of feasible wholesale prices, $[\underline{w}, \overline{w}]$, acceptable to both parties. Similar to the case where w is fixed, we assume that for any $w \in [\underline{w}, \overline{w}]$, the supplier's bottom-line profit $\underline{\pi}$ and the buyer's bottom-line profit satisfy $\underline{\pi} \geq Dw - sD(1 - q^c) - C(q^c)$ and $\underline{\Pi} \geq D(r - w) - sD(1 - q^c) - K$ respectively to avoid trivial cases. We focus on how this new addition of w impacts the comparison between QP and QR under each of the models we considered before.

Basic Model In the basic model, using the same methodology of analysis for the two strategies QP and QR, we obtained the following results.

Proposition 9. *In the basic model:*

- *Under QR, buyer chooses $w^{R*} = \overline{w}$ and λ^{R*} that solves $\pi^{R*} = \underline{\pi}$. Supplier's quality improvement plan $q^{R*} \leq q^c$. In addition, $\Pi^{R*} \leq V^c$.*
- *Under QP, $q^{P*} = q^c$. Supplier provides any $\{w^{P*}, \lambda^{P*}\}$ to the buyer, where $w^{P*} \in [\underline{w}, \overline{w}]$ and $\lambda^{P*}(w^{P*})$ solves $\Pi^P = \underline{\Pi}$. In addition, $\Pi^{P*} = V^c - K$.*
- *When $K \geq V^c - \Pi^{R*}$, buyer prefers QR; otherwise, she prefers QP.*

Proposition 9 indicates that when adding w as a decision, the primary driver still resides, that is, QP gives the supplier full incentive to improve quality to the first-best level, while QR limits supplier's incentive for quality improvement. Thus, when the verification cost required for QP is not too high, she prefers QP; otherwise, she prefers QR. Proposition 9 also indicates the impacts of adding w as a decision on QP and QR. Specifically, under QP, supplier can choose *any* w from the feasible range with a corresponding $\lambda^{P*}(w)$ to ensure the buyer obtain her expected bottom-line profit. Notice that while the payment related to wholesale price, Dw, is deterministic, the shared penalty cost related to λ is uncertain due to the uncertain conforming rate. Therefore, under QP, through the offers $\{w^{P*}, \lambda^{P*}\}$ provided by the supplier, buyer can trade off between a known payment now and an uncertain payment in the future. In contrast, under QR, to maximize her own profit, buyer has to induce the supplier to exert quality improvement efforts by letting him bear the highest possible proportion of penalty cost (λ), while still ensuring the supplier gets his bottom-line profit. Since the buyer can require the highest λ only by choosing the highest wholesale price, he is left with only one choice of the pair, $\{w,\lambda\}$. Hence, QP provides the buyer much more flexibility in terms of her choices of parameters.

Basic Model with Information Asymmetry When there is information asymmetry in the basic model, supplier decides $\{w_t, \lambda_t\}$ in the signaling game under QP, and buyer uses $\{w_t, \lambda_t\}$ to screen supplier's private cost type information under QR, where $t = H,L$. The following proposition summarizes the results:

Proposition 10. *In the basic model with asymmetric information:*

- *Under QP, $\tilde{q}_t^{P*} = q_t^c$. The supplier provides any $\{\tilde{w}_t^{P*}, \tilde{\lambda}_t^{P*}\}$ to the buyer, where $\tilde{w}_t^{P*} \in [\underline{w}, \overline{w}]$ and $\tilde{\lambda}_t^{P*}(\tilde{w}_t^{P*})$ solves $\tilde{\Pi}^P(t) = \underline{\Pi}$, $\forall t = H,L$. In addition, $\tilde{\Pi}^{P*} = V_H^c - K < \tilde{V}^c - K$.*
- *Under QR, buyer screens the supplier with the following menu of $\{\tilde{w}_t{}^{R*}, \tilde{\lambda}_t^{R*}\}$: $\tilde{w}_H^{R*} = \frac{1}{D}(\underline{\pi} - \tilde{\lambda}_H^{R*} sD(1 - \tilde{q}_H^{R*}(H)) - C(\tilde{q}_H^{R*}(H))$, $\tilde{w}_L^{R*} = \tilde{w}_H^{R*} - \frac{1}{D}(\lambda_H^{R*} sD(1 - \tilde{q}_L^{R*}(H)) + C(\tilde{q}_L^{R*}(H))) + \frac{1}{D}(\lambda_L^{R*} sD(1 - \tilde{q}_L^{R*}(L)) + C(\tilde{q}_L^{R*}(L)))$, and $\{\tilde{\lambda}_H^{R*}, \tilde{\lambda}_L^{R*}\}$ maximizes $\tilde{\Pi}^{R*} = p\tilde{\Pi}_H^{R*}(H) + (1 - p)\tilde{\Pi}_L^{R*}(L)$. In addition, $\tilde{\Pi}^{R*} \leq V^c$.*
- *When $K \geq V_H^c - \tilde{\Pi}^{R*}$, buyer prefers QR; otherwise, she prefers QP.*

Proposition 10 indicates little difference under QP when there is information asymmetry with w as the additional decision: Buyer suffers the same loss because of information asymmetry as under a fixed w, that is, she only obtains the optimal profit for the H-type supplier, $V_H^c - K$. In addition, buyer still enjoys the flexibility to trade off between a deterministic payment now and an uncertain payment in the future under QP, with w as a decision variable. On the other hand, under QR, the additional decision on w makes a big difference: it enables the buyer to screen the suppliers' information, using a menu of $\{\tilde{w}_t{}^{R*}, \tilde{\lambda}_t^{R*}\}$ (recall that buyer cannot screen the supplier's cost types under QR with fixed w). Thus, the information rent under QR is reduced.

Basic Model with Supplier Competition Compared to the basic model, we do not obtain new insights with supplier competition, when adding wholesale price as a new variable.

Hybrid Model with Information Asymmetry and Supplier Competition Adding wholesale price as a variable in the hybrid model under QP does not generate new insights in addition to those of the basic model: Under the same condition (7), each supplier will truthfully provide his best offer to the buyer according to his true type. Further, adding w as a decision, buyer has the flexibility to trade off between a known payment now and an uncertain payment in the future. However, under QR, although buyer can obtain the optimal profit and screen the suppliers' cost types without any cost when she chooses the highest possible wholesale price under the same condition (5) as in the fixed-w case, differently, when condition (5) is not satisfied, buyer has to pay information rent to screen the suppliers' cost types. The optimal menu design and how much information rent needs to be paid under QR are more complicated: they not only depend on the competition intensity and information

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asymmetry as shown in Theorem 1, but also on w as shown in Proposition 10.

As mentioned, in the paper, we define quality as conforming rate and use general functions for quality improvement cost in order to obtain insights of strategies QP and QR which do not rely on specific function forms. In Appendix S1, we study a special case where we follow Porteus (1986) to obtain specific functions for conforming rate and quality-related costs through modeling of the production processes. These specific function forms allow us to generate more detailed results about the buyer's optimal choice between QR and QP under different cases, some of which are presentable in figure forms.

8. Conclusion

In this article, we study the first-mover advantage in quality contracting and quality-based supplier selection with quality improvement opportunity. We explore two different strategies from the buyer's perspective: quality requirement strategy (QR), in which the buyer moves first by posting quality requirements to the supplier(s), and quality promise strategy (QP), in which the buyer foregoes her first-mover right to supplier(s) and requests him (them) to provide quality promises and then responds to his (their) offer(s). We investigate which strategy induces higher quality improvement effort from the supplier(s) and find key drivers in the buyer's choice between these two strategies when decisions are made based upon her expected profit. We start from a basic model with a single supplier, and then gradually add in other business features (e.g., supplier competition, asymmetric information of the supplier's quality improvement cost) and study how these features affect the buyer's choice of strategy. We study both the case when wholesale price is fixed and the case when wholesale price is an additional variable (negotiating tool) used by buyer and supplier(s) in quality contracting. We believe this paper not only address a pertinent question, but also enriches the limited literature on quality contracting with consideration of quality improvement and asymmetric information. The perspective on first-mover right in quality contracting is also unique. Based on our analysis, we obtain the following managerial insights in terms of buyer's choice between QP and QR, with the *italicized* portion as the essential decisions for the buyer:

- *The primary driver* of the buyer's choice between QR and QP is who can improve quality and who can improve quality more efficiently (when both buyer and supplier can make quality efforts). The benefit of moving first is to obtain the highest profit by maximizing the system profit while ensuring the other player the bottom-line profit. In the quality contracting context, improving *quality* maximizes system profit. Hence, given supplier is the party making quality improvement (the case we focus on), letting supplier move first (QP) gives supplier full incentives for quality improvement and potentially higher profit for the buyer, while keeping first-mover right to the buyer (QR) limits supplier's incentive for quality improvement. On the other hand, buyer needs to verify supplier's promised quality under QP but does not need to do so under QR because buyer controls supplier's quality through the required penalty sharing proportion. *In summary, in the basic model with a single supplier, buyer prefers QP if the quality verification cost is sufficiently small, and QR otherwise (condition provided in the paper).*
- *Supplier competition*. While competition does not affect buyer's optimal profit under QR, it limits buyer's potential profit under QP—the more efficient supplier will only make an offer to slightly beat the less efficient supplier if knowing his opponent is less efficient. *Therefore, when there is supplier competition but common knowledge of quality improvement efficiency, QR is likely better to the buyer unless suppliers are similar in quality improvement efficiency (competition is tense).*
- *Information asymmetry*. Information asymmetry of supplier's quality improvement cost leads to loss in buyer's profit under both strategies, but the loss under QR is smaller than that under QP. This puts QR above QP for the buyer, an opposite driving force to the primary driver. *Therefore, buyer's choice of strategy depends on the combination of these two driving forces (primary and information asymmetry). Conditions on when QR or QP is preferred are provided in the paper.*
- *Information asymmetry and supplier competition. Keeping or giving up the first-mover right changes the structure of information asymmetry (details below). Considering this impact, if competition is sufficiently high (threshold value provided in paper), QP is preferred by the buyer unless quality verification cost is too high; Otherwise, QR is preferred since suppliers' actions are unpredictable under QP. The following insights are also interesting:*
- *Interactions between asymmetric information and supplier competition*. While information asymmetry always leads to a loss in buyer's profit under both QR and QP when there is no competition, with supplier competition, information

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asymmetry in fact benefits the buyer under QP if competition is sufficiently highly although it still hurts the buyer under QR! This is because, giving up first-mover right (adopting QP) shifts the buyer's responsibility of dealing with information asymmetry to suppliers as suppliers have to estimate what their competitor will do in offering their promises to the buyer (buyer does not have to make a decision until receiving these offers). Thus, *giving up the first-mover right to suppliers (QP) changes the structure of information asymmetry hence changes the impact of information asymmetry*.

- *Information acquisition*. When there is both information asymmetry and supplier competition, while buyer can at least partially screen the suppliers' cost information through menus of different contracts under QR (we characterize conditions when buyer pays no information rent, and when "partial screening" is better/worse than "complete screening"), buyer can only find suppliers' information through a separating equilibrium under QP when competition is sufficiently intense.
- In terms of final improved quality, in all models, QP always motivates supplier(s) to improve quality to the first-best level, while QR limits the suppliers' incentive for quality improvement.
- The above results are obtained for fixed wholesale price, w. *When w is included as an additional variable in quality contracting, it affects QP and QR differently and the impacts are also different with and without information asymmetry*:
- Under common knowledge, adding wholesale price as a decision under QP brings buyer the flexibility to trade off between a deterministic payment now on every unit (related to w) and an uncertain payment in the future on defective units only (related to λ). However, QR does not provide this flexibility to the buyer. This is because under QP buyer can choose any wholesale price from the feasible range with an associated penalty sharing proportion, λ, since supplier is already motivated to improve quality to the first-best level. Under QR, however, buyer has to choose the highest wholesale price to force the highest sharing penalty proportion on supplier to induce her to improve quality so that she could potentially get the highest profit.
- Under information asymmetry, adding wholesale price as a decision gives the buyer more power to screen information to reduce information rent under QR but not under QP.

Acknowledgments

The authors highly appreciate the Department Editor, Professor Panos Kouvelis, the Senior Editor, and the anonymous reviewers for their insightful comments and suggestions that have significantly improved the quality of this article.

Note

[1]We assume perfect verification, that is, buyer knows q precisely from verification. Further, previous literature has shown the existence of truth-inducing verification mechanisms, for example, Reinganum and Wilde (1985) and Border and Sobel (1987). To focus on first-mover right in quality contracting, truth-inducing verification mechanism design is out of the scope of this study. We simply assume the supplier will truthfully reveal q under the verification mechanism, as in Nikoofal and Gumus (2014).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1: A Special Case.
Appendix S2: Proof of Proposition 1.
Appendix S3: Proof of Proposition 2.
Appendix S4: Proof of Proposition 3.
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