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Contracting with an urgent supplier under cost information asymmetry

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ABSTRACT

We investigate a contract setting problem faced by a manufacturer who can procure major modules from an overseas supplier, as well as a local supplier. The overseas supplier is prime and offers quality products, whereas the local supplier is viewed only as a backup, and its products are inferior in quality. As the local supplier needs to put in additional effort to fulfill the urgent order, it is difficult for the manufacturer to estimate this urgent supplier’s production cost. This asymmetric cost information becomes an obstacle for the manufacturer in managing the urgent supplier. In this paper, we study two types of contingent contracts. One is the common price-only contract, and the other is a contract menu consisting of a transfer payment and a lead time quotation. We construct a Stackelberg game model and evaluate how the involvement of an urgent supplier with private cost information affects performances of the prime supplier and the manufacturer in different scenarios (with or without the urgent supplier, under different contingent contracts). We also conduct numerical experiments to show how the parameters of the contracts affect profits of the manufacturer.

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1. Introduction

We study a supplier–manufacturer contract setting problem motivated by a real telecommunications firm, which has more than a 60% share in the competitive mainland Chinese mobile market. The operator implements a centralized procurement policy to procure major IT equipment for its provincial subsidiaries. The prime suppliers are multi-national companies which dominate the equipment market in terms of technology, quality and performance, and are treated as “strategic suppliers” by the operator. As the strategic suppliers usually produce equipment on a “Make-To-Order” (MTO) basis, their lead time is inevitably long for urgent orders.

On the other hand, there are local suppliers who are aggressively penetrating this niche market. These local suppliers offer lower price and better localized service. Especially, they are willing to put in additional effort to meet urgent needs, by temporarily increasing their production capacity, selecting the fastest possible transportation mode, etc. Therefore, the operator regards them as “backups”. When strategic suppliers cannot fulfill demand sufficiently, the operator turns to these local suppliers.

One difficulty of managing local suppliers is the asymmetry of information on production cost. As local suppliers claim that they have to put in additional effort to meet urgent demands, it is difficult for the operator to estimate their production costs. Consequently, the operator cannot determine the unit wholesale price on the basis of a supplier’s real cost; it can determine the price only on the basis of its own previous purchases. The operator has observed that local suppliers tend to deliver the products as late as possible, and suspects that the price-only contract being used is not efficient enough to induce the suppliers to adhere to delivery schedules. Therefore, the operator is also interested in ascertaining whether there exists a more efficient contract type.

We regard the operator as a “manufacturer” and its subsidiaries as “customers” who buy the products. We observe that this problem exists in many industries in China, where, quite often, a few large State Owned Enterprises (SOEs) dominate the market but have to rely on overseas suppliers for major modules, while local suppliers rely on these manufacturers for deals.

Therefore, we consider a manufacturer–supplier contract setting problem where the manufacturer procures a certain quantity of products from overseas supplier before the selling period, according to anticipated demand. When the actual demand exceeds the procurement, the manufacturer places urgent orders with the local supplier, whom we call the urgent supplier. We study two types of contracts in this paper. One is the price-only contract, and the other is a general contract menu stipulating $(L, T)$, where $L$ is the lead time quotation and $T$ is the corresponding transfer payment. It is a common practice to set a price-only contract with the local supplier, under which the supplier agrees to deliver the required product by a set deadline, at a certain unit price,
which is largely determined by the manufacturer. We investigate the efficiency of this contract, and its optimal price. We are especially interested in the \((L,T)\) optimal contract menu because the revelation principle of Myerson (1979) states that there is an optimal contract menu under which the party will truthfully share its private information with others. Hence the manufacturer needs to consider only contract menus that give the urgent supplier no incentive to hide its cost information.

Our main findings are as follows:

1. The manufacturer prefers to invite the local supplier into the game since it can serve not only as a recourse for meeting urgent demand, but also as a potential competitor of the prime supplier. Moreover, we observe that the more efficient the contract type is, the higher the profit the manufacturer can earn. In contrast, the prime supplier is disadvantaged by the efficiency of the contract.

2. Under the price-only contract, the urgent supplier tries to minimize its cost by delaying delivery to the greatest extent possible, and the contract is not efficient to reveal the local supplier’s true cost information. In contrast, under the \((L,T)\) contract, the local supplier would share its cost information truthfully, enabling the manufacturer to earn higher profit. We further prove that the manufacturer needs to adopt a threshold policy for its strategy in sourcing from the local supplier under both contracts.

3. By numerical studies, we observe that the manufacturer is more likely to adopt the \((L,T)\) contract when the urgent supplier’s quality is higher, when the urgent supplier has higher chance to be of the low cost type, or when compensation to end customers for inferior modules or delayed delivery is high. These observations can assist the manufacturer to determine whether it is worth introducing the \((L,T)\) contract, if there are costs (for example, administration costs) attached to it.

Now we briefly discuss the related literature. The first body of research related to our paper is the selection of, and procurement from, suppliers. In general, this study focuses on evaluating suppliers’ different characteristics (e.g., production capacity, product quality and cost structure) and making the right supplier selection, replenishment and contract setting decisions thereafter. Chen et al. (2001) analyzed optimal supplier selection, replenishment and inspection strategies, when the product quality and repairing costs of suppliers were different. Sethi et al. (2003) studied how the manufacturer replenishes from two suppliers with different production costs and lead times, in order to maximize its total profit. Feddergruen and Nan (2008) determined the optimal set of suppliers, and the optimal order quantity from each supplier, with a random yield factor. These papers investigate the buyer’s decision-making for optimal sourcing and replenishment from suppliers with similar characteristics, under complete information. In our paper, the prime supplier has better performance while the urgent supplier has higher flexibility in delivery time. Since the urgent supplier has private cost information, we study the contract setting problem and analyze the interaction between suppliers and the manufacturer in a Stackelberg game setting.

The second body of related research covers supply chain contracting under stochastic demand with complete information. Tsay (1999) focused on supply chain coordination with quantity flexibility contracts and Barnes-Schuster et al. (2002) proposed option contracts and developed sufficient conditions on cost parameters to achieve channel coordination. Cachon and Lariviere (2005) demonstrated that revenue sharing coordinated a supply chain even with price dependent demand. Chen and Xiao (2009) investigated models of coordination of a supply chain consisting of one manufacturer, one dominant retailer and multiple fringe retailers with demand disruption. A comprehensive survey of literature is provided by Cachon (2003). Our paper studies contract setting and replenishment decisions under private cost information, and thus differs from the above papers.

The salient feature of the third stream is analyzing how asymmetric information influences the performance of each party in various supply chain settings. Ozer and Wei (2006), Ha and Tong (2008), and Fu and Zhu (2009) studied contract issues under asymmetric demand information in different settings. Ha (2001), Corbett et al. (2004) and Sucky (2006) considered a supplier–buyer channel where the buyer had private cost information. Cachon and Zhang (2006) investigated procurement strategies in a queuing framework where the supplier had private capacity cost information. Yang et al. (2009) analyzed the manufacturer’s optimal procurement mechanism design problem when the supplier was privileged with the information about supply disruptions. Wang et al. (2009) studied the performance of an upstream manufacturer with private production cost information where the retailer faced price dependent deterministic demand, under four contract formats. Our paper also investigates the contract setting problem where the supplier has private cost information, as in Cachon and Zhang (2006), Yang et al. (2009) and Wang et al. (2009). Our paper differs from Yang et al. (2009) and Wang et al. (2009) as we consider a supply chain with two suppliers and one manufacturer, when the final demand is stochastic, and the production cost is lead time dependent. Compared with Cachon and Zhang (2006), our problem is under a single period setting, while theirs is a queuing model. The suppliers in our paper have different leverages, and we consider replenishment decision, instead of the capacity design problem.

The analytical underpinnings of our paper are provided by the principal-agent models originated from Economics. Ross (1973) provided an introduction to the principal-agency issue, and Mas-Colell et al. (1995) described two main variations (hidden action and hidden information scenarios) of the basic model. In this paper, we investigate the hidden-information scenario and analyze the so-called mechanism design problem.

The remainder of the paper is organized as follows. Section 2 briefly describes the model set up. Section 3 analyzes the manufacturer’s contract setting problem with the local supplier, while Section 4 investigates the overseas supplier’s optimal pricing decision, and compares the performance of each party under different scenarios (without, and with the urgent supplier under either the price-only contract, or \((L,T)\) contract). Section 5 demonstrates how the parameters affect the manufacturer’s profits, by numerical examples. We conclude the paper in Section 6. All proofs are stated in the online supplementary material.

2. Model description

Consider a manufacturer who sells a product directly to a market where demand \(D\) follows a continuous and differentiable distribution function \(F(\cdot)\) with \(F(\cdot) = 1 - F(\cdot)\), and its mean is \(\mu\). The manufacturer procures its key modules from dual sources (the long lead time overseas supplier and the short lead time local supplier).

The module produced by the overseas supplier \((S_1)\) is of higher quality and a final product made with this module will be sold at unit price \(r_1\). As the lead time is long, the manufacturer should place an order with \(S_1\) in advance, at the unit wholesale price \(w\) set by \(S_1\). Thereafter, based on the specific order, \(S_1\) produces the modules and delivers them before the selling period. After the selling period, any left over products would be salvaged at \(s\). Here, we assume \(S_1\)’s unit cost is \(c_1\) \((c_1 < w)\). The manufacturer also chooses a local supplier \((S_2)\) as the urgent source. As the module from \(S_2\) is
inferior in quality, the final product made with this module can only be sold at price $r_2$, $r_2 < r_1$. Moreover, only a fraction of customers would accept the product with $S_2$’s module; we denote this fraction as $z$: $0 < z < 1$, which could reflect the market acceptance of $S_2$’s modules.

When the realized demand exceeds supplies from $S_1$, the manufacturer could rely on $S_2$ for extra modules. $S_2$’s delivery time is cost dependent and controllable but the cost information is private. We assume this cost is $c_2 t^{b}\chi$ with $b > 0$, and $t$ denotes the delivery time. Here $c_2$ is unknown to other parties, who only know its ex ante distribution:

$$c_2 = \begin{cases} 
  c_i, & \text{with probability } \beta, \\
  c_h, & \text{with probability } 1 - \beta;
\end{cases}$$

where $c_i$, $c_h$ correspond to high and low price states, respectively, with $c_h > c_i > 0$. Though the two-price assumption is a simplification of the reality, two states are sufficient to capture the major effect of information on contracting and competition in our problem. A two-state distribution has been commonly employed in supply chain contracting and screening literature (see, for example, Lariviere, 2002; and Jaisingh et al., 2008).

The structure of cost $c_2 t^{b}\chi$ reflects that $S_2$ incurs higher cost when the due date is tighter, and immediate delivery is hard to accomplish (when $t = 0$, $c_2 t^{b}\chi \rightarrow +\infty$). Chen et al. (2008) consider a similar cost structure ($m t^{t}\chi$) for the direct channel cost, where $m$ is the direct channel cost parameter and $t$ is the delivery time. Their cost structure is treated as a special case in this paper ($b = 2$).

Furthermore, we assume the manufacturer’s production time is negligible and the unit production cost is normalized to zero without loss of generality. After receiving urgent supply from $S_2$, the manufacturer assembles the final product and delivers it to the customers. The manufacturer pays the customer a tardiness cost per unit time of delay, per unit. In this paper, fraction $\chi$ is constant for two reasons. Firstly, prices of final products are exogenous. Secondly, as the manufacturer is dominant in the market and promises to compensate customers for late delivery, customers are willing to wait; also it is difficult to find a suitable alternative source of supply. Besides, customers are insensitive to the delivery time as the manufacturer guarantees delivery before the industry standard time $T$, defined later in the next section.

In this paper, we assume the contract type is known to all parties. The objective of each firm (both suppliers and the manufacturer) is to maximize its own expected profit. $S_1$ determines the wholesale price $w$, which considers the trade-off between the likely effects: A higher price implies higher unit profit margin but potentially pushes the manufacturer to $S_2$ and hurts its profit. The manufacturer is likely to take advantage of the competition between the two suppliers. Hence it orders from $S_1$ at price $w$ and from $S_2$ under a contingent contract. $S_2$ decides whether to accept this contract, which depends on the contract type and payments offered by the manufacturer. Only when the expected profit is higher than its reserve profit (which is assumed to be type-dependent, and is denoted as $\pi_i$, with $i = \ell$ or $h$), $S_2$ will accept the contract.

The reserve profit reflects the bargaining power of $S_2$. In this paper, we assume $\pi_\ell \leq \pi_h$ to reflect that the local suppliers have similar production technology but different workloads (or market share). A supplier with heavy workload (or market share) has a greater bargaining power but an urgent order incurs higher contingent cost because of the need to rearrange production planning, transportation schedules and cost of corresponding postpositions of deliveries against other orders. Our formulation of type-dependent reserve profit is a generalization of the common assumption (type independent reserve profit) used in contract setting literature. For example, Ha (2001) assumes a buyer with asymmetric cost information has cost-independent positive reserve profit. In reality, the scenario $\pi_\ell > \pi_h$ may exist as suppliers with contingent cost advantages may have higher bargaining power. We have investigated this scenario and found that the decision of $S_2$ (type $h$ only, type $\ell$ only, both types, or neither type) to enter the market is rather parameters dependent (e.g. $\beta$, $\pi_\ell$, $\pi_h$ and contingent excess demand), and is technically intractable. Therefore, we consider scenario $\pi_\ell \leq \pi_h$ only to derive managerial insights in this paper.

Here we summarize the sequence of events as follows.

1. $S_1$ sets the wholesale price $w$, taking into consideration the threat of competition from $S_2$ and the contract type.
2. The manufacturer places the normal order with $S_1$ in advance, such that the modules can be received before the selling period.
3. During the selling period, when demand exceeds the normal order from $S_1$, the manufacturer procures modules from $S_2$ under the contingent contract (either a price-only contract, or an optimal incentive contract).

The above events constitute a two-stage game. In the first stage, as the Stackelberg game leader, $S_1$ determines $w$. In the second stage, the manufacturer places the normal order with $S_1$ before the selling period, and places the urgent order with $S_2$ under a contingent contract, when demand exceeds $S_1$’s supply.

Under the price-only contingent contract, the manufacturer offers a unit price $P$ to $S_2$. Whether $S_2$ accepts the contract or not depends on: the contingent demand volume, the cost type, and the related reserve profit. Under the optimal incentive contingent contract, the manufacturer offers a contract combining the lead time quotation $(L)$ and transfer payment $(T)$. If $S_2$ accepts the contract, it will receive payment $T$ and deliver the modules at the required time, i.e. $L$ time units after the order is placed. Below we analyze this two-stage game from a backward direction.

3. Stage 2 game: Manufacturer’s replenishment decision

In this section, we answer the following questions: 1. How does the manufacturer perform under the price-only contract? 2. What type of contract can bring the manufacturer higher expected profit? 3. Under different contract types, how does $S_2$ respond?

3.1. Price-only contract

We assume there exists a maximal acceptable delivery time $\bar{T}$ in the industry, and no order will allow a delivery time longer than that. We further assume that $r_2 - pL - c_1\bar{T}^{b}\chi > 0$, to guarantee that the manufacturer can earn nonnegative profit under a delivery time shorter than $\bar{T}$.

Given $w$, the manufacturer’s profit can be written as:

$$\pi_{\ell}(Q) = r_1 E \min(D, Q) + zE(Q - D) - wQ + E[U^d|z(D - Q)^\dagger]|].$$

(1)

Here $Q$ denotes the quantity ordered from $S_1$. If it cannot fully satisfy the demand $D$, the manufacturer will turn to $S_2$ to fulfill the remaining part $(D - Q)^\dagger$. However, as the urgent supplier’s product is inferior in quality, only $z(D - Q)^\dagger$ will be accepted. Therefore, the term $z(D - Q)^\dagger$ represents the potential sales volume (PSV) of products from $S_2$. The last item in Eq. (1) denotes the expected ex
post profit from the price-only contract. Note that $S_2$ may reject the contract if $S_2$ cannot earn more than its reserve profit, and the manufacturer may reject the deal if its ex post profit is negative. In neither case, can the PSV be completely fulfilled.

Below we discuss how to derive the function of $U_P^h(x)$. Assume the contingent PSV is $x$, and the manufacturer offers a contingent unit price $T_P$. This contract may not always be accepted by $S_2$. It depends on $S_2$’s cost type $i$ and related reserve profit level $\pi_i$ for $i = \ell$ or $h$. Type $i$ of $S_2$ will accept the contract if and only if $(T_P - c_L L^b) x \geq \pi_i; L_i \leq L$. Under the given $T_P$, $S_2$ wishes to deliver the product as late as possible to maximize its contingent profit $(T_P - c_L L^b) x$. Therefore, under the given $T_P$, if type $i$ of $S_2$ enters into the contract, the delivery time is $\min (T_P, \{c_i/(T_P - \pi_i/x)\})^{1/b_i}$.

The manufacturer offers the contract only if positive profits can be earned. In the following proposition, we provide the conditions under which the manufacturer is willing to offer the contract, and characterize the contract, if it is offered. Let us first introduce a parameter $\beta_0$:

$$\beta_0 = \frac{r_2 - p L - c_L L^b}{r_2 - p L - c_L L^b}.$$

**Proposition 1.** Define two thresholds:

$$x_0^h = \frac{\nu}{r_2 - p L - c_L L^b},$$
and

$$x_h^b = \begin{cases} \frac{r_2 - p L - c_L L^b}{r_2 - p L - c_L L^b} & \text{if } \beta < \beta_0, \\ +\infty & \text{otherwise.} \end{cases}$$

The ex post profit $U_P^h(x)$ is continuous, increasing and convex in $x$, which is written as:

(a) when $x \in [0, x_0^h]$, $U_P^h(x) = 0$;
(b) when $x \in [x_0^h, x_h^b]$, $U_P^h(x) = A_h^b x - \beta \pi$, with $T_P = \frac{c_h}{F_p} + \frac{\pi_h}{x}$, $A_h^b = \beta (r_2 - p L - c_L L^b)$, (2)
(c) when $x \in [x_h^b, +\infty)$, $U_P^h(x) = A_h^b x - \pi_h$ with $T_P = \frac{c_h}{F_p} + \frac{\pi_h}{x}$, $A_h^b = r_2 - p L - c_L L^b$.

This proposition implies that a $\beta$-dependent threshold policy is optimal for the manufacturer under the price-only contract. When the ex ante probability of low cost type is not high ($\beta < \beta_0$), the manufacturer refuses to offer the contract if the PSV is low ($x < x_0^h$), encourages only low cost $S_2$ when it is medium ($x \in [x_0^h, x_h^b]$), and entertains both types of $S_2$ if it is high enough ($x \in [x_h^b, +\infty)$). In contrast, when $\beta$ is high ($\beta \geq \beta_0$), $x_h^b = +\infty$ and the manufacturer will place no order from both types, simultaneously.

The intuition behind the policy is straightforward. When deciding on the contract, the manufacturer has three options: 1. Reject both types of suppliers; 2. reject high cost $S_2$ only; and 3. accept both. Each option is associated with a fixed cost incurred that ensures the reserve profit level (0, $\beta \pi$, and $\pi_h$ respectively) and a profit margin (0, $A_h^b$ and $A_h^b$ respectively). When $\beta$ is not high, Option 2 brings lower profit margin ($A_h^b < A_h^b$) and lower fixed cost ($\beta \pi < \pi_h$), compared with Option 3. Consequently, only when the PSV is sufficiently large, the manufacturer will select Option 3; when the PSV is medium, it will reject high cost $S_2$, and when the PSV is low, both will be rejected. However, when $\beta$ is high, Option 2 brings a higher profit margin ($A_h^b > A_h^b$) and a lower fixed cost ($\beta \pi < \pi_h$), which makes it better than Option 3. Therefore, the manufacturer will never entertain high cost $S_2$.

However, Proposition 1 illustrates that the price-only contract only controls the entry of different types of $S_2$; it is inefficient in differentiating $S_2$ in terms of delivery time. The manufacturer can either offer a price exactly equal to the high cost plus the average reserve profit of high cost $S_2$ ($C_L L^b + \pi_h x^{-1}$), allowing both types of $S_2$ to enter into contract, or offer a price equal to the low cost plus the average reserve profit of low cost $S_2$ ($C_L L^b + \pi_h x^{-1}$), to exclude high cost $S_2$. In the first case, only low cost $S_2$ will earn positive profit ($C_L L^b + (\pi_h - \pi_i) x^{-1}$) per unit due to the information distortion. In the latter, the manufacturer can offer a price slightly higher than the low cost plus the average reserve profit of low cost $S_2$. This will induce only low cost $S_2$. However, the manufacturer has no control on the delivery time, since after settlement of the unit price, both types of $S_2$ have incentives to produce as late as possible, to reduce their production and delivery cost. Finally, we observe that the ex post profit of the manufacturer is dependent on the economy of scale. The manufacturer obtains higher profit margin as the PSV becomes larger.

With Proposition 1, we can further rewrite the manufacturer’s profit function as:

$$\pi_p^h(Q) = r_1 E \min (D, Q) + s E (Q - D)^+ - w Q + E (U_P^h Q (D - Q)^+)$$

$$= (r_1 - s) E (D - (r_1 - s)) \int_0^{Q_1} F(x) dx - (r_1 - s A_p^h - s) \int_{Q_1}^{Q_2} F(x) dx - (w - s) Q,$$

where (4) is derived by integration of parts.

The manufacturer’s profit is composed of two parts: A newsvendor problem without $S_2$, and the expected ex post profit. In general, the profit function is neither convex, nor concave, in $Q$, as it is composed of a concave function and a convex function. Therefore, the optimal order quantity from $S_1$ is not uniquely determined by the first-order condition.

Now we discuss sufficient conditions under which the uniqueness of this quantity can be guaranteed.

**Condition I:** The support of the density function $f(d)$ is $[a, b]$, with $a, b > 0$, and there exist some constant $\bar{d}$, above which $f(d)$ is decreasing in $d$.

**Condition II:** Define $A^2 = \max \{ A_h^b, A_h^b \}$ and $Q_{ \bar{d} } = F^{-1} \left( \frac{a - \bar{d} - w}{a - \bar{d} - w} \right)$; inequality $Q_{ \bar{d} } \geq \bar{d}$ holds.

Here Condition I implies that customer demand is bounded in the sense that the probability of large value is low as it is beyond some threshold $\bar{d}$. Many commonly used distributions satisfy this, which can be categorized into three groups.

**Group 1:** The density function is decreasing in support (e.g. uniform and exponential distributions, Weibull distribution with parameters $(\lambda, k), \lambda > 0$ and $0 < k < 1$). Here $\bar{d} = 0$.

**Group 2:** The density function is concave in support (e.g. normal distribution with $d = \mu$). (3)

**Group 3:** Other commonly used density functions. We have listed some examples here.

A. Gamma distribution with parameters $(\alpha, \lambda), \alpha$ is integer and $\alpha > 0$. Here $f(d) = \frac{\lambda^\alpha \alpha^\alpha e^{-\lambda d}}{\Gamma(1 + \frac{\alpha}{\lambda})}$ with $\mu = \frac{\lambda}{\alpha}$ and $d = \frac{\alpha}{\lambda}$.

B. Weibull distribution with parameters $(\alpha, \lambda), \lambda > 0$ and $k > 1$.

Here $f(d) = \frac{\alpha}{\lambda} (\lambda d)^{\alpha - 1} e^{-\lambda d^{1/k}}$ with $\mu = \lambda^{1/k} (1 + \frac{1}{k})$ and $d = \lambda^{1/k} \sqrt[k]{\frac{\alpha^k}{\lambda}}$

According to (4), $Q_{\bar{d}} = F^{-1} \left( \frac{a - \bar{d} - w}{a - \bar{d} - w} \right)$ is the newsvendor order quantity from $S_1$, when $\pi_i = \pi_h = 0$. Condition II states that the final
products with high quality modules has the lowest quantity requirement \( d \), to ensure the service quality to end customers. By definition, distributions in Group 1 satisfy Condition II since \( d = 0 \). We observe \( d < \mu \) for all distributions in Group 2 and 3. Therefore, for most commonly used distributions in Groups 1 to 3, Condition II is equivalent to \( Q_{2} \gg \mu \).

**Proposition 2.** When the price-only contract is used between the manufacturer and S2, the first-order necessary condition of optimal replenishment quantity \( Q_{2} \) from S1 is given by

\[
F(Q_{2}) - \frac{2A_{1}p}{r_{1} - s} F(Q_{2} + \frac{x_{0}}{2}) - \frac{\alpha(A_{1}^{2} - A_{2}^{2})}{r_{1} - s} F(Q_{2} + \frac{x_{0}}{2}) = w - s
\]

(5)

with \( Q_{2} > Q_{1} \). Furthermore, when Condition I and II hold, optimal quantity \( Q_{2} \) is uniquely determined by (5) in the region \( \{Q_{2}, \infty \} \).

Expression (5) has an intuitive interpretation. Without the last two terms on the left-hand side, the expression becomes the solution to the simple newsvendor problem without the urgent supplier S2, in which case the underage cost is \( r - w \) and overage cost is \( w - s \). Further, the optimal order quantity from S1 is adjusted down (the second and third term) because of the possible flexibility to obtain modules from S2 when the PSV is above the threshold \( x_{0} \).

### 3.2. Optimal \((L, T)\) contract

From the previous study, we find that the price-only contract is inefficient to distinguish between S2 of different cost types. According to Myerson (1979), we need to find a mechanism for truthful disclosure of private cost information. As the price-only contract has no control on delivery time, we propose a \((L, T)\) contract that incorporates both transfer payment and lead time quotation and lead time quotation. In this section, we prove that this contract is indeed incentive optimal, and study the optimal contract parameters.

Given \( w \), the manufacturer’s profit can be written as:

\[
\pi_{m}^{D}(Q) = r_{1}E\min(D, Q) + sE(Q - D)^{+} - wQ + E(U^{p}(x|D - Q^{+}))
\]

(6)

where \( Q \) is the order quantity from S1, \( x(D - Q)^{+} \) represents the PSV of products with urgent orders, and the last item represents the expected ex post profit under \((L, T)\) contract when the stockout from S1 happens.

To derive the optimal order quantity from S1, we first study the contract design problem when the PSV is \( x \):

\[
U_{x}^{p}(x) = \max \{U_{x}^{p}(x), U_{0}^{p}(x), 0\}
\]

(7)

where \( U_{x}^{p}(x) \) represents the manufacturer’s ex post profit when both types of S2 accept the contract, and \( U_{0}^{p}(x) \) denotes the profit when only low cost S2 accepts the contract. The manufacturer cannot induce only the high cost S2 to enter into the contract because the low cost S2 can always pretend to be the high cost type and earn higher profit. Note that the manufacturer offers the contract only if its profit is nonnegative, so \( U_{x}^{p}(x) \) is nonnegative.

The contract design problem of inducing both types of S2 is formulated as:

\[
U_{x}^{p}(x) = \max_{L_{i}, T_{i}, t} [r_{i}x - \beta isl(x + T_{i}) - (1 - \beta)islx + T_{i}]
\]

subject to

\[
T_{i} - \frac{C_{x,i}}{L_{x,i}} \geq T_{h} - \frac{C_{x,h}}{L_{x,h}} \quad \text{(8)}
\]

\[
T_{h} - \frac{C_{x,h}}{L_{x,h}} \geq T_{i} - \frac{C_{x,i}}{L_{x,i}} \quad \text{(9)}
\]

(10)

(11)

(12)

In this formulation, the manufacturer seeks to maximize its ex post profit, subject to three sets of constraints. Constraints (8) and (9) are incentive-compatibility constraints, which induce S2 to share its true cost information. Constraints (10) and (11) are individual-rationality constraints, which ensure that S2 will earn at least its reserve profit. Finally, Constraint (12) says that the lead time quotation must be nonnegative.

The contract design problem of inducing only low cost S2 is formulated as:

\[
U_{x}^{p}(x) = \max_{k_{i}, T_{i}, t} [r_{i}x - (pl_{x} + T_{i})]
\]

subject to

\[
T_{i} - \frac{C_{x,i}}{L_{x,i}} \geq T_{h} - \frac{C_{x,h}}{L_{x,h}} \quad \text{(14)}
\]

\[
L_{i} \geq 0 \quad \text{(15)}
\]

Here, Constraint (14) is the individual-rationality constraint and Constraint (15) guarantees the lead time quotation is nonnegative.

Let the optimal solutions be \((L_{i}, T_{i}, L_{h}, T_{h})\), where \( L_{i} \) is the lead time quotation and \( T_{i} \) is the transfer payment under state \( i, i = l, h \).

**Theorem 1.** Given the PSV of \( x \), the contract design problems of \( U_{x}^{p}(x) \) and \( U_{x}^{0}(x) \) are summarized as follows.

(i) \( U_{x}^{p}(x) = A_{i}^{p}x - \pi_{x} \) with \( A_{i}^{p} = r_{2} - \frac{a_{i}^{1}}{p} \{1 - \sqrt{bc}, p^{2} + \sqrt{b(c_{i} - \beta c_{i})(1 - \beta)}p^{b}\} \), and the related contract parameters are:

\[
(L_{i}, T_{i}) = \left( \frac{c_{i}}{p}, \frac{c_{i} - c_{h}}{L_{h}} \right)(x + \pi_{x} \frac{c_{i} - c_{h}}{L_{h}} x + \pi_{x})
\]

(13)

(ii) \( U_{x}^{0}(x) = A_{i}^{0}x - \beta \pi_{x} \) with \( A_{i}^{0} = \beta \left[ r_{2} - \frac{a_{i}^{1}}{p^{2}} - \sqrt{bc}, p^{b}\right] \), and the related contract parameters are:

\[
(L_{i}, T_{i}) = \left( \frac{c_{i}}{p}, \frac{c_{i} - c_{h}}{L_{h}} \right)(x + \pi_{x})
\]

(16)

(17)

Profits in both PSVs are linear, with different profit margins and fixed costs. The fixed cost under the contract inducing only low cost S2 is smaller as the manufacturer only needs to pay a price that ensures the reserve profit for low cost type. However the profit margin is dependent on the ex ante probability of low cost type, and there exists a break-even point \( \beta_{1} \):

\[
\beta_{1} = \frac{r_{2}^{1} + \frac{a_{1}^{1}}{p} \frac{1}{p^{2}} bc, p^{b}}{r_{2}^{1} + \frac{a_{1}^{1}}{p} \frac{1}{p^{2}} bc, p^{b}}
\]

When \( \beta < \beta_{1} \), the profit margin under the contract that induces both types of S2 is larger, and vice versa. With the specific form of the profit function, we derive the optimal policy for the manufacturer in the following proposition.

**Proposition 3.** Define two thresholds: \( x_{0}^{\beta} = \frac{c_{x,0}}{A_{x,0}} \)
\[ x_0^b = \begin{cases} \frac{\pi_b - \pi_a^O}{\pi_b - \pi_a^O} & \text{if } \beta < \beta_1, \\ +\infty & \text{otherwise}. \end{cases} \]

Condition (II'): Define \( A_0^O = \max\left\{ A_t^O, A_h^O \right\} \) and \( Q_{10} = F^{-1}\left( \frac{\pi_a^O - \pi_b}{\pi_b - \pi_a^O} \right) \) with \( Q_s \), the newsvendor order quantity from \( S_t \), when the reserve profit level of \( S_2 \) equals zero. The inequality of \( Q_{10} \geq Q_s \) holds.

With Condition I and II', a unique optimal order quantity from \( S_t \) can be obtained, as shown in Proposition 4.

**Proposition 4.** When the optimal contract menu is used between the manufacturer and \( S_t \), the first-order necessary condition of optimal replenishment quantity \( Q_{10} \) from \( S_t \) is given by

\[
F(Q_{10}) - \frac{\pi_a^O}{r_1 - s} F\left(Q_{10} + \frac{X_0}{\alpha}\right) - \frac{\pi_a^O - \pi_b}{r_1 - s} F\left(Q_{10} + \frac{X_0}{\alpha}\right) = \frac{w - s}{r_1 - s},
\]

with \( Q_{10} \geq Q_s \). Furthermore, when Condition I and II' hold, the optimal quantity \( Q_{10} \) is uniquely determined by (17).

Expression (17) has an interpretation similar to (5). Without the last two terms on the left-hand side, the expression becomes the solution to the newsvendor problem, without \( Q_s \). The optimal order quantity from \( S_1 \) is adjusted down (the second and third term) due to the option of obtaining modules from \( S_2 \) when the PSV is above the threshold \( x^0 \).

Before closing this section, we compare the performances under both contracts.

**Theorem 2.** Comparing the price-only contract with the \((L, T)\) contract:

1. \( U^P(x) \geq U^O(x) \) and \( \frac{x^P(x)}{x^O(x)} \geq \frac{x^P(x)}{x^O(x)} \).
2. \( Q_s < Q_s^O \) and \( Q_s < Q_s^P \).
3. \( \pi_{10}^P(Q_s^O) > \pi_{10}^O(Q_s) \).

Given the contingent PSV of \( x \), the manufacturer always obtains higher ex post profit and profit margin under the \((L, T)\) contract, as it is an efficient contract that can discriminate suppliers efficiently. With better use of the flexibility of \( S_2 \), the manufacturer tends to order less from the overseas supplier \( S_1 \), and improves its profit.

4. **Stage 1 game: \( S_1 \)'s pricing decision**

At this stage, the overseas supplier \( S_1 \) determines its optimal wholesale price \( w \), considering the possible reaction of the manufacturer and urgent supplier \( S_2 \). A higher \( w \) leads to higher profit margin but fewer orders from the manufacturer. In addition, the nature of the contingent contract type also influences the pricing decision of \( S_1 \). In this section, we consider three scenarios: Scenarios \( N, O \), and \( P \). In Scenario \( N, S_2 \) does not participate in the supply chain. In Scenario \( P, S_2 \) is involved in the supply chain and the optimal price-only contract is used between \( S_2 \) and the manufacturer. In Scenario \( O, S_2 \) participates in the supply chain and the \((L, T)\) contract is used. Under each scenario, we first derive the optimal wholesale price, and then investigate the performance of each party.

Let \( u \) denote \( S_1 \)'s profit function in Scenarios \( N, O \) and \( P \):

\[
\pi_1^O(Q_s^O) = \max_{w_i} \left\{ w_i - c_i \right\} Q_s^O, \quad i \in \{N, O, P\},
\]

where

\[
w_n = (r_1 - s) F(Q_s^O) + s, \\
w_o = (r_1 - s) F(Q_s^O) - \alpha A_0^{O} F\left(Q_s^O + \frac{X_0}{\alpha}\right) + s,
\]

and

\[
\pi_1^P(Q_s^P) = \max_{w_i} \left\{ w_i - c_i \right\} Q_s^P, \quad i \in \{N, O, P\},
\]

where

\[
w_n = (r_1 - s) F(Q_s^P) + s, \\
w_o = (r_1 - s) F(Q_s^P) - \alpha A_0^{O} F\left(Q_s^P + \frac{X_0}{\alpha}\right) + s.
\]
where
\[ w_p = (r_1 - s)F(Q_p^*) - \alpha A_i^*F\left( Q_p^* + \frac{x_i^*}{2} \right) - \alpha \left( A_i^* - A_i^* \right)F\left( Q_p^* + \frac{x_i^*}{2} \right) + s. \] (19)

Scenario N has been widely studied in Lariviere and Porteous (2001). They find the optimal order quantity \( Q_p^* \) is uniquely determined by \( F(Q^*(A)) [1 - g(Q^*(A))] = \frac{r_1}{h_1} \) if the demand distribution holds an increasing general failure rate (IGFR) property. The function \( g(x) = \frac{x}{a} \) is the general hazard rate.

In Scenario N, the optimal order quantity from \( S_2 \) is uniquely determined by a newsvendor problem. However, in Scenarios P and O, as shown in Section 3, the optimal order quantity is not always uniquely determined due to the economics of scale of the ex post profit in the second stage game. These difficulties imply that the IGFR property of demand distribution cannot guarantee the uniqueness of the optimal order quantity from \( S_2 \). We determine the optimal order quantity in the following theorem.

**Theorem 3.** The optimal wholesale price is given by Eq. (18) or (19), where \( Q_i^* \) satisfies the first-order necessity optimality condition:
\[ dw_i \frac{Q_i^*}{Q_i^*} + w_i - c_i = 0, \quad \text{for } i \in \{P, O\}. \] (20)

(i) When \( w_i \) is decreasing and concave in \( Q_i^* \), \( Q_i^* \) is uniquely determined by Eq. (20). This property holds: (a) when the demand distribution is uniform; or (b) when the demand distribution is normal and \( \mu - \frac{\sigma^2}{2wi} > 0.5 \) holds over the region \( \mu, \infty \).

Thus \( Q_i^* \) is uniquely determined by Eq. (20) when (a) holds, and it is uniquely determined over the region \( \mu, \infty \) when (b) holds.

(ii) When \( \pi_i = \pi_n = 0 \), (20) can be further simplified into
\[ F(Q_i^*) [1 - g(Q_i^*)] = \frac{c_i - s}{r_1 - \alpha a_i} - \frac{c_i}{r_1 - \alpha a_i}. \] (21)

Assume the demand distribution has the IGFR property, \( Q_i^* \) is uniquely determined by (21).

In general, when \( S_2 \) has positive type-dependent reserve profits, the profit function of \( S_1 \) under either price-only or \( (L, T) \) contract might not be concave. Therefore, the optimal order quantity from \( S_1 \) can be selected from the complete set of all stationary points satisfying (20). We present two scenarios under which the uniqueness of the order quantity is guaranteed. Conditions in (i) state that the wholesale price has decreasing margin in order quantity, which implies that \( S_1 \)'s pricing decision becomes less sensitive to order quantity from the manufacturer as the quantity increases. When the reserve profit of \( S_2 \) is zero in (ii), a structure similar to Scenario N holds since the ex post profit of the manufacturer is linear (without the fixed payment), instead of convex. The IGFR property can guarantee the uniqueness of the optimal order quantity, which has an appealing implication that the manufacturer's order quantity from \( S_1 \) becomes less elastic as it holds more stock, and thus is less sensitive to any price cuts offered by \( S_1 \).

Below, we discuss how the options of selecting a local supplier as backup, and the adopted contract type influence performances of \( S_1, S_2 \), and the manufacturer. Let \( U^*(x) = 0 \). With the optimal wholesale price \( w \) determined by \( S_1 \) through Theorem 3, the manufacturer's profit function is rewritten as:
\[ \pi_m^* = r_T E \min \{ D, Q_i^* \} + sE \{ Q_i^* - D \} + w_i Q_i^* + E \{ Q_i^* (D - Q_i^*) \}. \] (22)

for \( i = N, P \) or \( O \) respectively.

Referring to Propositions 1 and 3, profit of \( S_2 \) is represented by:
\[ \pi_m^* = \int_{Q_i^*}^{Q_i^*} x dF \left( \frac{c_i - c_i}{E} \left( D - Q_i^* \right) + (\pi_n - \pi_i) \right) dF(D) + \beta \pi_i + (1 - \beta) \pi_n, \] (23)
\[ \pi_m^* = \int_{Q_i^*}^{Q_i^*} x dF \left( \frac{c_i - c_i}{E} \left( D - Q_i^* \right) + (\pi_n - \pi_i) \right) dF(D) + \beta \pi_i + (1 - \beta) \pi_n. \] (24)

As can be observed from (23) and (24), \( S_2 \) will obtain a positive profit from its trades with the manufacturer when it is in low cost type, and the PSV is high enough (\( x \geq x_t \)). The variable profit margin is \( (c_i - c_i)E + \beta \) under the price-only contract and \( (c_i - c_i)L_i^b \) under the \( (L, T) \) contract. Since \( L_i^b \leq L_T \) profit margin is higher under the \( (L, T) \) contract. Besides, low cost \( S_2 \) obtains \( (\pi_n - \pi_i) \) due to the information distortion.

We theoretically identify the relative positions of each party under Scenario N, O or P, in the special case when \( \pi_i = \pi_n = 0 \).

**Theorem 4.** When \( \pi_i = \pi_n = 0 \), the following inequalities hold:
\[ \begin{align*}
(i) \quad & \pi_m^*(Q_i^*) > \pi_m^*(Q_i^*), \\
(ii) \quad & \pi_m^*(Q_i^*) > \pi_m^*(Q_o^*), \\
(iii) \quad & \pi_m^*(Q_o^*) > \pi_m^*(Q_n^*).
\end{align*} \]

This theorem characterizes performances of parties under different scenarios when \( \pi_i = \pi_n = 0 \). By buying from the local supplier and diversifying its supply base, the manufacturer can increase its profit, irrespective of the type of contract used. The competition between \( S_1 \) and \( S_2 \) benefits the manufacturer despite the manufacturer having little bargaining power when dealing with \( S_1, S_2 \) provides the manufacturer a certain degree of flexibility to hedge the upside risk of the market demand. Due to the competition, \( S_1 \)'s profit is reduced under both contracts. The more efficient the contract adopted by the manufacturer is, the higher are the benefits that the manufacturer can extract from \( S_1, S_2 \)’s profits increase, because of additional supplies made to the manufacturer. \( S_2 \) indeed earns a higher profit under the \( (L, T) \) contract than under the price-only contract as \( S_2 \) may get larger orders.

In the above analysis, we assume that \( \pi_i = \pi_n = 0 \). It is interesting to investigate how different values of \( \pi_i, \pi_n \) affect each participant’s performance. However, the general case is analytically intractable and, therefore, we turn to numerical analysis. We create an example where \( b = 1, r_1 = 80, r_2 = 50, c_i = 20, p = 5, c_2 = 25, c_1 = 50, \beta = 0.4, a = 0.4, s = 2 \) and \( L = 5 \). The customer demand is uniformly distributed in \( [0, 100] \). We set \( \pi_n = 50 \), \( 15 \), and let \( \pi_i = 0.5 \pi_n \), and 1.0\( \pi_n \). Table 1 shows profits of the manufacturer, \( S_1, S_2 \), and the chain, under the \( (L, T) \) contract. The percentage (in parentheses) denotes the ratio of the participant’s profit to the chain’s profit. Table 2 reflects the corresponding profits under the price-only contract.

**Table 1**

<table>
<thead>
<tr>
<th>( \pi_i )</th>
<th>( \pi_n^0 )</th>
<th>( \pi_n^1 )</th>
<th>( \pi_n^2 )</th>
<th>Chain’s profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \pi_n = 50 )</td>
<td>25</td>
<td>983.9 (50.2%)</td>
<td>898.9 (45.9%)</td>
<td>77.5 (4.0%)</td>
</tr>
<tr>
<td>50</td>
<td>983.9 (50.0%)</td>
<td>898.9 (45.7%)</td>
<td>85.5 (4.3%)</td>
<td>1967.9</td>
</tr>
<tr>
<td>( \pi_n = 150 )</td>
<td>75</td>
<td>914.5 (45.6%)</td>
<td>936.1 (46.7%)</td>
<td>155.8 (7.8%)</td>
</tr>
<tr>
<td>150</td>
<td>911.2 (44.9%)</td>
<td>936.1 (46.1%)</td>
<td>182.6 (9.0%)</td>
<td>2029.9</td>
</tr>
<tr>
<td>( \pi_n = 250 )</td>
<td>125</td>
<td>857.5 (41.6%)</td>
<td>974.1 (47.3%)</td>
<td>228.0 (11.1%)</td>
</tr>
<tr>
<td>250</td>
<td>848.2 (40.4%)</td>
<td>974.1 (46.4%)</td>
<td>277.7 (13.2%)</td>
<td>2100.0</td>
</tr>
</tbody>
</table>
volved. Consistent with the trend demonstrated in Theorem 4, both $S_2$ and the manufacturer benefit, while $S_1$’s profit declines from adoption of a price-only or $(L,T)$ contract.

We also observe that the bargaining power of high cost type $S_2$ has significant effects on both the manufacturer and $S_1$. When $\pi_0$ remains constant, the manufacturer’s profit is slightly decreased and $S_1$’s profit is slightly increased when increasing $\pi_0$ under both contracts. In contrast, these trends become more obvious as $\pi_0$ increases. The manufacturer gets a greater share of the chain’s profit (45.4% on average under the $(L,T)$ contract and 43.3% under the price-only contract), which is sharply higher than the 33.3% share it gets when $S_2$ does not participate. Therefore, the competition between suppliers helps the manufacturer increase its profit.

5. Sensitivity analysis

From the analysis in the last section, we recognize that the type of contract with the local supplier will influence the manufacturer’s profit. However, there is a question which remains unanswered: “Under what market conditions has the $(L,T)$ contract higher advantages over the common price-only contract?” The answer to this question can help the manufacturer decide which contract to use, if execution of the optimal contract has costs attached to it. Therefore, we numerically test how the market acceptance of substitutable modules ($x$), the uncertain nature of local supplier ($b$), and the tardiness cost ($p$) affect the manufacturer’s profit.

5.1. Sensitivity analysis of $x$

We create an example where $b = 1$, $r_1 = 80$, $r_2 = 60$, $p = 5$, $c_1 = 20$, $c_1 = 25$, $c_0 = 50$, $\beta = 0.4$, $s = 2$, $I = 5$, $\pi_1 = 75$ and $\pi_0 = 150$. The customer demand is uniform between $[0,100]$. In the tests, we change $x$ from 0.1 to 1.0 in increments of 0.05. Fig. 1 illustrates the impact of market acceptance of substitutable modules, $x$, on the manufacturer’s profits, in Scenarios $N,O$ and $P$.

Although $x$ has no effect on ex post profit functions under either contract, it has direct influence on the PSV. As $x$ increases, more customers are willing to accept products with modules of $S_2$, and thus inclusion of the local supplier in the chain can improve profitability of the manufacturer under both contracts. The $(L,T)$ contract performs much better than the price-only contract at a higher $x$ since a higher PSV magnifies the advantage of $U^1(\cdot)$ on $U^2(\cdot)$.

5.2. Sensitivity analysis of $b$

We use the same parameter setting as before, except that $x$ is fixed at 0.4 here. In the tests, we change $b$ from 0.1 to 0.9 in increments of 0.1: Fig. 2 shows the manufacturer’s profits in all scenarios.

As the ex ante probability of low cost type, $b$, increases, involvement of $S_2$ still brings higher profits to the manufacturer under both contracts, due to cost efficiency of the urgent supplier. Table 3 can illustrate the intuition behind this phenomenon. The profit margin ($A_b^1$ in the region of $(x_1^b,x_0^b)$), and $A_b^2$ in the region of $(x_1^b,\infty)$ under the price-only contract; $A_b^1$ in the region of $(x_1^b,x_0^b)$, and $A_b^3$ in the region of $(x_1^b,\infty)$ under the $(L,T)$ contract) increases with $\beta$ due to lower costs of $S_2$. We also observe that the manufacturer delays the inclusion of high cost type $S_2$ (the thresholds of $x_1^b$ and $x_0^b$ increase) since $S_2$ has higher probability of being low cost type. The $(L,T)$ contract performs better at higher $\beta$ as the efficient contract can better utilize this information by extracting more profit when only low cost type $S_2$ enters the market, and by differentiating between different $S_2$ when both types are involved. Moreover, we can see that, when $\beta$ is large (0.9 in the

<table>
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<th>Table 2</th>
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<tr>
<td>Profits under the price-only contract.</td>
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<td>$\pi_1$, $\pi_0^m$, $\pi_0^c$, $\pi_0^e$, Chain’s profit</td>
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<td>150</td>
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<td>$\pi_0 = 250$</td>
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<table>
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<th>Fig. 1. Manufacturer’s profit differences as a function of $x$.</th>
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<tr>
<td>Fig. 2. Manufacturer’s profit differences as a function of $b$.</td>
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<th>Table 3</th>
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<tr>
<td>Effects of $\beta$ on the ex post profits under both contracts.</td>
</tr>
<tr>
<td>$\beta$</td>
</tr>
<tr>
<td>0.3</td>
</tr>
<tr>
<td>0.5</td>
</tr>
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<td>0.7</td>
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<td>0.9</td>
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</table>
example), the manufacturer only includes low cost type $S_2$ under both contracts, which are characterized in Propositions 1 and 3.

5.3. Sensitivity analysis of $p$

We use the same parameter setting as in the previous analysis, except that $\beta = 0.4$. In the tests, we change $p$ from 3 to 8, in increments of 0.5. The manufacturer’s profits in Scenarios $N$, $O$ and $P$ are depicted in Fig. 3.

When the unit tardiness cost, $p$, increases, benefits from using urgent supplier $S_2$ decrease. Hence we observe that the profit of the manufacturer is decreasing in both scenarios, $O$ and $P$. However the magnitude of this decrease is small in Scenario $P$. Table 4 explains the intuition as follows. As $p$ increases, the manufacturer needs more volume to balance the reserve profits of $S_1$ and thus thresholds under both contracts increase. Moreover, the profit margin decreases since the manufacturer has to reimburse customers more for the inferior quality and/or extended delivery. Both effects weaken benefit of inclusion of $S_2$. However, the efficiency of $(L,T)$ contract can help the manufacturer earn a reasonable profit margin, compared to the price-only contract. Therefore, $(L,T)$ contract performs much better when the economic environment becomes worse ($p$ increases).

6. Conclusion

This paper studies the effects of the presence of a contingent urgent supplier with private cost information on the performance of both the prime supplier and the manufacturer. Contingent contracts of both types, price-only and $(L,T)$, are investigated. The manufacturer’s optimal strategy for sourcing from the urgent supplier follows a $\beta$-dependent threshold policy under both contracts.

We find that right combinations of lead time quotations and transfer payments can induce the urgent supplier to share its true cost information, whereas under the price-only contract, the urgent supplier delays its delivery time as much as possible. We also observe that involvement of the urgent supplier benefits the manufacturer and hurts the prime supplier, irrespective of the type of contract; the efficiency of the contingent contract enhances this phenomenon. From numerical examinations, we find that the manufacturer is more likely to adopt the optimal incentive contract when possibility of substitutability by the local supplier is high, or when the ex ante probability of low cost type, local supplier, is high, or when the cost of delays in supplies to end customers is high.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ejor.2010.03.012.

References


Table 4

<table>
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<tr>
<th>$p$</th>
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Fig. 3. Manufacturer’s profit differences as a function of $p$.


