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Research Article

Procurement Strategy with Backup Sourcing under Stochastic Supply Risk

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Supply risk can have a negative impact on a manufacturer's performance. Backup sourcing is one of the most commonly used strategies to mitigate the adverse consequences of supply risks. In this paper, we study a procurement strategy with backup sourcing when a manufacturer faces stochastic supply risk and demand. The optimal decisions of the players involved are investigated theoretically using the game theoretic framework, and the impacts of the key parameters, such as wholesale prices and the risk probability, are assessed numerically under supply information symmetry and asymmetry. The results illustrate that the reservation price provided by the backup supplier varies greatly under different information-sharing conditions. Reservation quantity is negatively correlated with the reservation price, which is affected by the risk probability, wholesale prices, and marginal cost of the backup supplier. We also show that given the same wholesale prices, the potential supply risk has a substantial impact on the manufacturer's expected profit, and the performance of the manufacturer under asymmetrical supply information is not always better than that under symmetrical information. In addition, we also discuss the impact of wholesale prices on reservation price and participants' profits based on numerical examples. The research enriches the understanding of a procurement strategy under stochastic supply risk, and the conclusions have certain management significance.

1. Introduction

With the promotion and application of the asset-light strategy, more original equipment manufacturers (OEMs) outsource noncore manufacture business to reduce capital investment and ensure the core competitiveness of enterprises. Boeing, the world's largest aircraft manufacturer, only produces cockpits and wing tips; Google, Samsung, Sony, and many other original equipment manufacturers adopt radio frequency front-end designed and manufactured by Qualcomm Technologies. OEMs and external suppliers form a partnership in the process of business outsourcing, and the manufacturer's service level largely depends on the performance of outsourced suppliers. However, manufacturing outsourcing complicates OEMs' ability to completely control the production process of contract suppliers. In many cases, OEMs can only obtain partially ordered products or the quality of products delivered cannot be guaranteed, thus introducing a supply risk [1]; for example, the impact of Philips' fire incidents on Ericsson and Nokia [2], the volcanic eruption in Iceland that stopped Nissan from producing three auto models, BMW's production cuts in Germany [3], and an earthquake in Japan caused companies around the world to rebuild their supply chains to cope with supply disruption. All of these incidents indicated that a supply risk can cause large or even fatal injuries to enterprises.

Realizing the potential losses from supply risks, enterprises have shown a growing interest in incorporating risk management into their operations. Dual sourcing is a prevailing strategy for mitigating supply risk to ensure supply chain stability [3]. One approach to work with a dual supply strategy is to order products from two or multiple suppliers at the same time (Tomlin [4]; Yu, Zeng, and Zhao [5]; Ju, Gabor, and Ommeren [6]). All suppliers provide similar-quality products for enterprises, but homogeneous products may have differences in terms of price, lead time, reliability, and other attributes [7]. Another method is to allow enterprises to order products in advance from the backup supplier and decide whether to place an emergency order after observing the primary supplier's supply [8]. In addition, research on the coexistence of multiple suppliers and backup suppliers also exist [9]. Generally, since enterprises must consider production and procurement costs, the primary suppliers are always unreliable but the wholesale price is lower, while the backup supplier is reliable but the wholesale price is higher. Overall, regardless of how dual-source procurement is implemented, dual-source procurement is beneficial for reducing the bullwhip effect in supply, enhancing the flexibility and stability of the supply chain, and reducing operating costs [10].

While dual sourcing has attracted considerable attention, most studies focus on its effect on manufacturer performance under disruption risk. Research on a procurement strategy under stochastic supply risk and considering the benefit of each participant is very limited. In this paper, we consider a supply chain in which the manufacturer mainly procures a critical component from one primary supplier with stochastic capacity risk, and supply chain stability is built through a capacity reservation contract with a backup supplier. We examine the manufacturer's strategic purchasing use of a backup supplier in a single-period model. We will mainly solve the following problems: when does the manufacturer need to reserve capacity? What is the optimal reservation quantity for the manufacturer and how will the reservation price affect it? What is the optimal quantity of a manufacturer's emergency order when the primary supplier's supply has been observed? In addition, we will also compare the impact of information sharing on the reservation price and expected profits of the manufacturer and backup supplier based on procurement strategy models under information asymmetry and symmetry.

The major contribution of this paper is that it extends research on a procurement strategy with backup sourcing from the following dimensions. First, we study the capacity reservation strategy and utilization strategy in the context of a supply chain with both stochastic supply risk and demand. In this setting, the backup is an important component in maintaining supply chain stability. Second, we consider the Stackelberg game problem in the capacity reservation with a backup supplier as the pioneer. We believe that the manufacturer is at a disadvantage in emergency procurement, and the decision made in the presence of risk should be mutually beneficial and acceptable to both partners. In addition, we also consider the impact of information sharing on the procurement strategy. To our best knowledge, this has not been examined in the existing research on dual sourcing procurement.

The remainder of this paper is organized as follows. Section 2 reviews related literature. Section 3 presents the model setup. Section 4 characterizes the procurement strategy of the manufacturer and the pricing strategy of the backup supplier in different cases. Section 5 provides numerical studies. We conclude this paper in Section 6. All the proofs are included in the Appendix.

2. Literature Review

The importance of supplier diversification for mitigating supply risks has been recognized, and a large amount of research has emphasized various issues around sourcing strategies under supply risk. Multiple sourcing provides greater assurance of timely delivery and increased flexibility of the supply chain [11]. Burke, Carrillo and Vakharia [12], Federgruen and Nan [13], Mansini, Savelsbergh and Tocchella [14], and Silbermayr and Minner [3] provide in-depth discussions of multisource procurement strategy issues, such as supplier quantity selection and optimal order. However, a diversification strategy may involve higher costs and complexity [15]. Fang et al. [2] study the performance of different sourcing strategies (single, dual, multiple, and contingent sourcing) and find that the addition of a third or more suppliers yields considerably reduced marginal benefits.

Considering relevance, we summarize the existing literature on dual sourcing procurement from four profiles, which can highlight the literature positioning of this paper, as shown in Table 1. In these studies, most scholars only focus on the manufacturer's behavior and ignore the game between the manufacturer and the backup supplier. Actually, when a manufacturer cooperates with a backup supplier to mitigate potential supply risks, it may not be the primary customer of the backup supplier. Thus, the backup supplier will maximize its own interests through the reservation price game in the process. Therefore, the interaction between the manufacturer and reserve supplier should not be neglected. In addition, due to different research objectives and the diversity of parameter settings, the decision-making scenarios of the procurement strategy with reliable and unreliable suppliers are very complicated. Although the paper is most similar to those of Zeng and Yu [16] and Chen and Xiao [17] in terms of risk profiles and strategic profiles, significant differences in specific methods and objectives remain.

In this paper, we focus on the procurement strategy with backup sourcing, where the manufacturer faces stochastic supply risk and demand risk. Using the game theory, we study the interaction between the backup supplier's reservation pricing and the manufacturer's optimal reservation contract in which the backup supplier is the pioneer in the Stackelberg game, which represents the major gap that we try to fill. We argue that the reservation price determined by the backup supplier has a significant impact on the manufacturer's capacity reservation strategy. We assume that the backup supplier is in the leading position in this game and first determines the price strategy according to the manufacturer's response to the price, and the manufacturer will determine the reserved amount of capacity based on the observed reservation price.

Moreover, another focus of this paper is the impact of information sharing on procurement strategies. Some existing research on procurement strategies has focused on this issue. Wagner and Friedl [18] analyze the impact of symmetric or asymmetric information about the backup supplier's cost structure on the transformation of procurement strategies. Yang, Aydin, and Babich [19] consider that a supplier has private information on supply reliability, and they investigate the risk-management strategies of the manufacturer. Xu et al.

Table 1: Representative studies of dual source procurement.

Authors	Risk profile	Strategy profile	Objective	Characteristics/ Contributions
Yu et al. [5]	Deterministic demand Supply disruption	Dual sourcing	Sourcing strategy selection	Price-sensitive demand
J. Chen, Zhao and Yun [22]	Stochastic demand Supply disruption	Dual sourcing	Order decision	A multiperiod inventory system and the backup supplier has limited capacity
Sawik [8]	Deterministic demand Supply disruption	Dual sourcing	Supplier selection; Order scheduling	Integration of supplier selection and customer order scheduling
Zeng and Yu [16]	Stochastic demand Stochastic supply risk	Backup sourcing	Reserved capacity; Revenue-sharing contracts	A combination of a decision-tree and the Nash game is used
Tao, Sethi and Zhang [23]	Deterministic demand Stochastic supply risk	Dual sourcing	Optimal procurement strategy	Price-sensitive and elastic demand; the two suppliers are both unreliable
Huang and Xu [9]	Stochastic demand Supply disruption	Backup sourcing & Dual sourcing	Sourcing strategy selection	Coexistence and exclusivity of backup sourcing and dual sourcing
Chen and Xiao [17]	Stochastic demand Stochastic supply risk	Backup sourcing	Order strategy	The value of backup sourcing in decentralized and centralized channels
Silbermayr and Minner [24]	Deterministic demand Supply disruption	Dual sourcing	Order allocation	The impacts of supplier characteristics, reliability, cost and learning ability on the procurement strategy
Li and Li [25]	Stochastic demand Supply disruption	Dual sourcing	Order strategy	Maximizing the expected utility considering a loss-averse preference
Hou, Zeng and Li [7]	Deterministic demand Supply disruption	Backup sourcing	Capacity reservation contract	The contract has minimum order quantity constraints
Freeman et al. [26]	Stochastic demand Supply disruption	Dual sourcing	Optimal strategy	Product alternatives are considered
Zhe and Chen [27]	Deterministic demand Supply disruption	Backup sourcing	Strategy selection	Consider three categories of backup strategic options

[20] evaluate how the involvement of a backup supplier with private cost information affects the performance of the primary supplier and the manufacturer by constructing a Stackelberg game model. Nosoohi and Nookabadi [21] investigate an option contract design problem of the manufacturer when the supplier has private information on cost. In contrast to the above works, which regard cost information as private information, another focus of this paper is to analyze the impact of supply information on the purchasing strategies of manufacturers and the profits of backup suppliers.

3. Model Description

We consider a single-period problem where the manufacturer faces a stochastic market demand D with a density function of $f_1(D)$, which is subject to uniform distribution, and orders N units of components from the primary supplier with unit price w at the beginning of the period. This primary supplier is prone to stochastic capacity risk; we denote the probability for the primary supplier of capacity loss as p_r and the probability of working normally is therefore $1-p_r$. When the production capacity is abnormal, the residual capacity θ is also composed of random variables that also obey a uniform distribution with a density function of $f_2(\theta)$. We assume that the manufacturer takes the initiative in the market and that the primary supplier will endeavor to meet the needs of the manufacturer. That is, the primary supplier can provide N units of components when it works normally and $N\theta$ units when its capacity is partially disrupted.

In addition, the manufacturer will evaluate the production status of the primary supplier, i.e., the probability of supply risks, before each phase begins and decide whether to reserve components according to the evaluation result, the negotiated wholesale prices ($\eta_1 w$ and $\eta_2 w$), and the reservation price provided (k) by the backup supplier. When the primary supplier's production is abnormal, the manufacturer will decide whether to place an emergency order or the order quantity if the manufacturer reserves components depending on the actual situation of risk.

Facing possible supply risk, we study the optimal procurement strategies that may be adopted by the manufacturer under different situations: one strategy is that the manufacturer regards the supply information of the primary supplier as private information. The backup supplier only has access to the expected emergency order quantity and the risk possibility of the primary supplier when negotiating the reserved contract with the manufacturer. The other strategy is that the manufacturer shares supply information with the backup supplier. That is, the backup supplier knows not only the risk probability before offering the reservation price but also the quantity delivered by the primary supplier under different risk conditions.

We assume that the backup supplier is reliable and that the emergency order will be delivered on time. For the manufacturer, to ensure that these components can be delivered by the backup supplier in time, the manufacturer must pay extra reserve expenses. We assume that this cost is linearly related to the reservation quantity. In addition, for the components reserved, the wholesale price will be $\eta_1 w$, and the manufacturer can still buy the components that are not reserved but at a higher price $\eta_2 w$. Thus, we can describe the emergency order cost when the manufacturer purchases from the backup supplier using the following equation:

$$c_R(x) = \begin{cases} kQ + \eta_1 w x & x \le Q \\ kQ + \eta_1 w Q + \eta_2 w (x - Q) & x > Q \end{cases} \tag{1}$$

where x represents the emergency order quantity and Q represents the reservation quantity. kQ is the reservation cost, $\eta_1 w x$ is the purchase cost when the actual emergency order quantity is lower than the reserved quantity, and $\eta_1 w Q + \eta_2 w(x - Q)$ is the purchase cost when the actual emergency order quantity is greater than the reserved quantity. The backup supplier must bear the operating cost caused by production rescheduling, resource reallocation, adjusting delivery dates for other customers and so on. Therefore, in this paper, we consider $w \le \eta_1 w < \eta_2 w < p$.

4. Optimal Decision Model with Stochastic Supply Risk

The procurement strategy under supply risk includes three decision-making stages: in the first stage, the backup supplier offers the reservation price to the manufacturer; then, the manufacturer determines the reservation quantity according to the reservation price in the second stage and determines the emergency order quantity according to the specific situation of risk in the third stage. We characterize these optimal decisions in this section.

4.1. The Emergency Ordering Decision Stage. In the third stage, the manufacturer makes ordering decisions contingent on the state of the primary supplier. Suppose that the quantity reserved by the manufacturer in the second stage is Q and that the reservation price provided by the supplier is k. Therefore, the profit of the manufacturer when the backup is utilized can be characterized as

$$\pi_M(q;\theta) = \begin{cases} -wN\theta - \eta_1 w q - kQ + h(N\theta + q) & q \le Q \\ -wN\theta - \eta_1 w Q - \eta_2 (q - Q) - kQ + h(N\theta + q) & q > Q \end{cases} \tag{2}$$

Equation (2) denotes the manufacturer's profit when the emergency order quantity q is less than or greater than the reservation quantity Q. We assume that each unit of a component can produce one unit of a finished product whose residual value is 0. Therefore, the quantity of the finished products that can be produced at the end of the period is $N\theta + q$; therefore, the expected revenue that the manufacturer can obtain is $h(N\theta + q) = p(\int_0^{N\theta+q} D f_1(D) dD + \int_{N\theta+q}^{b} (N\theta + q) f_1(D) dD)$. Let q^* denote the optimal emergency order quantity, and its value is given in the following proposition.

Proposition 1. *When the primary supplier's order delivery rate satisfies $\theta \le b(p - \eta_1 w)/Np$, the optimal emergency order quantity is*

$$q^* = \begin{cases} 0 & \theta > \dfrac{b(p - \eta_1 w)}{Np} \\ q_1 & \dfrac{b(p - \eta_1 w) - pQ}{Np} \le \theta \le \dfrac{b(p - \eta_1 w)}{Np} \\ Q & \dfrac{b(p - \eta_2 w) - pQ}{Np} < \theta < \dfrac{b(p - \eta_1 w) - pQ}{Np} \\ q_2 & \theta < \dfrac{b(p - \eta_2 w) - pQ}{Np} \end{cases} \tag{3}$$

where $q_1 = (b(p - \eta_1 w) - N\theta p)/p$, $q_2 = (b(p - \eta_2 w) - N\theta p)/p$.

From Proposition 1, one can intuitively understand that the fewer components that the primary supplier actually supplies, the greater the quantity that the manufacturer will order from the backup supplier. The emergency order quantity is also affected by the reservation quantity.

4.2. The Reservation Ordering Decision Stage. In the second stage, the manufacturer determines the reservation quantity to maximize the expected profit based on the actual purchasing quantity q^* in the emergency ordering decision stage and the reservation price k. If the manufacturer reserves Q units of components, then the manufacturer's expected profit function can be expressed as follows:

$$E(\pi_M^R) = (1 - p_r)(-wN\theta - kQ + h(N)) + p_r \int \pi_M(q^*;\theta) f_2(\theta) d\theta \tag{4}$$

In (4), the first part, which is multiplied by $1-p_r$, denotes the profit when the supplier works normally; the second term, multiplied by p_r, shows the profit function when the primary supplier suffers a risk and can only deliver $N\theta$ units of components to the manufacturer.

Proposition 2. *When the reservation price of a unit component k is given, the optimal reservation quantity of the manufacturer is as follows:*

$$Q^* = \begin{cases} \Phi_1 k + \Phi_2 & p_r > \dfrac{2pNk}{w(\eta_2-\eta_1)(2p-w(\eta_1+\eta_2))b} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

where $\Phi_1 = -N/w(-\eta_1+\eta_2)p_r$, $\Phi_2 = (2pb-(\eta_2+\eta_1)bw)/2p$, $k>0$

Proposition 2 describes the conditions under which the manufacturer will reserve components and the optimal reservation quantity. Note that $\eta_1 w < \eta_2 w < p$, $\Phi_1 < 0$ regardless of the value of p_r when $p_r > 0$, indicating that the reservation price has a significant impact on the quantity that the manufacturer reserved. The lower the reservation price is, the more the manufacturer will reserve. Note that $\widehat{p_r} = 2pNk/w(-\eta_1+\eta_2)(2p-w(\eta_1+\eta_2))b$. From Proposition 2, backup sourcing will be utilized only when $p_r > \widehat{p_r}$. Notably, the wholesale prices and reservation price have been identified by the manufacturer and the backup supplier; therefore, we can regard $\widehat{p_r}$ as the parameters that can reflect the manufacturer's risk tolerance. We can obtain the following corollary.

Corollary 3. *The manufacturer's tolerance for supply risk increases as the reservation price k increases.*

4.3. The Pricing Decision Stage. As a pioneer in the game, we assume that the backup supplier knows the manufacturer's reflection function on its reservation price. Therefore, the reservation price should be accepted by both parties willingly, and the backup supplier will select its own optimal pricing strategy based on the manufacturer's strategy to maximize its own interests while ensuring that the reserved price can be accepted by the manufacturer.

4.3.1. The Pricing Decision under Asymmetric Supply Information. If the delivery information is the manufacturer's private information as we emphasized earlier, then the backup supplier can only set the reservation price $k_A > 0$ according to the expected purchase quantity provided by the manufacturer. According to (3), the expected quantity of the manufacturer's emergency order is

$$\begin{aligned} E(q_A^*) = &\int_{(b\cdot(p-\eta_{A1}w)-p\cdot Q_A)/Np}^{b(p-\eta_{A1}w)/Np} q_{A1} f_2(\theta)\,d\theta \\ &+ \int_{(b\cdot(p-\eta_{A2}w)-p\cdot Q_A)/Np}^{(b\cdot(p-\eta_{A1}w)-p\cdot Q_A)/Np} Q_A f_2(\theta)\,d\theta \\ &+ \int_0^{(b\cdot(p-\eta_{A2}w)-p\cdot Q_A)/Np} q_{A2} f_2(\theta)\,d\theta \end{aligned} \quad (6)$$

where q_{A1}, q_{A2} represent the emergency order quantity, and other parameters are set in the same manner. In this paper, we assume that θ obeys the distribution of uniform 0-1; then, (6) can be simplified as follows:

$$E(q_A^*) = \frac{b^2(p-w\eta_{A2})^2}{2Np^2} - \frac{wQ_A(\eta_{A1}-\eta_{A2})b}{Np} \quad (7)$$

Since the backup supplier may be a primary supplier to other manufacturers, we assume that the marginal production costs (c_0) are stable and unaffected by the manufacturer's reservation quantity. Therefore, the profit of the backup supplier can be calculated as

$$\pi_{BA}^R(k_A) = \begin{cases} k_A Q_A^* + p_r(\eta_{A1}w - c_0)E(q_A^*) & E\left(q_A^{R*}\right) \le Q_A^* \\ k_A Q_A^* + p_r((\eta_{A2}w-c_0)(E(q_A^*)-Q_A^*) + (\eta_{A1}w-c_0)Q_A^*) & E\left(q_A^{R*}\right) > Q_A^* \end{cases} \quad (8)$$

Equation (8) denotes the manufacturer's profit when the expected emergency order quantity $E(q_A^*)$ is less than or greater than the reservation quantity Q_A^*, where $\eta_{A1}w - c_0$ and $\eta_{A2}w - c_0$ indicate the sales profit of the unit components when the actual sales volume is less than or greater than the reservation quantity.

Proposition 4. *When the backup supplier has access to information about the expected quantity of the manufacturer's emergency procurement $E(q_A^*)$ and the risk probability of its primary supplier p_r, the optimal reservation price provided by the backup supplier to the manufacturer is as follows:*

$$k_A^* = \begin{cases} \max\{k_{A1}^*, 0\} & \dfrac{(2p-2c_0)b-pN}{2b^2} \ge \dfrac{(w\eta_{A2}+p)^2}{w(\eta_{A1}-\eta_{A2})b+pN} \\ \max\{k_{A2}^*, 0\} & \dfrac{(2p-2c_0)b-pN}{2b^2} < \dfrac{(w\eta_{A2}+p)^2}{w(\eta_{A1}-\eta_{A2})b+pN} \end{cases} \quad (9)$$

where $k_{A1}^* = ((\eta_{A1}-\eta_{A2})(\eta_{A1}w-c_0)wb/2Np)p_r - \Phi_2/2\Phi_1$; $k_{A2}^* = (\eta_{A2}-\eta_{A1})(Np+b(c_0-\eta_{A2}w))wp_r/2Np - \Phi_2/2\Phi_1$.

Proposition 4 shows the optimal pricing strategy of the backup supplier. Considering $bw(\eta_{A1} - \eta_{A2}) + Np > 0$, using equal (9), proving that ${k_{A2}}^* - {k_{A1}}^* > 0$ is easy. Additionally, the backup supplier has different pricing decisions when facing different wholesale prices. If η_{A1} is lower and η_{A2} is high, the supplier is more likely to choose a higher pricing strategy, while it may use a lower reservation pricing strategy when η_{A1} is high. When we further analyze the monotonicity of the reservation price, we can obtain the following corollary.

Corollary 5. *When $p_r \in (0, 1]$,*

(1) *if $(3\eta_{A1} + \eta_{A2})w < 2p + 2c_0$, then ${k_{A1}}^* > 0$ and ${k_{A1}}^*$ increases with p_r;*

(2) *if $2(p + c_0) + 2Np/b > (\eta_{A1} + 3\eta_{A2})w$, then ${k_{A2}}^* > 0$ and ${k_{A2}}^*$ increases with p_r.*

According to Corollary 5, the risk probability is an important factor affecting the reservation price. When the reservation price ${k_A}^* > 0$, a higher risk probability corresponds to a higher reservation price. When the reservation price ${k_A}^* = 0$, retaining sufficient components is advantageous for the manufacturer. In this case, we assume that the manufacturer's reservation quantity equals the maximum emergency-ordered quantity, i.e., ${Q_A}^* = q_{A1}$, where $\eta_1 = \eta_{A1}$, $\eta_{A2} = 0$, and $\theta = 0$. Therefore, we can draw the following corollary.

Corollary 6. *The reservation quantity determined by the manufacturer under information asymmetry is as follows:*

$$
{Q_A}^* = \begin{cases} \dfrac{b\left(p - \eta_1 w\right)}{p} & p_r > \widehat{p_r} \text{ and } {k_A}^* = 0 \\ \dfrac{b\left(w\eta_{A1} - w\eta_{A2} + 2p - 2c_0\right)}{4p} & p_r > \widehat{p_r} \text{ and } {k_A}^* = {k_{A1}}^* > 0 \\ \dfrac{\left(2p - 2c_0 + \left(\eta_{A2} - \eta_{A1}\right) w\right) b - 2Np}{4p} & p_r > \widehat{p_r} \text{ and } {k_A}^* = {k_{A2}}^* > 0 \\ 0 & p_r \le \widehat{p_r} \end{cases} \tag{10}
$$

From Corollary 6, we can see intuitively that the impacts of η_{A1} and η_{A2} on the reservation quantity are different. If ${k_A}^* = {k_{A1}}^*$, ${Q_A}^*$ increases with η_{A1} and decreases with η_{A2}, while ${Q_A}^*$ increases with η_{A2} but decreases with η_{A1} if ${k_A}^* = {k_{A2}}^*$.

4.3.2. The Pricing Decision under Symmetric Supply Information. Notably, if the backup supplier is in a favorable position in the reservation contract, then the backup supplier does not expect any loss in the reservation process regardless of how much the manufacturer orders from it. Therefore, the backup supplier will try to achieve symmetry of the supply information. When the backup supplier has exactly the same information as the manufacturer, the profit of the backup supplier can be described as

$$
\begin{aligned}
E\left(\pi_{BS}^{R}\right) &= k_S Q_s^* \\
&+ p_r \left(\int_0^{(b\cdot(p-\eta_{S2}w)-p\cdot Q_s^*)/Np} \left(\left(\eta_{S2}w - c_0\right)\left(q_{S2} - Q_s^*\right)\right.\right. \\
&+ \left.\left(\eta_{S1}w - c_0\right) Q_s^*\right) f_2(\theta)\, d\theta \\
&+ \int_{(b\cdot(p-\eta_{S2}w)-p\cdot Q_s^*)/Np}^{(b\cdot(p-\eta_{S1}w)-p\cdot Q_s^*)/Np} \left(\eta_{S1}w - c_0\right) Q_s^* f_2(\theta)\, d\theta \\
&+ \left.\int_{(b\cdot(p-\eta_{S1}w)-p\cdot Q_s^*)/Np}^{b(p-\eta_{S1}w)/Np} \left(\eta_{S1}w - c_0\right) q_{S1} f_2(\theta)\, d\theta \right)
\end{aligned} \tag{11}
$$

where $\eta_{S1}w$ and $\eta_{S2}w$ also represent the wholesale prices. According to Proposition 2, we have $Q_s^* = \Phi_{S1}k_S + \Phi_{S2}$, where $\Phi_{S1} = -N/w(-\eta_{S1} + \eta_{S2})p_r$, $\Phi_{S2} = (2pb - (\eta_{S2} + \eta_{S1})bw)/2p$. Let ${k_S}^*$ denote the optimal reservation price for the backup supplier under information symmetry; its value is given in the following proposition.

Proposition 7. *When the manufacturer shares supply information with the backup supplier, the optimal reservation price is ${k_S}^*$:*

$$
{k_S}^* = \begin{cases} \dfrac{b\left(p + c_0 - w\eta_{s1} - w\eta_{s2}\right)\left(\eta_{s2} - \eta_{s1}\right) w p_r}{pN} & p + c_0 > w\eta_{s1} + w\eta_{s2} \\ 0 & p + c_0 \le w\eta_{s1} + w\eta_{s2} \end{cases} \tag{12}
$$

Proposition 7 indicates that the wholesale prices $\eta_{S1}w$ and $\eta_{S2}w$ are important reference factors for the backup supplier to decide whether to charge for the reservation fees, and the supply risk probability faced by the manufacturer is the important factor affecting the reservation price.

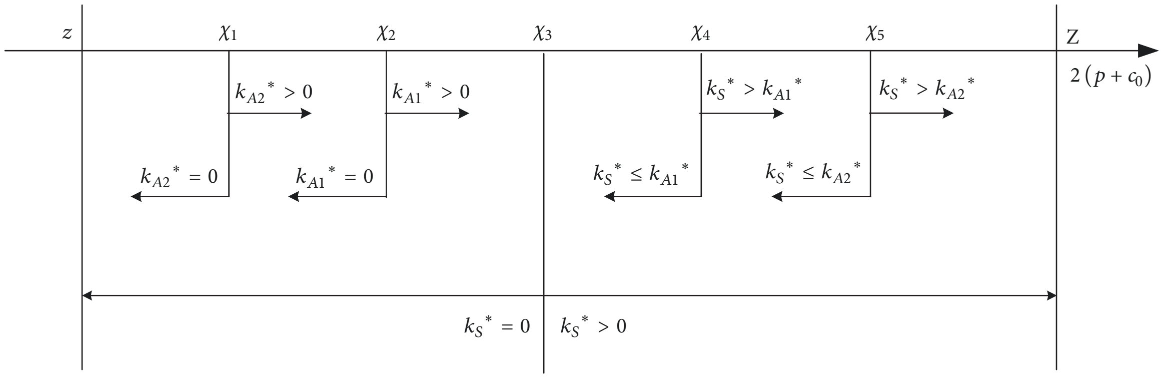

Figure 1: Value relationships between reservation prices.

Table 2: Comparison of reservation prices in different scenarios.

Condition	$z < \phi \leq \chi_1$	$\chi_1 < \phi \leq \chi_2$	$\chi_2 < \phi \leq \chi_3$	$\chi_3 < \phi \leq \chi_4$	$\chi_4 < \phi \leq \chi_5$	$\chi_5 < \phi \leq Z$
${k_A}^*$	$(z, \chi_1]0$ $(\chi_1, Z]\, {k_{A2}}^*$	$(z, \chi_2]0$ $(\chi_2, Z]\, {k_{A2}}^*$	$(z, \chi_2]0$ $(\chi_2, \phi]\, {k_{A1}}^*$ $(\phi, Z]\, {k_{A2}}^*$	$(z, \chi_2]0$ $(\chi_2, \phi]\, {k_{A1}}^*$ $(\phi, Z]\, {k_{A2}}^*$	$(z, \chi_2]0$ $(\chi_2, \phi]\, {k_{A1}}^*$ $(\phi, Z]\, {k_{A2}}^*$	$(z, \chi_2]0$ $(\chi_2, \phi]\, {k_{A1}}^*$ $(\phi, Z]\, {k_{A2}}^*$
${k_s}^*$	$(z, \chi_5]$ ${k_s}^* \leq {k_A}^*$ $(\chi_5, Z]$ ${k_s}^* > {k_A}^*$	$(z, \chi_5]$ ${k_s}^* \leq {k_A}^*$ $(\chi_5, Z]$ ${k_s}^* > {k_A}^*$	$(z, \chi_5]$ ${k_s}^* \leq {k_A}^*$ $(\chi_5, Z]$ ${k_s}^* > {k_A}^*$	$(z, \chi_5]$ ${k_s}^* \leq {k_A}^*$ $(\chi_5, Z]$ ${k_s}^* > {k_A}^*$	$(z, \chi_4]$ & $(\phi, \chi_5]$ ${k_s}^* \leq {k_A}^*$ $(\chi_4, \phi]$ & $(\chi_5, Z]$ ${k_s}^* > {k_A}^*$	$(z, \chi_4]$ ${k_s}^* \leq {k_A}^*$ $(\chi_4, Z]$ ${k_s}^* > {k_A}^*$

Corollary 8. *Under symmetric information, the reservation price increases with p_r when $p + c_0 > w\eta_{s1} + w\eta_{s2}$.*

As in the case of information asymmetry, we also assume that the reservation quantity equals the maximum emergency-ordered quantity and $\eta_{s2} = 0$ when $k_s = 0$. Therefore, we can obtain the following corollary.

Corollary 9. *The reservation quantity under information asymmetry is*

$$Q_S^* = \begin{cases} \dfrac{((\eta_{s1} + \eta_{s2})\, w - 2c_0)\, b}{2p} & p + c_0 > w\eta_{s1} + w\eta_{s2} \text{ and } p_r > \widehat{p_r} \\ 0 & p + c_0 > w\eta_{s1} + w\eta_{s2} \text{ and } p_r \leq \widehat{p_r} \\ \dfrac{b\,(p - \eta_{s1} w)}{p} & p + c_0 \leq w\eta_{s1} + w\eta_{s2} \text{ and } p_r > \widehat{p_r} \end{cases} \quad (13)$$

Corollary 9 indicates the manufacturer's reservation decision in the face of different reservation prices. Obviously, when the manufacturer cooperates with the supplier, Q_S^* increases with $w\eta_{s1}, w\eta_{s2}$ if the wholesale prices are low but decreases with η_{s1} if the wholesale prices are high.

Assume that the wholesale prices are the same under different information-sharing conditions, i.e., $\eta_{A1} = \eta_{S1}$ and $\eta_{A2} = \eta_{S2}$. It is easy to determine that ${k_S}^* > {k_{A1}}^*$ when $2p + 6c_0 > (5\eta_{A1} + 3\eta_{A2})w$, and ${k_S}^* > {k_{A2}}^*$ when $2(p + c_0) > (3\eta_{A1} + \eta_{A2})w + 2pN/b$. According to Propositions 4 and 7, let $\chi_1 = (\eta_{A1} + 3\eta_{A2})w - 2Np/b$, $\chi_2 = (3\eta_{A1} + \eta_{A2})w$, $\chi_3 = 2(w\eta_{s1} + w\eta_{s2})$, $\chi_4 = (5\eta_{A1} + 3\eta_{A2})w - 4c_0$ and $\chi_5 = (3\eta_{A1} + \eta_{A2})w + 2pN/b$. Proving that $\chi_1 \leq \chi_2 \leq \chi_3 \leq \chi_4 \leq \chi_5$ is easy. The value of the reservation price under different information-sharing situations and the relationships between them are shown in Figure 1.

Let $\phi = 4p - Np/b - (2(p - w\eta_{A2})^2 \cdot b)/(pN + w(\eta_{A1} - \eta_{A2})b)$; the reservation price under symmetric information can be simply expressed as

$${k_A}^* = \begin{cases} \max\{{k_{A1}}^*, 0\} & 2(c_0 + p) \leq \phi \\ \max\{{k_{A2}}^*, 0\} & 2(c_0 + p) > \phi \end{cases} \quad (14)$$

Assume that $z \leq 2(p + c_0) \leq Z$. Therefore, we can obtain the following the corollary.

Corollary 10. *The relationship of the reservation price under information symmetry and information asymmetry is shown in Table 2, where $(z, \chi_1]0$ represents ${k_A}^* = 0$ when $z < 2(c_0 + p) \leq \chi_1$.*

5. Numerical Experiment and Comparisons

In the previous section, we obtained analytical results associated with the manufacturer's optimal reservation decision and pricing strategy under information asymmetry and symmetry. In this section, we rely on a numerical analysis to obtain more insights into the properties of procurement decisions and the expected profit functions and identify the relevant price parameters affecting the manufacturer's procurement strategy. For these purposes, we consider the following basic parameters: $p = 20$, $b = 1000$, $c_0 = 3$, $w = 6$, and $N = 700$.

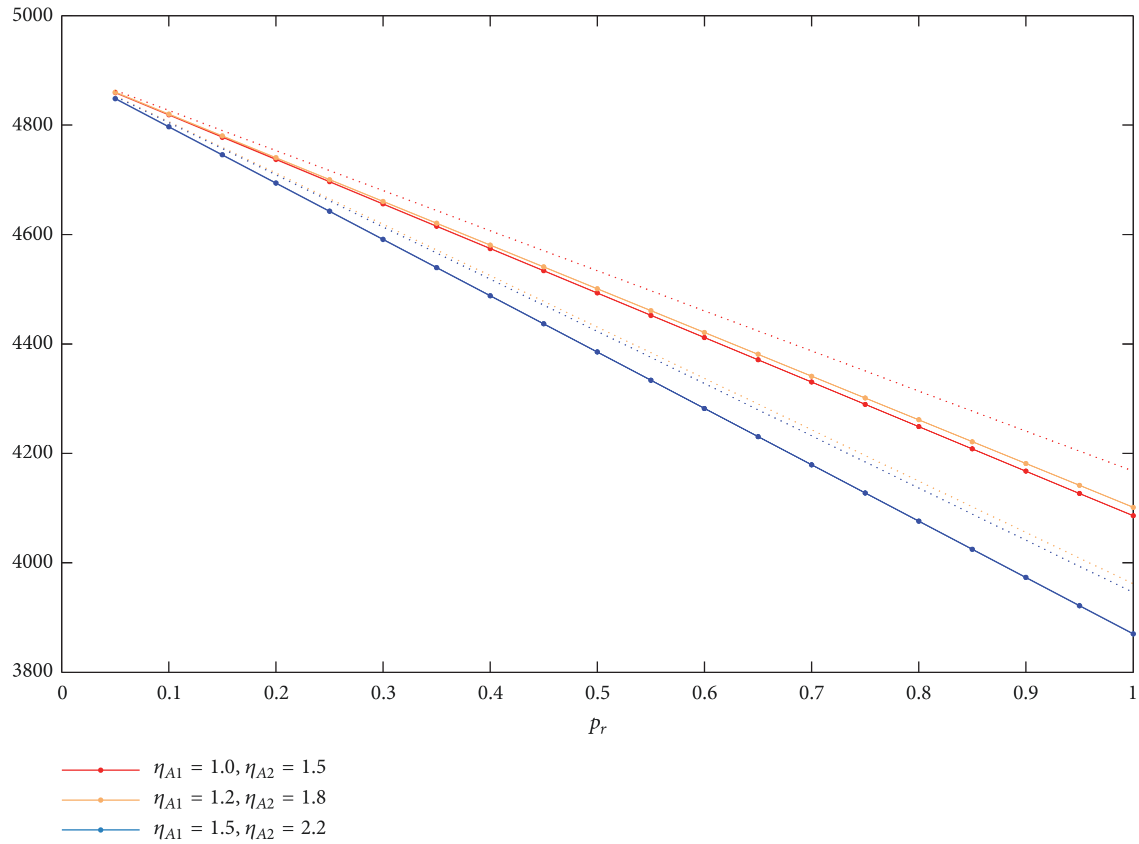

FIGURE 2: The manufacturer's expected profit under different conditions.

5.1. The Impact of Risk Occurrence on the Expected Profit of the Manufacturer. We start by studying the manufacturer's expected profit under the risk probability of the primary supplier p_r and comparing performance under supply information asymmetry and symmetry. Using (4), the manufacturer's expected profit function under different conditions is plotted against the risk probability ranging from 0.05 to 1 with wholesale prices $\eta_1 w = 1.0w$ $\eta_2 w = 1.5w$, $\eta_1 w = 1.2w$ $\eta_2 w = 1.8w$ and $\eta_1 w = 1.5w$ $\eta_2 w = 2.2w$, where $\eta_1 w$ and $\eta_2 w$ represent the same wholesale prices under different information-sharing situations, as displayed in Figure 2.

Figure 2 shows the manufacturer's expected profit when given wholesale prices, where the solid lines and dotted lines represent the profit under information asymmetry and symmetry, respectively. We can see that regardless of whether supply information is shared, the expected profit always decreases with the risk probability p_r, and the profit difference between information symmetry and information asymmetry under the same given wholesale prices is constantly increasing. At the same time, we also find that sharing supply information with the backup supplier under different wholesale prices has different effects on the manufacturer. When $\eta_1 = 1.0$, $\eta_2 = 1.5$ and $\eta_1 = 1.5$, $\eta_2 = 2.2$, the manufacturer can increase its expected profits by sharing supply information; in contrast, when $\eta_1 = 1.2$, $\eta_2 = 1.8$, private supply information is more beneficial to the manufacturer.

5.2. The Sensitivity to (η_1, η_2) under Asymmetric Information. Next, we analyze the impact of wholesale prices on the manufacturer's procurement strategy and discuss two cases at $p_r = 0.3$ and $p_r = 0.7$. In each case, we assign η_{A1} with different values. Considering that $p > \eta_{S2} w$, we only discuss the condition where η_{A2} ranges from $\eta_{A1} + 0.05$ to 2.8. The results are illustrated in Figures 3 and 4.

Figure 3 clearly shows the condition for reservation price decision making. When we focus on $\eta_{A1} = 1.2$, given the wholesale price $\eta_{A1} w$, the backup supplier has different pricing strategies with η_{A2}. If the wholesale price $\eta_{A2} w$ is low ($\eta_{A2} < \widehat{\eta_{A2}}$), the backup supplier will set a higher reservation price $k_{A2}{}^*$, and if the wholesale price $\eta_{A2} w$ is high ($\eta_{A2} > \widehat{\eta_{A2}}$), the backup supplier will set a lower reservation price $k_{A1}{}^*$. However, when $\eta_{A1} = 1.5$, the backup supplier will always set a lower reservation price $k_{A1}{}^*$.

Figure 4 illustrates the effect of wholesale prices on the order quantity. According to Proposition 4 it yields $\widehat{\eta_{A2}} = 1.486$ when $\eta_{A1} = 1.2$, as shown in Figures 3 and 4. We see that when $\eta_{A2} = 1.2$ and $\eta_{A2} < \widehat{\eta_{A2}}$, the optimal reservation price will be higher and the reservation quantity will be lower than the expected emergency order quantity; otherwise, the optimal reservation price of a unit component is relatively low, but the reservation quantity will be higher than the expected emergency order quantity. In addition, based on Section 4, we know that the risk probability does not affect the pricing strategy selection of the backup supplier and

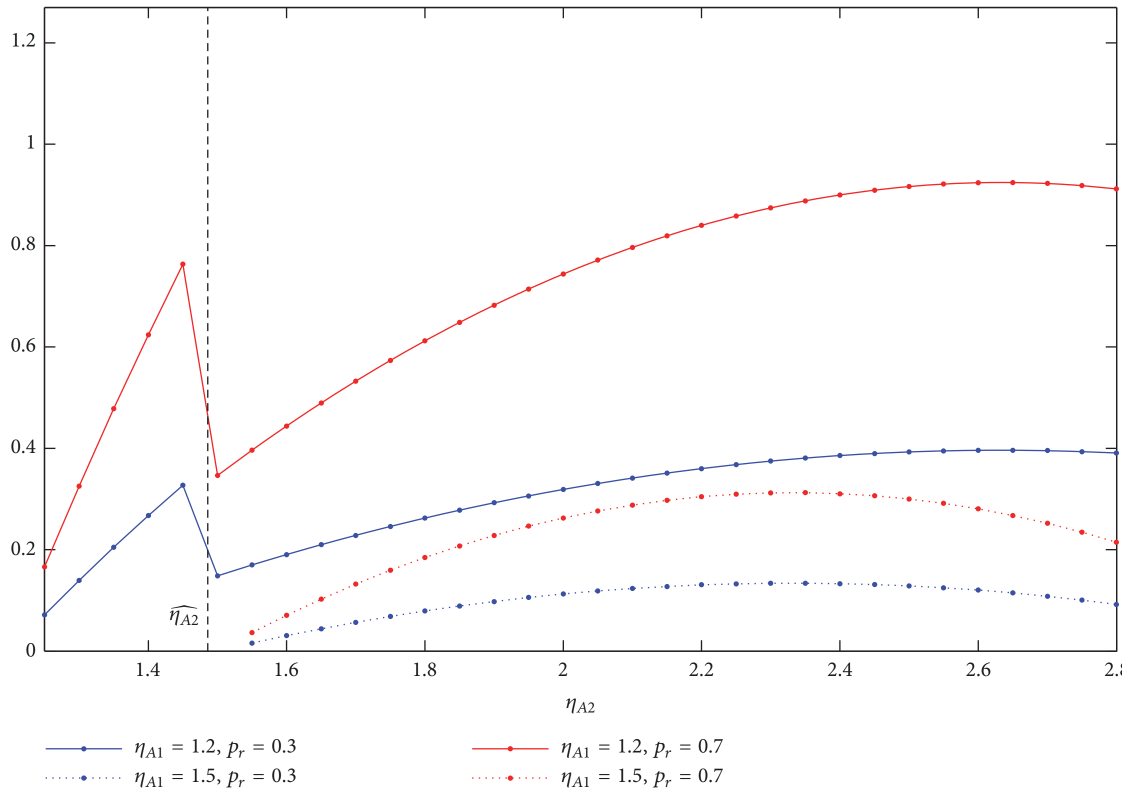

Figure 3: The optimal reservation price.

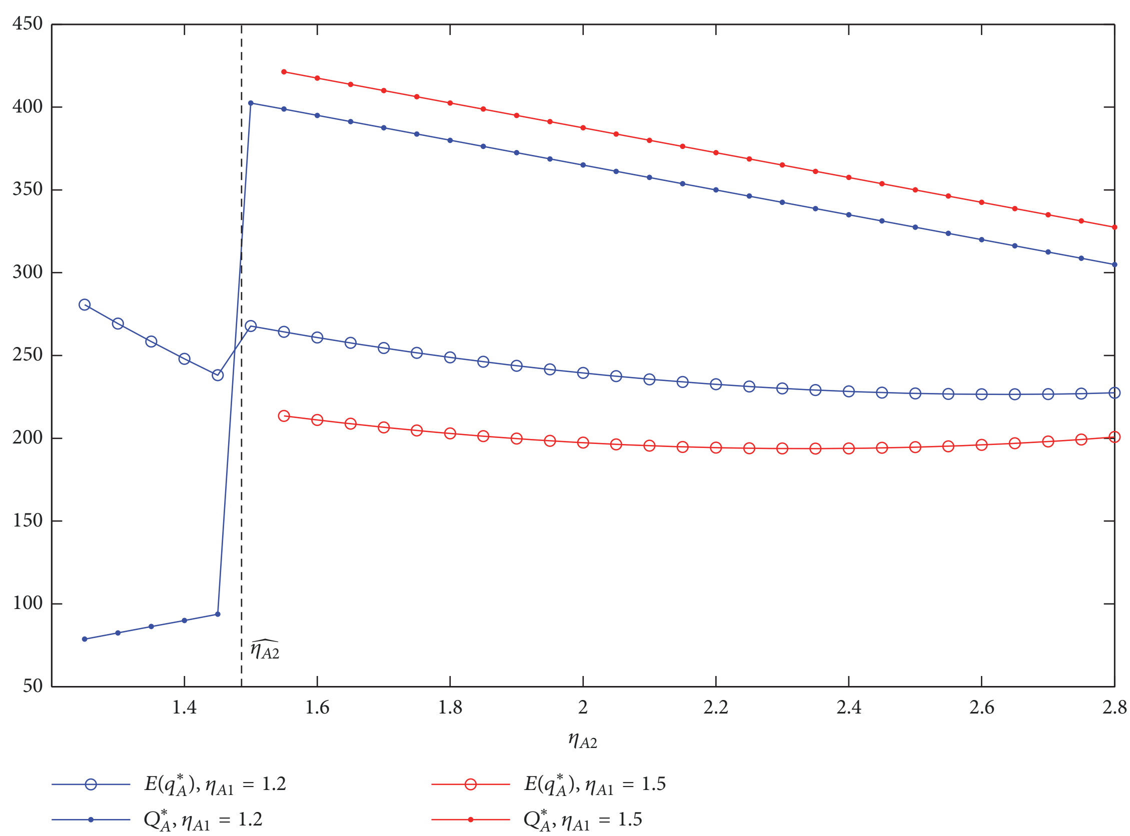

Figure 4: Reservation quantity and expected emergency order quantity.

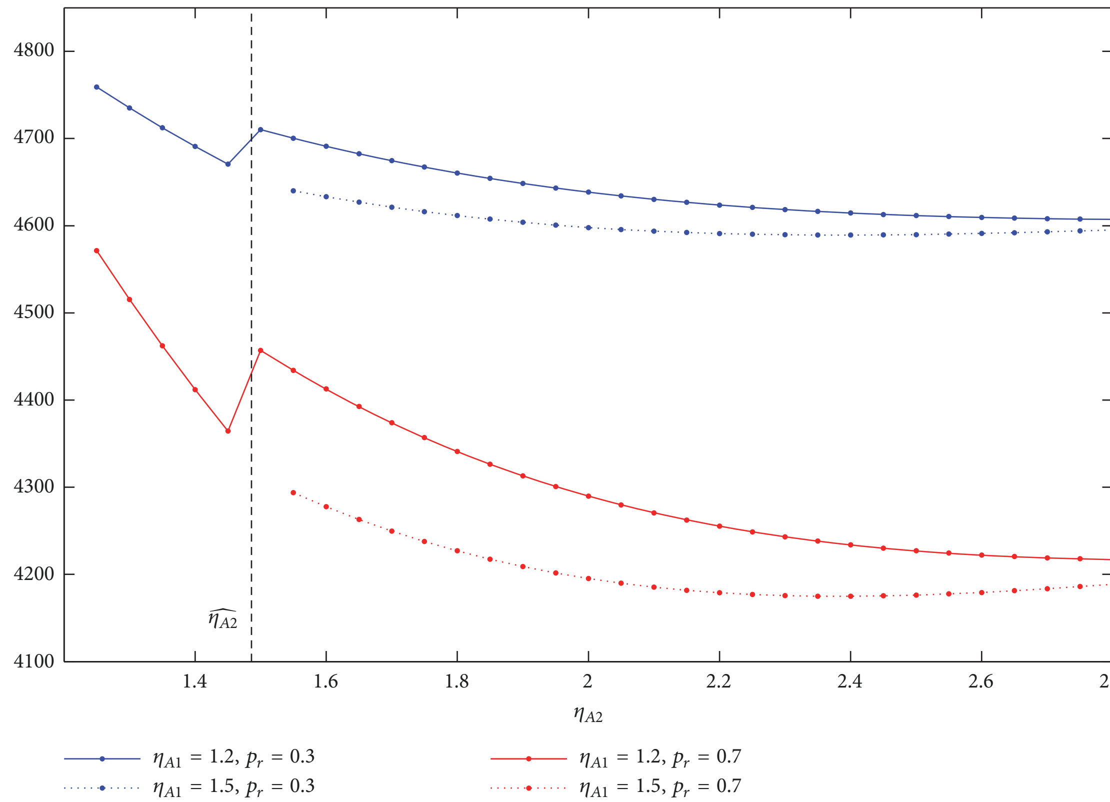

FIGURE 5: Manufacturer's expected profit.

the manufacturer's expected order quantity and reservation quantity, indicating that the same situation appears when $p_r = 0.7$.

Understandably, a greater reservation quantity cannot save more cost for the manufacturer if the primary supplier's production capacity is partially invalid when the wholesale price $\eta_{A1}w$ is low and the difference between $\eta_{A1}w$ and $\eta_{A2}w$ is small. This situation will cause the manufacturer to lose the motivation to reserve more products. Therefore, for the backup supplier, increasing the reservation price and obtaining more reserved revenue from reservations are wise actions. In contrast, when η_{A1}, η_{A2} are high, a lower reservation price can encourage the manufacturer to reserve more components because the manufacturer's emergency procurement cost will be lower if the supply risk has a greater impact on the system. The backup supplier will also obtain satisfactory profits because of the larger reservation.

When we observe the expected profit of the manufacturer, we find that the increased supply risk probability will reduce its expected profit. When $\eta_{A1} = 1.2$, the manufacturer's profit is increased after the reservation price strategy changes, as shown in Figure 5. The reason for the increased profit may be that the lower reservation price encourages the manufacturer to reserve more components, resulting in a higher reservation quantity than the expected emergency order quantity, as shown in Figure 4. The manufacturer can therefore obtain sufficient parts to produce finished products to meet the random market demand.

5.3. Comparisons of Optimal Strategies under Different Information-Sharing Conditions. To further discuss the impact of supply information sharing on the manufacturer's procurement strategy, we assume that $\eta_{A1} = \eta_{S1} = 1.2$, $\eta_{A2} = \eta_{S2}$ and discuss the expected profit and quantity when $p_r = 0.3$ and $p_r = 0.7$, respectively. For the convenience of the description, we use η_1 and η_2 to represent the wholesale price with or without reservation, respectively. All the results are plotted in Figures 6–9.

Figure 6 shows the optimal pricing of the backup supplier for different information-sharing situations. In contrast to information asymmetry, the optimal reservation price under information symmetry increases first and then decreases as η_2 increases. From Corollary 10, we know that when the wholesale prices changes, different reservation price relationships will emerge. If supply information is symmetric, the reservation price value is higher when $\underline{\eta_2} < \eta_2 < \overline{\eta_2}$ and lower when $\eta_2 < \underline{\eta_2}$ *or* $\eta_2 > \overline{\eta_2}$. Accordingly, when $\underline{\eta_2} < \eta_2 < \overline{\eta_2}$, the reservation quantity under information symmetry is lower, as shown in Figure 7. Furthermore, the manufacturer's reservation quantity increases with η_2 when $k_s^* > 0$ and is constant when $k_s^* = 0$, as stated in Corollary 9.

The expected profits of the manufacturer and backup supplier are presented in Figures 8 and 9, where the red lines represent profits under symmetric information while blue lines represent profits under asymmetric information. When observing the profits of the manufacturer under information symmetry, we can see that information symmetry does not

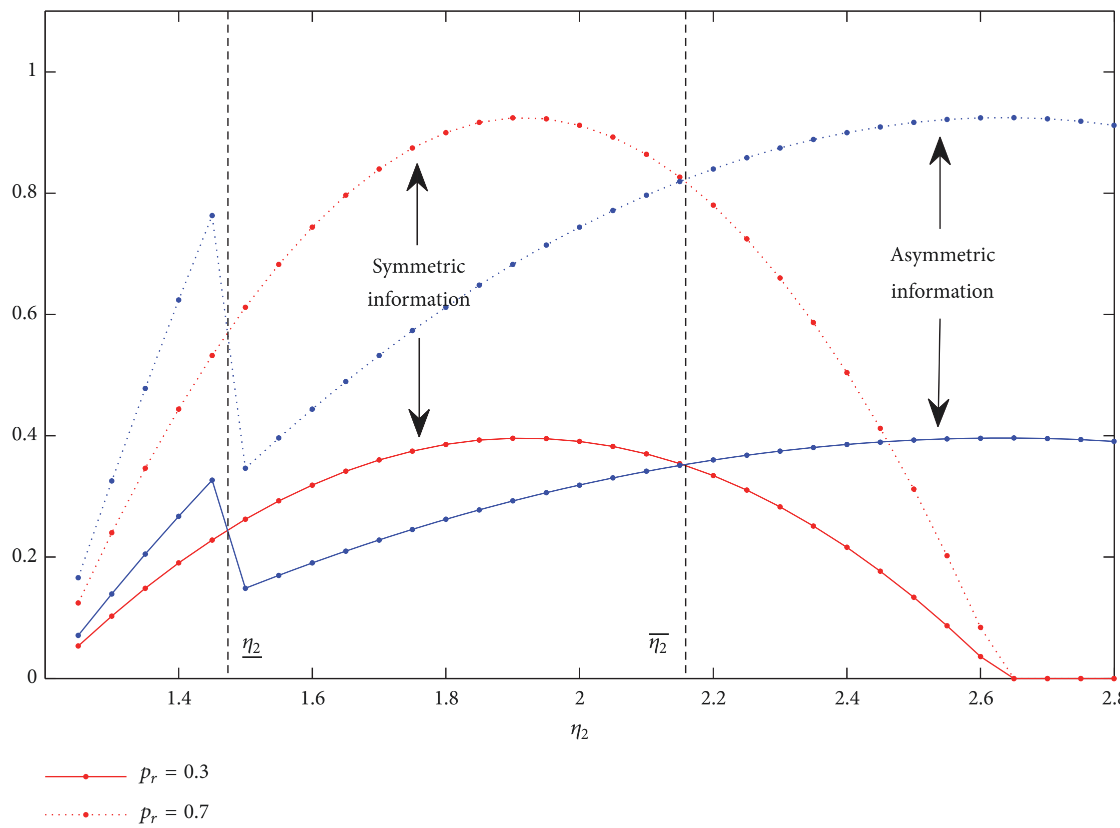

Figure 6: Optimal reservation price under different situations.

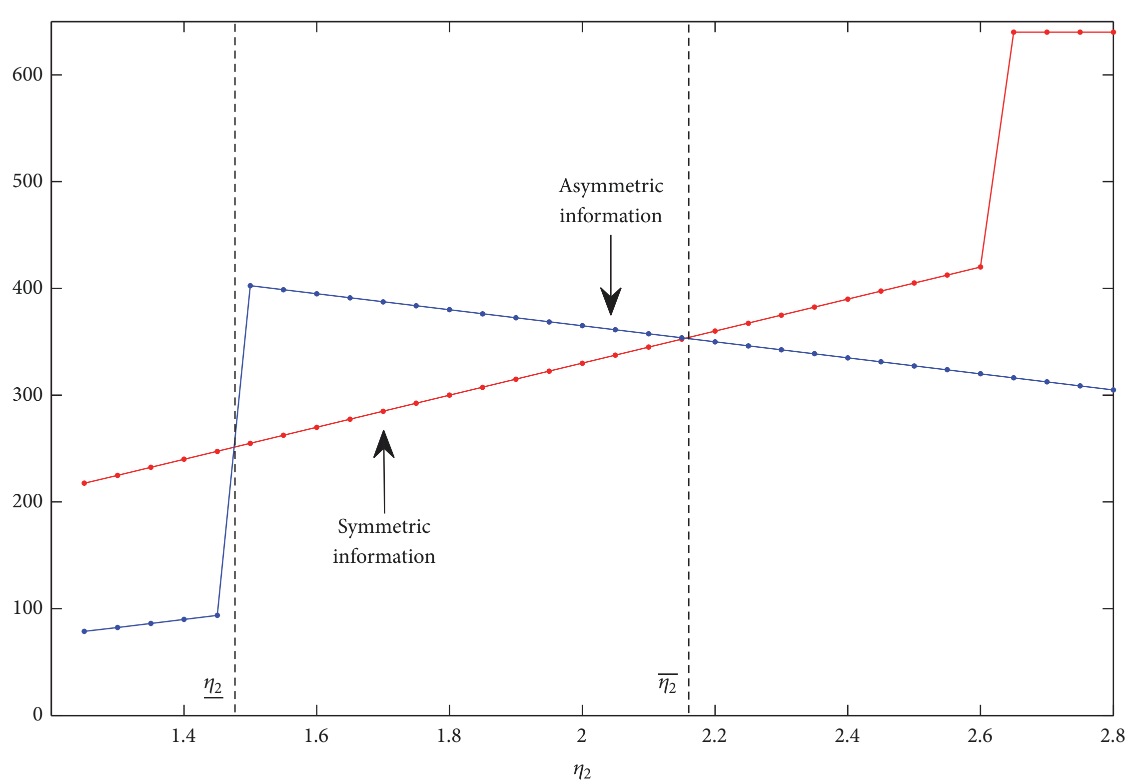

Figure 7: Reservation quantity under different situations.

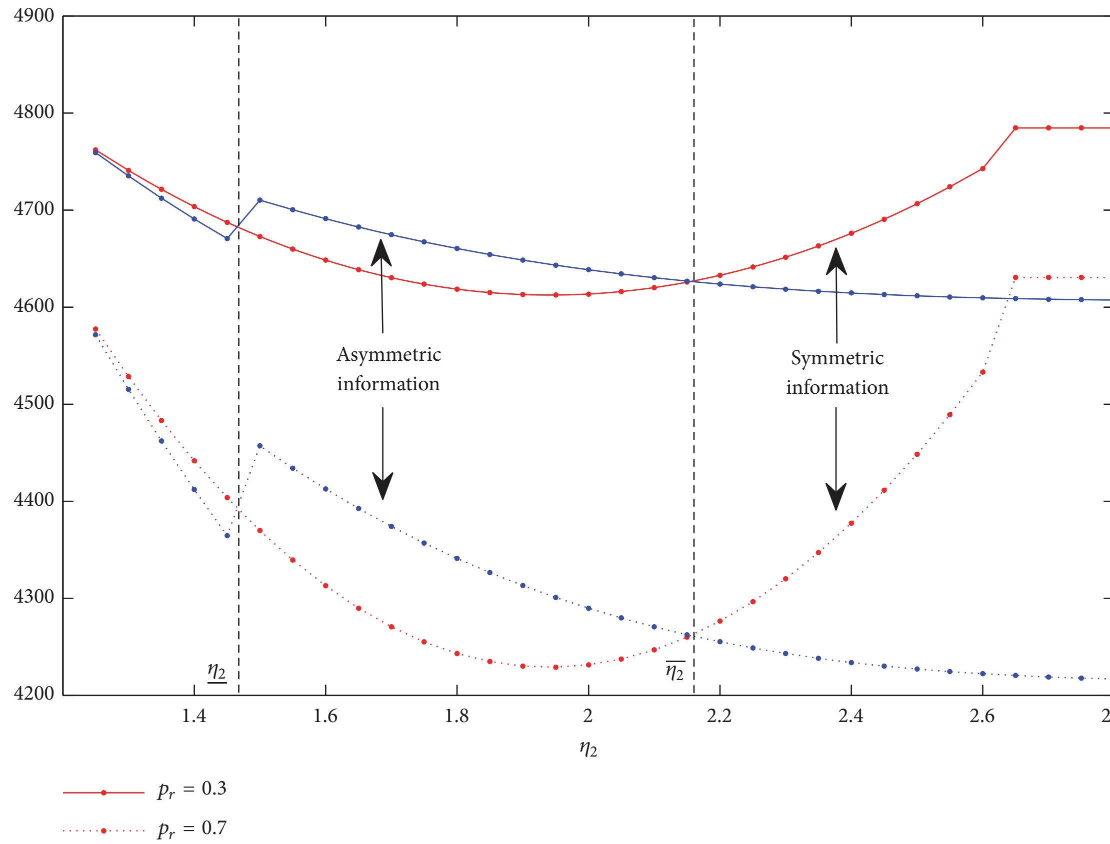

Figure 8: The manufacturer's expected profit under different situations.

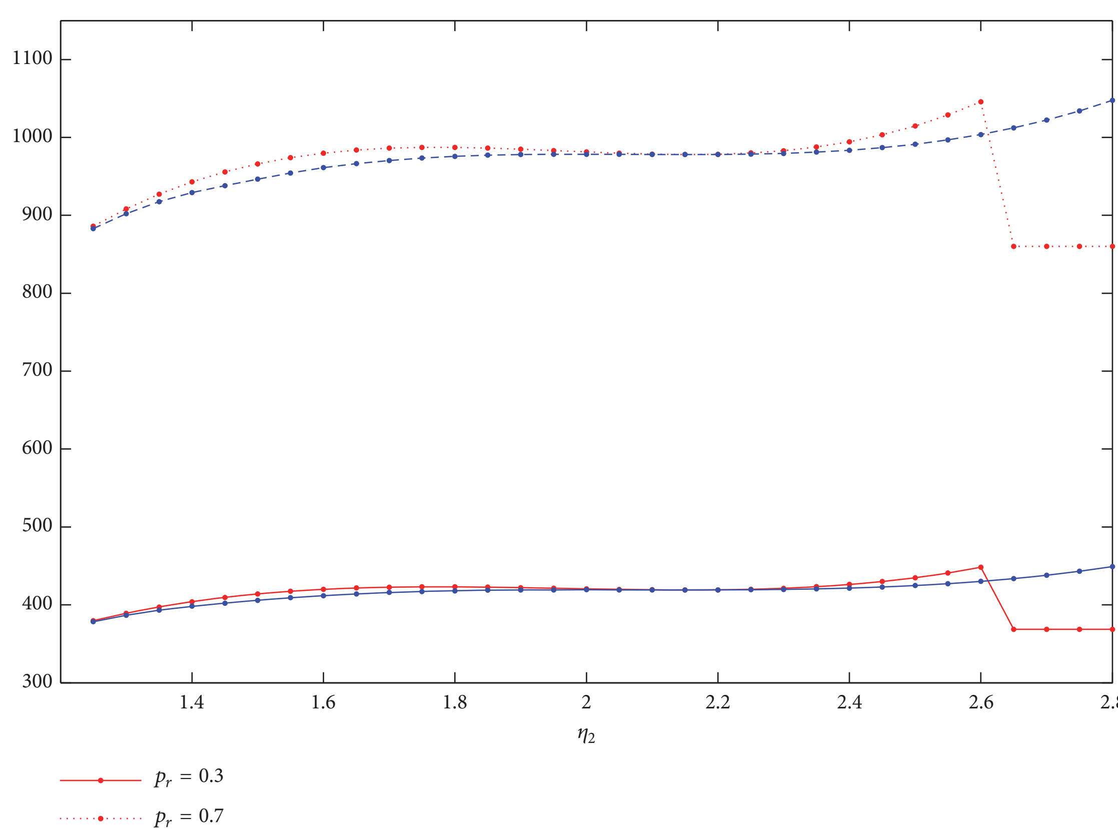

Figure 9: The backup supplier's expected profit under different situations.

necessarily lead to more profit for the manufacturer. When the manufacturer's wholesale price $\underline{\eta_2} < \eta_2 < \overline{\eta_2}$, sharing supply information with the backup supplier will reduce the expected profit. The higher reservation price (see Figure 6) leads to a decrease in the reservation quantity (see Figure 7), which ultimately leads to this phenomenon.

However, the backup supplier can gain higher profits under information symmetry when $k_s^* \neq 0$, as shown in Figure 9, which is easy to understand because when the manufacturer shares the original private supply information with the backup supplier, the manufacturer's bargaining power is weakened, and the backup supplier can occupy a more favorable position in procurement. However, if $k_s^* = 0$, the source of the backup supplier's revenue is only the emergency order when the delivery quantity of the primary supplier does not meet the demand of the manufacturer, which leads to a reduction in the backup supplier's expected profits.

6. Conclusions

Backup sourcing is one of the most frequently used operational strategies of firms to mitigate supply risks. We consider a supply chain in which the manufacturer mainly procures a critical component from one unreliable primary supplier with stochastic capacity risk and guarantees supply chain stability through a capacity reservation contract with a reliable backup supplier. We construct the base model in which the manufacturer first decides whether to reserve components from the reliable backup supplier and then may activate backup sourcing after observing the primary delivery, where the manufacturer is subject to random demand. The central issue in this paper is the optimal procurement strategy with backup sourcing for the manufacturer. We characterize the manufacturer's optimal reservation and ordering decisions and analyze the pricing decisions of the backup supplier with the game theoretic framework under supply information asymmetry and symmetry.

From the perspective of decision-making strategies in different scenarios, we find that the backup supplier will implement differential reservation pricing according to the negotiated wholesale prices and whether the manufacturer shares specific supply information. The value of the reservation price is affected by the wholesale prices, supply risk probability, and marginal cost of the backup supplier probability. The boundary conditions for the manufacturer to pay the reservation cost are also are also discussed in this paper. Notably, the reservation price increases with the risk probability of the primary supplier, and when the reservation price is higher than 0, the manufacturer's reservation quantity is linearly related to the reservation price. From the perspective of strategy selection, when the risk probability is uncertain, our analysis shows that supply information symmetry is always more beneficial to the backup supplier. However, whether the manufacturer can improve its expected profit by sharing private supply information is affected by the wholesale price. When the risk probability is certain, the results show that the relationship between the wholesale price and the manufacturer's profit is very complicated, and lower wholesale prices are not always beneficial to the manufacturer.

This paper has the following managerial implication for the manufacturer. When the primary supplier has a low probability of capacity risk, reserving components from the backup supplier will not confer more benefits to the manufacturer. When the risk probability is high and the price of components on the reserve market is reasonable, the manufacturer can contract with the backup supplier for an emergency order. The manufacturer should determine the reservation quantity based on the reservation price, the wholesale prices, and whether the delivery information of the primary supplier should be shared with the backup supplier. We find that a favorable action for the manufacturer is to protect specific supply information from being acquired by the backup supplier when the wholesale prices are determined and the reservation price under information symmetry is higher; otherwise, the manufacturer should share the information with the backup supplier.

From the perspective of the backup supplier, it has two different pricing strategies when the information is asymmetric. If the backup supplier adopts the lower pricing strategy, then the increase in the wholesale price of reserved components will reduce the manufacturer's demand for reservation, while the increase in the wholesale price of unreserved components will encourage the manufacturer to reserve more products. The effect of the wholesale prices is reversed if the backup supplier adopts the higher pricing strategy. When the information is symmetric, an advantageous action for the backup supplier is to charge the reserved cost, and the appropriate increase in the wholesale prices will not reduce the reservations. Therefore, the backup supplier can choose the appropriate pricing strategy to expand its potential market according to different situations. Notably, obtaining the delivery information of the primary supplier is always beneficial to the backup supplier in the presence of reserved costs.

We can expand future research as follows. First, the residual value of products and extension of the procurement strategy to multiple-period cases should be considered. Second, the time constraints in the procurement and supply processes will be interesting to consider. In addition, studying a situation in which a manufacturer uses another unreliable supplier as a backup supplier may be worthwhile.

Appendix

Proof of Proposition 1. When $0 \le q \le Q$, $d\pi_M(q;\theta)/dq = -\eta_1 w - (N\theta + q)p/b + p$ and $d^2\pi_M(q;\theta)/dq^2 = -p/b < 0$. Therefore, $\pi_M(q;\theta)$ is concave with q, and the optimal emergency order quantity satisfies $d\pi_M(q;\theta)/dq = 0$, which leads to $q_1 = (b(p - \eta_1 w) - N\theta p)/p$. Similarly, when $q > Q$, we have $q_2 = (b(p - \eta_2 w) - N\theta p)/p$. If $0 \le q_1 \le Q$, then determining that $b(p-\eta_1 w)/Np > \theta \ge (b(p-\eta_1 w)-pQ)/Np$ is easy, and the optimal emergency quantity is q_1; if $q_1 < 0$, we have $\theta > b(p - \eta_1 w)/Np$, and the manufacturer will order nothing from the backup supplier; if $q_1 > Q$, $\theta \ge (b(p - \eta_1 w) - pQ)/Np$, the optimal order quantity is Q or q_2. When $q_2 > Q$, $\theta < (b(p - \eta_2 w) - pQ)/Np$, the optimal order quantity is q_2 and $\theta > (b(p-\eta_2 w) - pQ)/Np$, and Q is the optimal choice. □

Proof of Proposition 2. Taking the derivative of $E(\pi_M^R)$ with respect to the variable Q yields the following equation:

$$\frac{dE\left(\pi_M^R\right)}{dQ} = \frac{2w\left((Q-b)\,p + (1/2)\,bw\left(\eta_{A1}+\eta_{A2}\right)\right)\left(\eta_{A1}-\eta_{A2}\right)p_r - 2Npk}{2Np} \tag{A.1}$$

Let Q^* denote the optimal reservation quantity; then, we have

$$Q^* = \frac{b\left(\eta_{A1}-\eta_{A2}\right)\left((1/2)\left(-\eta_{A1}-\eta_{A2}\right)w + p\right)wp_r + Npk}{pw\left(\eta_{A1}-\eta_{A2}\right)p_r} \tag{A.2}$$

Combined with k, we have

$$Q^* = -\frac{Nk}{w\left(-\eta_{A1}+\eta_{A2}\right)p_r} + \frac{\left(2p - w\left(\eta_{A1}+\eta_{A2}\right)\right)b}{2p} \tag{A.3}$$

Let $\Phi_1 = -(N/w(-\eta_{A1}+\eta_{A2})p_r)$ $\Phi_2 = (2p - \eta_{A2}w - \eta_{A1}w)b/2p$; it can be proved that $\Phi_1 < 0$, $\Phi_2 > 0$, and then $Q^* = \Phi_1 k + \Phi_2$. When $p_r > 2pNk/w(-\eta_{A1}+\eta_{A2})(2p - w(\eta_{A1}+\eta_{A2}))b$, the optimal reservation quantity is greater than 0. □

Proof of Proposition 4. Without loss of generality, we assume that $N \geq (p-w)b/p$ and $w \leq w\eta_{A1} < w\eta_{A1} < p$, and then $bw(\eta_{A1}-\eta_{A2}) + Np > 0$ and $(-bw\Phi_1(\eta_{A1}-\eta_{A2})/pN - \Phi_1) > 0$ is always true. Therefore, the optimal value of ${k_{A1}}^*$ satisfies $d\pi_{BA}^R(k_A)/dk_A = (\eta_{A2}-\eta_{A1})(\eta_{A1}w - c_0)w\Phi_1 bp_r/Np + 2\Phi_1 k_A + \Phi_2 = 0$ when $E(q_A^*) \leq Q_A^*$, which leads to ${k_{A1}}^* = ((\eta_{A1} - \eta_{A2})(\eta_{A1}w - c_0)wb/2Np)p_r - \Phi_2/2\Phi_1$ if $\Phi_2 \geq \overline{k_{A1}}$, where $\overline{k_{A1}} = (p - \eta_{A2}w)^2 b^2/p(b(w\eta_{A1} - \eta_{A2}w) + Np) - ((\eta_{A1}w - \eta_{A2}w)(\eta_{A1}w - c_0)b/Np)\Phi_1 p_r$. Similarly, when $E(q_A^*) > Q_A^*$, the optimal value of ${k_{A2}}^* = (\eta_{A2}w - w\eta_{A1})(Np + b(c_0 - \eta_{A2}w))p_r/2Np - \Phi_2/2\Phi_1$ if $\Phi_2 < \overline{k_{A2}}$, where $\overline{k_{A2}} = (p - \eta_{A2}w)^2 b^2/p(b(w\eta_{A1} - \eta_{A2}w) + Np) - (w(\eta_{A2}-\eta_{A1})(Np + b(c_0 - \eta_{A2}w))\Phi_1/Np)p_r$, proving that $\overline{k_{A2}} > \overline{k_{A1}}$ is easy. Therefore, we need to compare the two pricing strategies when $\overline{k_{A1}} < \Phi_2 < \overline{k_{A2}}$. Let $\Delta\pi_{BA}^R = \pi_{BA}^R({k_{A1}}^*) - \pi_{BA}^R({k_{A2}}^*)$. Solving $\Delta\pi_{s_2A}^R > 0$, which indicates that ${k_{A1}}^*$ is a better choice than ${k_{A2}}^*$, we can obtain $\Phi_2 > (1/2)(\overline{k_{A1}} + \overline{k_{A2}})$; when $\Delta\pi_{s_2A}^R < 0$, which is $\Phi_2 < (1/2)(\overline{k_{A1}} + \overline{k_{A2}})$, ${k_{A2}}^*$ will be a better strategy, and when $\Phi_2 = 1/2(\overline{k_{A1}} + \overline{k_{A2}})$, the backup supplier can gain the same profit regardless of which strategy is adopted. When $\Phi_2 < (1/2)(\overline{k_{A1}} + \overline{k_{A2}})$, we have $((2p - 2c_0)b - pN)/2b^2 < (w\eta_{A2} + p)^2/(w(\eta_{A1} - \eta_{A2})b + pN)$. □

Data Availability

All data underlying the findings described in our manuscript are fully available without any restriction and all relevant data are within the paper.

Conflicts of Interest

No conflicts of interest exist in the submission of this manuscript, which has been approved by all authors for publication.

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