Research Article

Dual-Source Procurement and Supplier Pricing Decision under Supply Interruption

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The occurrence of major public health events usually leads to interruptions in the supply chain. This article studies the supply chain consisting of two suppliers and one manufacturer. In the case of supply interruptions, the manufacturer adopts two models of unit cost subsidies and proportional subsidies. The reliability of the supplier’s supply is incentivized and ensured. A Stackelberg game model is established in which the manufacturer is the leader and the supplier is the follower. The research results show that the optimal order quantity of the supplier manufacturer and the optimal wholesale price of the supplier will be affected by the reliability level, and the optimal supply chain profits of the two models under different parameters are compared.

1. Introduction

With the development of supply chain management towards lean performance and globalization, the supply chain has been extended in time and space, but its complexity has also increased, and the risk of supply interruption has also increased. Since the spread of the new crown pneumonia epidemic, it has had a huge impact on the economy, especially the supply chain. At present, the supply chain is in a critical period of transition from fragmentation to systemization and from node to network as a whole, with a large total scale and rapid development speed. As an emergency, the new crown pneumonia epidemic has caused a short-term interruption of the supply chain, which has a huge impact on both ends of supply and demand. The impact of the epidemic on the supply chain through up and down transmission and repeated pulses will cause a series of chain reactions. In order to prevent and control the spread of the epidemic, various places have adopted phased “city closures” and strict traffic control measures. Traditional logistics have been interrupted and offline supply chains have suffered severe setbacks. On the upstream production side, suppliers cannot transport raw materials to other places, and purchasers from other places cannot go to the place of production to purchase. On the downstream sales side, consumers cannot make normal purchases. At the same time, due to the epidemic prevention measures of various countries, international logistics have been blocked, and the import and export trade of products has also been severely set back. [1].

The mismatch between supply and demand has become a challenge and difficulty in the supply chain field [2, 3]. In the face of disruption, suppliers and manufacturers will take some measures to improve the reliability of the supply chain. Dual-source supply is an important means to improve the reliability of the supply chain [4]. Another way to mitigate the risk of supply interruption that cannot be ignored is to improve the reliability of the supply process [5–7]. However, suppliers themselves must face the problem of balancing the improvement of reliability and input costs. Moreover, in order to maintain the autonomy of operation, supply chain member companies often aim to maximize their own interests [8]. Therefore, whether the supplier’s reliability cost investment is necessary and how much the investment is determine the stability and profit level of the overall supply chain.
In order to maintain the stability of supply, downstream manufacturers will adopt some strategies, such as revenue sharing contracts and quantity discount contracts, to encourage upstream suppliers to maintain a certain degree of supply reliability. Most of the existing studies on supply chain interruption have established that the level of supply reliability is endogenous [4, 9] and when there is a supply interruption in the supply chain, literature on retailers adopting different incentive strategies to promote supplier investment in supply reliability construction is relatively lacking.

Through the above content, it can be found that the failure of supply nodes in the supply chain due to accidents will have an adverse impact on the entire supply chain [10, 11]. In order to effectively respond to accidents, supply chain member companies have adopted relevant coping methods and measures. Therefore, this article intends to solve the following questions: (1) In the face of supply interruption, how do manufacturers make purchasing decisions? (2) What incentives should the manufacturer take to maintain supply stability when it is impacted by supply disruptions? (3) Under the manufacturer's subsidy policy, whether it is necessary for the supplier to invest in reliability costs.

This article studies the supply chain interruption problem by means of dual-source supply. In particular, it takes the two-tier supply chain, including dual suppliers, and single manufacturer, such as the research object, and constructs a dynamic game model between suppliers and manufacturers to discuss the purchase and supply of manufacturers considering cost subsidies and supply reliability cost inputs and pricing issues. Finally, it was verified by numerical simulation.

Compared with the existing research, in the dual-source supply chain, the manufacturer's subsidy is also considered to improve the reliability of supply, and the research on the pricing decision-making of the dual-source procurement based on the manufacturer's subsidy and the supplier's reliability cost input has not been seen yet. Second, most of the literature considers supply reliability issues from the perspective of manufacturers and purchasers. However, suppliers can also avoid supply interruption risks by affecting the reliability of the supply process. Therefore, discussing the response mechanism of supply interruption from the perspective of suppliers also has important research value. Finally, innovative suggestions and conclusions are put forward for the optimal decision-making of supply chain members.

In the past related literature in the field of supply chain management, many scholars have conducted extensive research on the Stackelberg game, Cournot game, and Bertrand game in the supply chain system. However, in the related research on dual-source procurement strategy, there are still few considerations of vertical game behaviour between upstream and downstream companies or horizontal game behaviour between homogenized product companies, and there are only a handful of studies that combine the above-mentioned games. In response to this problem, in several chapters, this article considers the influence of different competitive behaviours between companies on the supply chain decision-making according to the characteristics of the decision-making environment in which the member companies are located and fully considers the decision-making research considering mixed competition. Each member company faces relevant decision-making and optimization problems in horizontal and vertical competition, which have not yet appeared in previous studies.

2. Literature Review

2.1. Supply Chain Coordination under Supply Disruption.

The literature on supply disruptions includes qualitative and quantitative studies. Most of the research methods used are mathematical programming and game models. Baghersad has found through empirical research that companies of different sizes and different industry sectors have announced the interruption, not only in the short term, but also in the long term; after the interruption occurred, different losses were shown [12]. Ma developed a three-layer supply chain network equilibrium model using probability of risk occurrence and risk loss function to express the characteristics of risk management in the supply chain network [13]. Ivanov proposed a new supply chain interruption risk management method, in which supply chain behaviour is less dependent on the certainty of our knowledge of the environment and its changes, that is, the low certainty demand (LCN) supply chain. By combining lean elements with elastic elements, three key characteristics of the LCN supply chain are determined, namely, the reduction of structural complexity, the flexible use of processes and resources, and efficient parameter redundancy [14].

2.2. Supply Chain Coordination of Different Procurement Modes.

In order to better solve the problem of manufacturer procurement and supplier supply under supply interruption, many scholars have carried out research on this. Hou believed that issues such as the dual-source supply model decision and supplier pricing are important measures to mitigate interruption risks and reduce supply network losses and are worthy of in-depth analysis [15]. Konishi believed that only when the purchaser cannot obtain diversified benefits through other channels and the supplier's supply capacity is greater than the demand for market products, single-source procurement will be the manufacturer's optimal procurement strategy; otherwise, dual-source procurement will be the best optimal procurement strategy [16]. Ji and Gong constructed a CLSC model with two competitive dominant upstream suppliers and one following a downstream (re-)manufacturer and then coordinated supply chain through a cost-sharing contract [17]. Liu et al. compared the supply chain coordination issues when supplier groups and buyers adopt revenue sharing + second penalty contracts and option contracts [18]. Ping studied the optimal decision-making problem when a manufacturer purchases parts from two suppliers with random output and the possibility of supply interruption under the conditions of demand and supply uncertainty [19]. Wan and Chen studied the multiperiod dual-source procurement and supply
problem using options and spot markets. The study found that the option strategy is better than the procurement strategy without options [20].

2.3. Establishing a Contract or Coordination Mechanism Supply Chain. Feng et al. considered the reliability factor, reviewed the profit distribution mechanism of supply chain members in a multilevel supply chain, and discussed how to optimize the operating efficiency of the supply chain under different reliability conditions [21]. Liu et al. studied how companies make investment decisions and adopt new technologies to improve supply reliability [22]. Gurnani showed that the degree of input from suppliers to improve reliability depends on their ability to negotiate prices with downstream manufacturers [23]. For example, Walmart uses radio frequency identification technology to track products in real-time, eliminating manual errors in factories, distribution centres, warehouses, and shopping malls, greatly improving the level of supply reliability [24]. On the other hand, retailers provide incentive strategies to encourage suppliers to improve the stability of supply. Giri and Roy constructed a profit model for decentralized and centralized decision-making underprice disturbances and believed that appropriate modification of the revenue sharing contract parameters will increase the profit of the supply chain [25]. Huang and Yang analyzed the impact of asymmetric cost disturbance information on the performance of the supply chain, introduced the principal-agent theory to build a decision-making model with the goal of maximizing supply chain profits, and believed that an effective contract menu was designed, and the manufacturer’s production quantity was affected according to the actual situation. The decision-making combination of retail prices is an effective means to deal with asymmetric information disturbances [26]. Different supply chain entities cope with different types of disturbances, and there are more effective coordination methods such as linear quantity discount contracts, two-part fee system contracts, promotion subsidy contracts, and reward and punishment contracts [27–29]. Tan studied the reward and punishment contract under the supply chain contract model, focusing on the problem of how to coordinate the closed-loop supply chain when facing emergencies. The research results show that the coordination problem of the closed-loop supply chain caused by emergencies can be achieved through contract mediation [30].

Most of the above-mentioned documents are related studies on the methods used by supply chain members to maintain supply stability when responding to supply interruptions, from the purchasing mode chosen by the manufacturer to ensuring the stability of the supply process. There are few literatures that analyze the impact of manufacturers’ subsidy policies on supply chain members under dual-source supply and the necessity of suppliers to maintain stable supply. This article is mainly based on predecessors’ research on supply chain risk and emergency management, starting from the supply chain procurement field, through the use of manufacturer cost subsidies to coordinate the interests within the supply chain. At the same time, consider the impact of two different subsidy methods on the supplier’s supply stability and its own profits. On this basis, is it necessary for the supplier to invest in costs based on the probability of supply interruption in order to obtain the optimal order quantity and supply in the supply chain when the benefits of the supply chain member companies are also balanced while the overall benefits of the supply chain are maximized? The wholesale price of raw materials from suppliers can solve the problem of income distribution between manufacturers and suppliers in the supply chain.

3. Model Symbols and Assumptions

This article considers that two suppliers provide buyers with products with no difference in quality to meet random market demand. The main purpose of buyers choosing two suppliers is to ensure the reliability of long-term supply and maintain certain bargaining power. The two suppliers have differences in supply costs and supply reliability. Affected by factors such as production technology and logistics distribution, the suppliers may not be able to deliver on time, causing supply interruptions. Purchasers and suppliers will adopt a unit cost subsidy policy in order to improve their production and transportation processes to reduce supply costs and improve supply reliability; that is, purchasers will provide appropriate subsidies for supplier losses to achieve supply chain coordination.

In this supply chain, suppliers and buyers form a Stackelberg game of decision-making. Figure 1 is a conceptual model when a buyer purchases raw materials from a supplier, and the market is disrupted by supply disruptions and market demand caused by supply disruptions.

Assumption 1. Information is symmetrical between manufacturers and retailers; that is, they are fully aware of each other’s cost and demand information.

Assumption 2. Assuming that the purchaser’s order quantity to each supplier is $Q_1$ and $Q_2$, respectively, similar to the literature [31–33], the actual supply quantity is 0 when the supplier has an emergency that causes the supply to be interrupted; otherwise, the actual supply quantity is equal to the order quantity; that is, “all-or-noting” [34] supply is completely interrupted mode. Assume that two strategic suppliers are exactly the same, and the unit production cost is $c$. When the supply is interrupted, the supplier’s early input unit loss is $\lambda c$ [35], $\lambda \geq 0$. The sales price changes with the supply volume and satisfies $s = a - b(Q_1 + Q_2)$ [7]; $a$ and $b$ are constants greater than 0; based on the actual supply volume of the supplier, the retailer pays the unit wholesale price $\omega$.

Assumption 3. The probability that the supplier does not have the risk of interruption is $\theta$; then, the probability of the risk of interruption is $(1 - \theta)$. The probability of occurrence of interruption risk between two suppliers is independent and irrelevant, while the market’s demand for manufacturers’ products is price-sensitive and changes with changes.
in sales prices [36]. The first letter \( I \) and \( R \) of the subscript in the model represent model 1 and model 2, respectively; the subscripts \( s \) and \( m \) represent supplier and manufacturer, respectively. When the supplier is unable to supply due to supply interruption because of an emergency, the retailer will give the supplier subsidy \( \delta c \) for every unit of the product ordered by the retailer.

Table 1 is a parameter table obtained by summarizing the above assumptions.

### 4. Model

#### 4.1. Manufacturer’s Unit Wholesale Price Subsidy Policy Model

Model 1 is to provide a fixed cost subsidy to the supplier when the manufacturer considers the supplier’s supply interruption, that is, to add an additional subsidy to the original wholesale price. In the supply chain, the manufacturer, as the leader of the Stackelberg game, first decides the order quantity and unit wholesale price subsidy; the supplier, as a follower, decides its product production volume and wholesale according to the order quantity and unit wholesale price subsidy set by the retailer price. Using the reverse induction method to solve, first solve the manufacturer’s optimal order quantity and then solve the supplier’s optimal wholesale price. Under the decentralized decision-making, based on the above assumptions and symbol descriptions, considering the possibility of supply interruption, there are four possible scenarios for the final supply:

The first situation is that supplier 1 supplies successfully and supplier 2 supplies interruption. The probability of occurrence is \( \theta_{I1} (1 - \theta_{I2}) \). The manufacturer’s expected profit is as follows:

\[
\Pi_{I,m1} = \theta_{I1} (1 - \theta_{I2}) (a - bQ_{I1})Q_{I1} - \omega_{I1}Q_{I1} - \delta cQ_{I12}. \tag{1}
\]

The second scenario is that supplier 2’s supply is successful and supplier 1’s supply is interrupted. The probability of occurrence is \( \theta_{I2} (1 - \theta_{I1}) \). The manufacturer’s expected profit is as follows:

\[
\Pi_{I,m2} = \theta_{I2} (1 - \theta_{I1}) (a - bQ_{I2})Q_{I2} - \omega_{I2}Q_{I12} - \delta cQ_{I1}. \tag{2}
\]

The third situation is that both suppliers 1 and 2 have supply interruption, and the probability of occurrence is \( (1 - \theta_{I1})(1 - \theta_{I2}) \). The manufacturer’s expected profit is as follows:

\[
\Pi_{I,m3} = (1 - \theta_{I1}) (1 - \theta_{I2}) [ - \delta c (Q_{I1} + Q_{I2})]. \tag{3}
\]

The fourth situation is that both suppliers 1 and 2 supply successfully, and the probability of occurrence is \( \theta_{I1} \theta_{I2} \). The manufacturer’s expected profit is as follows:

\[
\Pi_{I,m4} = \theta_{I1} \theta_{I2} [a - b(Q_{I1} + Q_{I2})] (Q_{I1} + Q_{I2}) - \omega_{I1}Q_{I1} - \omega_{I2}Q_{I12}. \tag{4}
\]

Establish the overall expected profit function model of the manufacturer in four situations, where \( Q_{I1} \) and \( Q_{I2} \) are the main variables that affect the expected profit, and other values are related parameters; then, the expected profit function is as follows:

\[
\text{Max}\Pi_{I,m} = \Pi_{I,m1} + \Pi_{I,m2} + \Pi_{I,m3} + \Pi_{I,m4}. \tag{5}
\]

Based on the manufacturer’s total profit function, the optimal purchase quantity of the manufacturer is then solved. First, find the first-order partial derivative and the second-order partial derivative of the total expected profit function to \( Q_{I1} \) and \( Q_{I2} \), and get the following:
\[ \frac{\partial \Pi_{l,m}}{\partial Q_{11}} = \theta_{11} \theta_{12} [a - 2b(Q_{11} + Q_{12})] - 2\omega_{11} + (\theta_{12} - 1)[-\theta_{11} (a - bQ_{11}) + b \theta_{11} Q_{11} - \delta \lambda \theta_{11}], \]  

(6)

\[ \frac{\partial \Pi_{l,m}}{\partial Q_{12}} = \theta_{11} \theta_{12} (a - 2b(Q_{11} + Q_{12})) - 2\omega_{12} + (\theta_{11} - 1)[-\theta_{12} (a - bQ_{12}) - \delta \lambda \theta_{12} + bQ_{12} \theta_{12}], \]

(7)

Secondly, verify whether there is an optimal solution for the profit function and perform the Hessian matrix operation. Therefore, the Hessian matrix is as follows:

\[ H(Q_{11}, Q_{12}) = \begin{bmatrix} -2b \theta_{11} & -2b \theta_{11} \theta_{12} \\ -2b \theta_{11} \theta_{12} & -2b \theta_{12} \end{bmatrix}. \]

(8)

Calculate the Hessian matrix; get \( |H_1(Q_{11}, Q_{12})| = \theta_{11}^2 \theta_{12} \delta \lambda \theta_{12} > 0 \). It can be seen from \( H_1 \) and \( H_2 \) that the Hessian matrix is negative definite, indicating that the objective function has a maximum value. Currently, \( Q_{11} \) and \( Q_{12} \) exist and are unique.

Let \( \frac{\partial \Pi_{l,m}}{\partial Q_{11}}, \frac{\partial \Pi_{l,m}}{\partial Q_{12}} \) be equal to zero; then, the optimal solution is the solution of \( \frac{\partial \Pi_{l,m}}{\partial Q_{11}} = 0, \frac{\partial \Pi_{l,m}}{\partial Q_{12}} = 0 \) equations. Solve the two formulas \( \frac{\partial \Pi_{l,m}}{\partial Q_{11}} = 0 \) and \( \frac{\partial \Pi_{l,m}}{\partial Q_{12}} = 0 \) together and calculate the manufacturer’s optimal purchase quantity from suppliers 1 and 2.

\[ Q_{11}^* = \frac{2\omega_{11} - \theta_{11} (a + 2\omega_{12} - a\theta_{12}) + 2\delta - \delta \lambda \theta_{12} + \delta \lambda \theta_{12} (\theta_{11} - 3 + 2\theta_{12} - \theta_{11} \theta_{12})}{2b \theta_{11} (\theta_{11} \theta_{12} - 1)}, \]

(9)

\[ Q_{12}^* = \frac{2\omega_{12} - \theta_{12} (a + 2\omega_{11} - a\theta_{11}) + 2\delta - \delta \lambda \theta_{11} + \delta \lambda \theta_{11} (\theta_{12} - 3 + 2\theta_{11} - \theta_{11} \theta_{12})}{2b \theta_{12} (1 - \theta_{11} \theta_{12})}. \]

At this time, the expected profit objective function of supplier 1 is as follows:

\[ \Pi_{l,s,1} = \left[ \theta_{11} (\omega_{11} - c) + (1 - \theta_{11}) (\delta \lambda - \lambda c) \right] Q_{11}^*. \]

(10)

The expected profit objective function of supplier 2 is as follows:

\[ \Pi_{l,s,2} = [\theta_{12} (\omega_{12} - c) + (1 - \theta_{12}) (\delta \lambda - \lambda c)] Q_{12}^*. \]

(11)

Same as the method of solving the optimal purchase quantity, by processing the supplier’s profit function, the supplier’s optimal wholesale price is obtained:

\[ \Pi_{l,s} = \theta_{12} (\omega_{12} - c) + (1 - \theta_{12}) (\delta \lambda - \lambda c) Q_{12}^*. \]
4.2. Manufacturer’s Cost Proportional Subsidy Model. The manufacturer first issues an order to the supplier and adopts a cost subsidy policy for the upstream supplier. Unlike Model 1, in Model 2, the manufacturer subsidizes the supplier according to a certain proportion. At the same time, the supplier depends on the manufacturer, the subsidy ratio of the company, and the cost input to the level of its own supply reliability, thus improving the production process and optimizing the logistics system, so as to improve supply reliability, prevent supply interruption, and send the produced products to the retailer; finally, the manufacturer sends the product to the retailer. Sell to the customer market and get profit. Suppose that the supplier’s supply reliability cost input \((1 - \alpha)kR_1^2/2\) is a quadratic function of the supply reliability level, \(k\) is the reliability cost sensitivity coefficient, and \(k > 0\) [37, 38].

The supplier invests in the cost of supply reliability, and the manufacturer subsidizes it in proportion to \(\alpha\). Similar to the situation in Model 1, therefore, the manufacturer’s profit function is as follows:

\[
\Pi_{\text{m1}} = \theta_{R1} (1 - \theta_{R2}) (a - bQ_{R1})Q_{R1} - \omega_{R1}Q_{R1} - \frac{\alpha_1 k^2 \theta_{R1}^2}{2},
\]

\[
\Pi_{\text{m2}} = \theta_{R2} (1 - \theta_{R1}) (a - bQ_{R2})Q_{R2} - \omega_{R2}Q_{R2} - \frac{\alpha_2 k^2 \theta_{R2}^2}{2},
\]

(15) (16)

Establish the overall expected profit function model of the manufacturer in four situations, where \(Q_{R1}\) and \(Q_{R2}\) are the main variables that affect the expected profit, and other values are related parameters; then, the expected profit function is as follows:

\[
\Pi_{\text{m1}} = \Pi_{\text{m1}} + \Pi_{\text{m2}} + \Pi_{\text{m3}} + \Pi_{\text{m4}}.
\]

(19)

The calculation process is the same as that in Model 1. Find the first-order partial derivative and the second-order partial derivative of formula (19), and by calculating the Hessian matrix, it is determined that the manufacturer’s profit function has a unique solution. The derivative analysis of (19) shows that the manufacturer’s optimal purchase quantity is as follows:

\[
Q^{*}_{R1} = \frac{(2 \theta_{R1} - a \theta_{R1} - 2 \theta_{R1} \omega_{R2} + a \theta_{R1} \theta_{R2})}{2b \theta_{R1} (\theta_{R1} \theta_{R2} - 1)},
\]

(20)

\[
Q^{*}_{R2} = \frac{(2 \theta_{R2} - a \theta_{R2} - 2 \theta_{R2} \omega_{R1} + a \theta_{R1} \theta_{R2})}{2b \theta_{R2} (-b \theta_{R1} \theta_{R2} + b)}.
\]

(21)

The manufacturer’s optimal purchase quantity and its subsidy policy are determined, and the supplier responds accordingly. Then, the profit functions of supplier 1 and supplier 2 are, respectively:

\[
\Pi_{\text{s1}} = \frac{\theta_{R1} (1 - \theta_{R1}^2) - (1 - \alpha)k \theta_{R1}^2}{2} Q^{*}_{R1},
\]

(22)

\[
\Pi_{\text{s2}} = \frac{\theta_{R2} (1 - \theta_{R2}^2) - (1 - \alpha)k \theta_{R2}^2}{2} Q^{*}_{R2},
\]

(23)

\[
\frac{\partial \Pi_{\text{s1}}}{\partial \omega_{R1}} = \frac{2 \theta_{R1} (1 - \theta_{R1}) \omega_{R1} - a \theta_{R1} (1 - \theta_{R1}) - \theta_{R1} (c - \omega_{R1}) + \theta_{R1}^2 k (\theta_{R1} - 1) (\alpha_1 - 1)}{2b \theta_{R1} (\theta_{R1} \theta_{R2} - 1)},
\]

(24)
Calculate the partial derivative of the supplier’s profit function, and then use \( \partial \Pi_{R_1}/\partial \omega_{R_1} = 0 \) and \( \partial \Pi_{R_2}/\partial \omega_{R_2} = 0 \), to find the optimal solution of \( \omega_{R_1} \) and \( \omega_{R_2} \); then,

\[
\omega_{R_1}^* = \frac{4c + 2\theta_{R_1}(a + c + k - \alpha_1) - 2k\theta_{R_2}^2(1 - \alpha_1) + \theta_{R_1}\theta_{R_2}(-a + k - a\theta_{R_1} - k\theta_{R_2} - k\alpha_2 + k\alpha_2\theta_{R_2})}{2(\theta_{R_1}\theta_{R_2} - 4)}
\]

\[
\omega_{R_2}^* = \frac{4c + 2\theta_{R_2}(a + c + k - \alpha_2) + \theta_{R_1}\theta_{R_2}(-a + k - a\theta_{R_1} - k\theta_{R_2} - k\alpha_1 - k\alpha_1\theta_{R_1})}{2(\theta_{R_1}\theta_{R_2} - 4)}
\]

Bring \( Q_{R_1}^*, Q_{R_2}^*, \omega_{R_1}^*, \omega_{R_2}^* \) into the function of manufacturer’s profit and supplier’s target profit, respectively, to obtain the optimal profit of manufacturer, supplier, and the entire supply chain:

\[
\Pi^*_R = \Pi^*_{R, m} + \Pi^*_{R, r_1} + \Pi^*_{R, r_2}.
\]

5. Numerical Analysis

Assume that there are two suppliers and one manufacturer in the secondary supply chain. The manufacturer is a medium-sized industrial enterprise that needs to purchase raw materials and process them into finished products for sale. Suppliers 1 and 2 are upstream suppliers of the manufacturer. Two suppliers of the same products are produced on different scales, so the probability of supply interruption when subjected to shocks is different. Their main business is to provide manufacturers with raw materials, and their production volume is affected by the supplier’s purchase volume, while being affected by uncertain factors will produce different interruption probabilities. The manufacturer purchases raw materials from two suppliers. In order to maintain the continuity and stability of the supply, the supplier will adopt incentives and the supplier will also invest in reliability costs. Moreover, the information among business members in the supply chain is completely symmetrical. That is, the revenue function of each participant and the supplier’s improvement function, cost, and supply stability information are common information among all participants. Therefore, the specific parameters are set to \( \theta_1 = 0.4, \delta = 0.7, a = 1000, b = 10, \lambda = 0.4, c = 20, k = 80, \alpha_1 = \theta_{R_1}, \alpha_2 = \theta_{R_2} \). The loss cost of the supplier’s early input caused by the supply interruption is \( \lambda c = 8 \).

5.1. Sensitivity Analysis. The following analyzes the impact of the change of supplier 1’s supply reliability level on the supplier’s supply price and the manufacturer’s purchase volume when supplier 2’s supply reliability level is 0.4. The result is shown in the figures.

Figure 2 shows the impact of supplier 1’s supply reliability changes on the manufacturer’s purchase volume. It can be seen that under the condition that the supply reliability level of supplier 2 remains unchanged, as the supply reliability level of supplier 1 changes, the manufacturer’s purchasing decision is also different. In Model 1, when \( 0 < \theta_1 < 0.3 \), the manufacturer’s purchase at supplier 1 shows a downward trend. Later, as the supply reliability level of supplier 1 increases, the manufacturer’s optimal order quantity for raw material supplier 1 will gradually increase, while the optimal order quantity for raw material supplier 2 will gradually decrease. When \( 0.4 < \theta_1 < 0.4 \), the manufacturer chooses supplier 2 for more raw materials, and supplier 2 has a competitive advantage. When \( 0.4 < \theta_1 < 1 \), manufacturers purchase more raw materials from supplier 1, and supplier 1 has a greater competitive advantage.

In Model 2, the manufacturer’s purchase changes are roughly the same as in Model 1. The key point is \( \theta_1 = 0.4; \) at this point, the two suppliers get the same optimal order quantity from the manufacturer, which means that under this probability combination, supplier 1 has no competitive advantage over supplier 2. The number of orders obtained by supplier 1 is equal to that of supplier 2. This is because the two suppliers have the same other conditions except for the probability of interruption, which does not affect the optimal order quantity.

As shown in Figure 3, for model 1, the total optimal order quantity first shows a downward trend, and then it flattens out. When the supplier 1’s supply reliability level is greater than 90%, the total order quantity will gradually decrease, mainly because of the maintenance of high supply stability. The cost for manufacturers and suppliers to invest is higher, which in turn leads to higher prices for suppliers, which will cause manufacturers to hesitate, and the gains are not worth the loss. In Model 2, the total amount of optimal orders shows a trend of first increasing and then decreasing.

Figure 4 reflects the two models in the stable state of supplier 2’s supply. As supplier 1’s supply reliability level increases, supplier 1’s supply price gradually increases, while supplier 2’s supply price gradually decreases. When the reliability levels of supplier 1 and supplier 2 are the same, their supply prices are the same. At this time, the level of competition between the two is the same. When \( 0.4 < \theta_1 < 1 \), the supply price of supplier 1 is greater than that of supplier 2 because at this time, the supply reliability level of supplier 1 is greater than the supply reliability level of supplier 2. The same is true, when \( 0 < \theta_1 < 0.4 \), the supply price of supplier 1 is lower than the price of supplier 2.
In our perception, the higher the supplier’s price is, the less the manufacturer purchases, but what is interesting is that in the model, the higher the supplier’s price is, the more the manufacturer purchases. This proves that supply stability plays an important role in the supply and purchase process. A high supply price represents a stable supply level, so manufacturers are willing to pay for the high price. Of course, the supplier’s pricing is also affected by the manufacturer’s incentives. The following is a comparative analysis of the two models.

5.2. Profit Analysis of Model 1 and Model 2. Figure 5 describes the relationship between the total profit of the supply chain and the supply reliability level of supplier 1 when the probability of occurrence of interruption risk of supplier 2 is 0.6. It can be seen from the figure that when the supply reliability level of supplier 1 is less than 0.75, the profit of model 1 is greater than that of model 2, and when the supply reliability level is greater than 0.75, the profit of model 2 gradually exceeds the profit of model 1. Therefore, when the supply reliability level of supplier 2 is stable, when \(0 < \theta_1 < 0.75\), choose model 1 and the overall supply chain will obtain greater profits; when \(0.75 < \theta_1 < 1\), choose model 2, the overall supply chain will obtain greater profits.

Figure 6 is a comparison of the profits of the two suppliers in Model 1 when the profits of the two suppliers are affected by the level of supply reliability. It can be observed from the figure that supplier 1 is greatly affected by its own supply reliability level, and as the reliability of the supply chain increases, supplier 1’s profit rises rapidly. Supplier 2 is less affected by the reliability of supplier 1’s supply. It can be seen from the figure that the profit of supplier 2 changes smoothly, indicating that when the supplier itself is stable, it is less affected by other external conditions.
6. Conclusions

Modern procurement management is an important part of supply chain management. The quality of procurement activities and material supply determines to a large extent whether a company’s production, business management, and other tasks can be effectively carried out. Various uncertain factors are widely present in the current globalized market environment, which makes the benign operation of the supply chain system more and more susceptible to influence. The dual-source procurement strategy can greatly reduce the probability of supply risk and its possible losses. At the same time, the manufacturer’s incentives to suppliers can also encourage suppliers to improve supply reliability. Therefore, this article mainly studies the dual-source procurement supply chain game problem based on the risk of supply interruption in a single cycle and analyzes the following two situations: the use of subsidy policy optimization supply chain model in the case of decentralized decision-making and the use of cost proportional subsidy policy optimization in the case of decentralized decision-making and, at the same time, considers the supply chain game model of supplier reliability cost input in two situations. Based on two raw material providers with different interruption probabilities, and considering the possible interruption probability, the expected profit function model of the core enterprise and the raw material provider is constructed, and the optimal order quantity and the optimal order quantity when the entire supply chain and the members obtain the expected profit are obtained. The value range of the correlation coefficient is obtained. The advantages and disadvantages of the two models are analyzed, and finally, the corresponding management enlightenment is obtained. The main research conclusions and results obtained in this article are as follows:

(1) When the supplier’s reliability level is low, the total profit of the supply chain optimized based on the unit price subsidy is higher than the total profit of the proportionally subsidized supply chain; but when the supplier’s supply reliability level is high, the total profit of the supply chain optimized by the unit price subsidy is higher than the total profit of the supply chain with the proportional subsidy.

(2) When a manufacturer chooses to adopt a dual-source supply strategy to prevent possible supply interruption risks, the first thing to pay attention to is the impact of supplier interruption probability. For two homogeneous suppliers, in order to prevent the possibility of supply interruption risk, the manufacturer should order more products from the supplier with the lower interruption probability and the one with the higher interruption probability should order fewer products to ensure maximum profit.

(3) In the face of supply interruption, under the premise that the manufacturer adopts the subsidy policy, it is necessary for the supplier to invest in the reliability cost, but an appropriate amount of investment must be made to ensure the stability of the supply while maintaining the optimal cost and own profit.

(4) Aiming at the procurement problem with the risk of supply interruption, this article considers that the manufacturer adopts the strategic mode of backup procurement to ensure the stability of its supply quantity. On this basis, comparing the supply stability and pricing and profit changes of the two suppliers, it is found that when the suppliers themselves are stable, they are less affected by homogeneous suppliers.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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References

[1] H. N. Wang, A. Xy. Ning, and J. J. Ma, “Optimizing paths and strategies of my country’s fresh agricultural products supply chain after the epidemic,” Rural Economy, vol. 10, no. 10, pp. 107–113, 2020.
[2] J. J. Yu, G. Y. Zhong, and W. Xie, “Ordering and subsidy strategies of loss-averse retailers under dual-source supply,”
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C. Che, W. P. Luo, and X. L. Qi, "The influence of space and social distance on the online word-of-mouth valence of virtual communities," *Soft Science*, vol. 31, no. 4, pp. 117–144, 2017.

S. A. Torabi, M. Bagherias, and S. A. Mansouri, "Resilient supplier selection and order allocation under operational and disruption risks," *Transportation Research Part E: Logistics and Transportation Review*, vol. 79, pp. 22–48, 2015.

X. J. Li, "Coordination and optimization of dual sourcing under supply disruptions," *Journal of Industrial Engineering/Engineering Management*, vol. 28, no. 3, pp. 141–147, 2014.

C. Che, W. Q. Ma, and S. F. Cao, "Research on time distance, social distance and the effect of online shopping decision framework," *Social Studies Today*, vol. 2015, no. 9, pp. 130–136, 2015.

X. Xu, J. Hao, and Y. Zheng, "Multi-objective artificial bee colony algorithm for multi-stage resource levelling problem in sharing logistics network," *Computers & Industrial Engineering*, vol. 142, no. 4, Article ID 106338, 2020.

W. Zhang, M. Zhang, W. Zhang, Q. Zhou, and X. Zhang, "What influences the effectiveness of green logistics policies? a grounded theory analysis," *Science of the Total Environment*, vol. 714, Article ID 136731, 2020.

X. Xu, J. Hao, L. Yu, and Y. Deng, "Fuzzy optimal allocation model for task-resource assignment problem in collaborative logistics network," *IEEE Transactions on Fuzzy Systems*, vol. 27, no. 5, pp. 1112–1125, 2019.

C. X. Feng, Q. Zhong, and J. Tan, "Retailer’s incentive strategy based on supplier reliability cost input," *Chinese Journal of Management*, vol. 16, no. 11, pp. 1729–1738, 2019.

X. F. Xu, Z. Lin, and J. Zhu, "DVRPLS with variable neighbourhood region in refined oil distribution," *Annals of Operations Research*, 2020.

Zobei, "Assessing the extended impacts of supply chain disruptions on firms: an empirical study," *International Journal of Production Economics*, vol. 231, Article ID 107862, 2021.

J. Ma, "Dynamic supply chain super network equilibrium model based on risk management," *Operations Research and Management Science*, vol. 24, no. 1, pp. 1–9, 2015.

D. Ivanov, "Low-certainty-need (LCN) supply chains: a new perspective in managing disruption risks and resilience," *International Journal of Production Research*, vol. 57, no. 15, pp. 5119–5136, 2019.

G. J. Burke, J. E. Carrillo, and A. J. Vakharia, "Single versus multiple supplier sourcing strategies," *European Journal of Operational Research*, vol. 182, no. 1, pp. 95–112, 2007.

H. Konishi, "Optimal slice of a VWAP trade," *Journal of Financial Markets*, vol. 5, no. 2, pp. 197–221, 2002.

J. Li and S. Gong, "Coordination of closed-loop supply chain with dual-source supply and low-carbon concern," *Complexity*, vol. 2020, Article ID 7506791, 14 pages, 2020.

L. W. Liu, X. Y. Yan, and J. K. Wang, "Supply chain coordination under interruption based on supplier group evaluation," *International Journal of Modelling in Operations Management*, vol. 7, no. 4, p. 344, 2018.

C. C. Ping and Z. X. Chen, "Dual-source procurement decision under random supplier output and supply interruption," *Chinese Journal of Management Science*, vol. 27, no. 6, pp. 113–122, 2019.

N. Wan and X. Chen, "Multi-period dual-sourcing replenishment problem with option contracts and a spot market," *Industrial Management & Data Systems*, vol. 41, no. 3, pp. 782–805, 2018.

X. Feng, "Revenue-sharing contracts in an N-stage supply chain with reliability considerations," *International Journal of Production Economics*, vol. 147, 2014.

S. Liu, K. C. So, and F. Zhang, "Effect of supply reliability in a retail setting with joint marketing and inventory decisions," *Manufacturing & Service Operations Management*, vol. 12, no. 1, pp. 19–32, 2010.

H. Gurnani, "A bargaining model for a first-time interaction under asymmetric beliefs of supply reliability," *Management Science*, vol. 52, no. 6, pp. 865–880, 2008.

D. Delen, "RFID for better supply-chain management through enhanced information," *Production and Operations Management*, vol. 16, no. 5, pp. 613–624, 2007.

B. Roy and Z. Giri, "Supply chain coordination with price-sensitive demand under risks of demand and supply disruptions," *Technology and Operation Management*, vol. 2, no. 1, pp. 29–38, 2011.

C. Huang and C. Yang, "Supply chain contract design under asymmetric cost disturbance information and nonlinear demand function," *Chinese Journal of Management Science*, vol. 22, no. 8, pp. 80–88, 2014.

Y. Q. Wang, "Literature review and research prospects of supply chain resilience under disruption," *Management Review*, vol. 29, no. 12, pp. 201–216, 2017.

C. Meng, "A review of research on emergency management of supply chain emergencies based on flexibility," *Soft Science*, vol. 28, no. 04, pp. 127–130, 2014.

X. D. Li, "Research on the perfection of emergency logistics model based on the application of blockchain in public health emergencies," *Contemporary Economic Management*, vol. 42, no. 04, pp. 57–63, 2020.

X. Tan, "Supply chain repurchase contract model under emergencies and asymmetric information," *Industrial Engineering Journal*, vol. 15, no. 5, pp. 99–104, 2012.

S. Y. Tang, H. Gurnani, and D. Gupta, "Managing disruptions in decentralized supply chain with endogenous supply reliability," *Production and Operations Management*, vol. 23, no. 7, pp. 1198–1211, 2014.

D. Sun and Y. M. Yu, "Determination of the government’s optimal subsidy policy in the green product market," *Journal of Management*, vol. 15, no. 1, pp. 118–126, 2018.

C. Che, Y. Chen, X. G. Zhang, and Z. H. Zhang, "The impact of different government subsidy methods on low-carbon emission reduction strategies in dual-channel supply chain," *Complexity*, vol. 2021, Article ID 6668243, 9 pages, 2021.

C. Che, X. L. Qi, W. Q. Ma, and D. X. Shao, "An empirical study on the influencing factors of mobile social network marketing effectiveness," *Chinese Journal of Management Science*, vol. 25, no. 5, pp. 145–149, 2017.

H. H. Yu, H. Song, and C. Qian, "Research on the performance of supply chain operational flexibility in different environments," *Journal of Management Science*, vol. 27, no. 1, pp. 43–54, 2014.

C. Che, X. G. Zhang, Y. Chen, L. Y. Zhao, and Z. H. Zhang, "A model of waste price in a symbiotic supply chain based on Stackelberg algorithm," *Sustainability*, vol. 13, no. 04, p. 1740, 2021.

H. Wang, "High-value transportation disruption risk management: shipping insurance with declared value," *Transportation Research Part E: Logistics and Transportation Review*, vol. 109, pp. 293–310, 2018.

X. Q. Wen, "Government subsidy strategy and effect analysis in green supply chain," *Journal of Management*, vol. 15, no. 4, pp. 625–632, 2018.