# Research on Inventory Decisions in Dual-Channel Supply Chain Considering Supply Disruption Risk

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**Abstract.** With the rapid development of internet technology, the coverage of supply chain networks is expanding, and supply disruption issues are gradually becoming apparent, with increasingly severe consequences. Meanwhile, dual-channel supply chain model, as core modes of enterprise development, hold significant importance in devising rational inventory decisions to address the supply disruption risks. Thus, this paper constructs a dual-channel inventory decision-making model considering supply disruption risks. It analyzes the optimal inventory levels and expected profits under decentralized, VMI and JMI modes. Numerical calculations and sensitivity analyses are conducted accordingly.

**Keywords:** Supply disruption, dual-channel supply chain, inventory decisions.

## 1 Introduction

With economic globalization, the coverage of supply chains is becoming increasingly extensive, and their complexity and risk are also growing. Even a minor disruption in one link can potentially lead to the disruption of the entire supply chain[1]. Scholars both domestically and internationally have explored supply chain disruption issues from various perspectives. Parast and Subramanian[2] categorized the causes of supply chain disruptions into four types: demand disruption, supply disruption, process disruption, and environmental disruption. Konstantaras et al.[3] studied the quantity of orders prepared under regular inventory inspection strategies to prevent sudden events in the supply chain. Hendricks et al.[4] concluded through research that the cost of supply chain disruptions is the highest among various supply chain risks. Developing appropriate strategies to mitigate the impact of supply chain disruptions plays a crucial role in enhancing supply chain profitability.

Simultaneously, with intensified market competition, more and more manufacturers are adopting dual-channel models to increase profits. However, this also leads to increased channel conflicts, and inventory competition between manufacturers and retailers becomes inevitable. Seifert[5] studied centralized inventory strategies and compared them with decentralized inventory strategies. Dai et al.[6] considered multi-channel order inventory replenishment plans with capacity constraints. Berling et al.[7] proposed a new combined inventory strategy. Huang et al.[8] studied inventory decision-making


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issues in dual-channel supply chains under random demand. Hamed et al.[9] investigated the mitigation of medication shortages within healthcare systems by employing secondary suppliers, and conducted a sensitivity analysis on the frequency and duration of shortages from secondary suppliers. Rational inventory decisions are the primary issue for the enterprises.

Supply disruption, as a current focal and hot issue, has been extensively researched by scholars. However, there is limited literature that considers the impact of supply disruption risk on inventory decisions and profits in dual-channel supply chains from the perspective of supply disruption probability and the percentage of orders deliverable during disruption. Therefore, this paper investigates inventory decisions in dual-channel supply chains under three different inventory modes when considering supply disruption risk, analyzing how supply disruption probability and the percentage of orders deliverable during disruption affect the optimal inventory level and expected profits.

## 2 Model

This article establishes a dual-channel supply chain inventory mode consisting of a manufacturer and an independent retailer. The manufacturer owns online channel, while the retailer owns offline channel. From the perspective of inventory holders, this article investigates decentralized, VMI and JMI modes. The article assumes that the demands between channels, denoted as D, are mutually independent and follow a normal distribution; the production cost $c$, wholesale price $w$, retail price $p$ of the product are exogenous variables, with the same retail price for each channel. The probability of supply disruption is denoted as $\beta$, and the percentage of orders deliverable during a supply disruption is denoted as $y$, where the inventory level is $y*Q$. Additionally, the distribution cost, stockout cost, salvage value are represented by $t$, $g$, $v$, respectively, and the inventory holding cost is $a+b*Q$, where subscripts $m$, $r$ denote the manufacturer and retailer, respectively.

In the decentralized inventory mode, both the manufacturer and the retailer hold inventory separately, and each makes inventory decisions to determine their optimal inventory level. In this mode, the expected profits for the manufacturer and the retailer are respectively represented by formulas (1) and (2):

$$\pi_m^1 = (p - t_m - v_m) * \int_0^{Q_m} (x - Q_m) * f(x)dx - \quad g_m * \int_{Q_m}^{+\infty} (x - Q_m) * f(x)dx + w * Q_r - c * (Q_m + Q_r) - (a_m + b_m * Q_m) + (p - t_m) * Q_m \tag{1}$$

$$\pi_r^1 = (p - v_r) * \int_0^{Q_r} (x - Q_r) * h(x)dx - g_r * \int_{Q_r}^{+\infty} (x - Q_r) * h(x)dx - \ w * Q_r - (a_r + b_r * Q_r) + \mathrm{p} * Q_r \tag{2}$$

The solution yields the optimal inventory level for the manufacturer as $Q_m^* = F^{-1}(\frac{t_m + b_m + c - g_m - p}{t_m + v_m - g_m - p})$, and for the retailer as $Q_r^* = H^{-1}(\frac{b_r + w - g_r - p}{v_r - g_r - p})$. When considering the risk of supply disruption, the optimal inventory level for the manufacturer is $Q_m^{1*} = \frac{\beta}{y} * Q_m^* + (1 - \beta) * Q_m^*$, and for the retailer is $Q_r^{1*} = \frac{\beta}{y} * Q_r^* + (1 - \beta) * Q_r^*$.

In the VMI mode where the manufacturer determines and holds inventory, the retailer transmits order information to the manufacturer. When market demand exceeds inventory, the manufacturer prioritizes fulfilling orders from the online channel, with no stockout cost incurred by the online channel, stockout costs are borne by the retailer. In this mode, the expected profits for the manufacturer and the retailer are represented by formulas (3) and (4), respectively.

$$\pi_m^2 = (p - t_m - v_m) * \int_0^{Q_m} (x - Q_m) * f(x)dx + w * \mu_r - c * (Q_m + \mu_r) - (a_m + b_m * (Q_m + \mu_r)) + (p - t_m) * Q_m \quad (3)$$

$$\pi_r^2 = (p - w) * \mu_r - g_r * \int_{Q_m}^{+\infty} (x - Q_m) * f(x)dx \quad (4)$$

When considering the risk of supply disruption, the manufacturer's optimal total inventory level in the VMI mode is $Q^{2*} = \frac{\beta}{y}(F^{-1}\left(\frac{t_m+b_m+c-g_m-p}{t_m+v_m-g_m-p}\right) + \mu_r) + (1 - \beta)(F^{-1}\left(\frac{t_m+b_m+c-g_m-p}{t_m+v_m-g_m-p}\right) + \mu_r)$.

In the JMI mode, neither the manufacturer nor the retailer holds inventory. Both parties' demands are fulfilled by a central warehouse, they jointly formulate inventory strategies and share risks. In this mode, the total expected profit of the supply chain is represented by formula (5).

$$\pi^3 = (p - \mathrm{t} - v) * \int_0^{\mathrm{Q}} (x - Q) * g(x)dx - c * \mathrm{Q} - \mathrm{g} * \int_{\mathrm{Q}}^{+\infty} (x - Q) * g(x)dx - (\mathrm{a} + \mathrm{b} * \mathrm{Q}) + (p - \mathrm{t}) * \mathrm{Q} \quad (5)$$

Thus, the total optimal inventory level considering supply disruption risk is $Q^{3*} = \frac{\beta}{y} G^{-1}(\frac{\mathrm{t+b}+c-g-p}{\mathrm{t}+v-g-p}) + (1 - \beta)G^{-1}(\frac{\mathrm{t+b}+c-g-p}{\mathrm{t}+v-g-p})$. Based on the total expected profit of the supply chain, the expected profits of the manufacturer and the retailer can be deduced, as shown in formulas (6) and (7):

$$\pi_m^3 = \left(\frac{\mu_m}{\mu} * p - \frac{\mu_m}{\mu} * v - t\right) * \int_0^{\mathrm{Q}} (x - Q) * g(x)dx - \frac{\mu_m}{\mu} \mathrm{g} * \int_{\mathrm{Q}}^{+\infty} (x - Q) * g(x)dx - \frac{\mu_m}{\mu} * \mathrm{a} + \left(\frac{\mu_m}{\mu} * p + \frac{\mu_r}{\mu} * w - \frac{\mu_m}{\mu} * b - t - c\right) * Q \quad (6)$$

$$\pi_r^3 = \frac{\mu_r}{\mu}[(p - v) * \int_0^{\mathrm{Q}} (x - Q) * g(x)dx - \mathrm{g} * \int_{\mathrm{Q}}^{+\infty} (x - Q) * g(x)dx - \mathrm{a} + (p - \mathrm{b} - \mathrm{w}) * \mathrm{Q}] \quad (7)$$

## 3 Results and Discussion

In order to present the results more intuitively, this section assigns values to various parameters and then conducts numerical analysis, the model parameters are shown in Table 1.

**Table 1.** Model Parameter Assignment

| $p$ | $c$ | $w$ | $\mu_m$ | $\mu_r$ | $\mu$ | $t_m$ | $t$ | $g_m$ | $g_r$ |
|---|---|---|---|---|---|---|---|---|---|
| 20 | 6 | 10 | 200 | 200 | 400 | 2 | 2 | 2 | 1 |
| $g$ | $v_m$ | $v_r$ | $v$ | $a_m$ | $a_r$ | $a$ | $b_m$ | $b_r$ | $b$ |
| 2 | 4 | 3 | 4 | 5 | 5 | 5 | 0.5 | 0.5 | 0.5 |

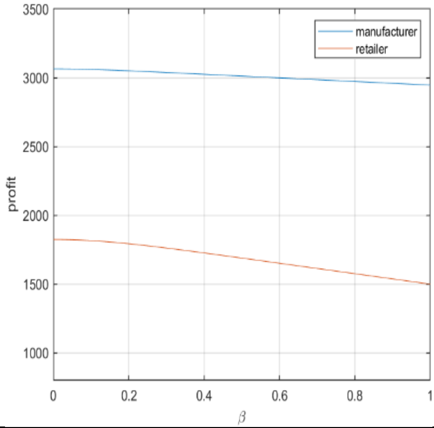
When the demand uncertainty is 10, $\beta$ is 0.2, and $y$ is 0.8, the optimal inventory levels and expected profits under three different inventory modes are shown in Table 2. From the table, it can be observed that the total inventory level is the lowest in the VMI mode and the highest in the decentralized mode. The manufacturer's profit is highest in the decentralized mode and lowest in the JMI mode. The retailer's profit is highest in the VMI mode and lowest in the decentralized mode. The total profit of the supply chain is highest in the VMI mode and lowest in the JMI mode.

**Table 2.** Comparison of Inventory Levels and Expected Profits

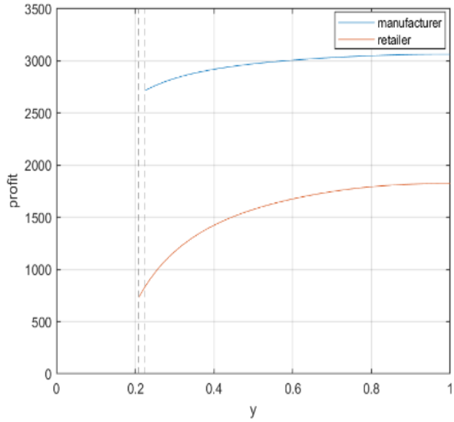
| Inventory mode | $Q^{i*}$ | $\pi_m^i$ | $\pi_r^i$ | $\pi^i$ |
|---|---|---|---|---|
| decentralized | 433 | 3065 | 1825 | 4890 |
| VMI | 429 | 2958 | 1999 | 4957 |
| JMI | 429 | 2699 | 1858 | 4557 |

To examine the impact of the probability of supply disruption $\beta$ and the percentage of orders deliverable during supply disruption $y$ on inventory levels and profits, sensitivity analyses were conducted on $\beta$ and $y$, as depicted in Figure 1.

a. decentralized




b. decentralized



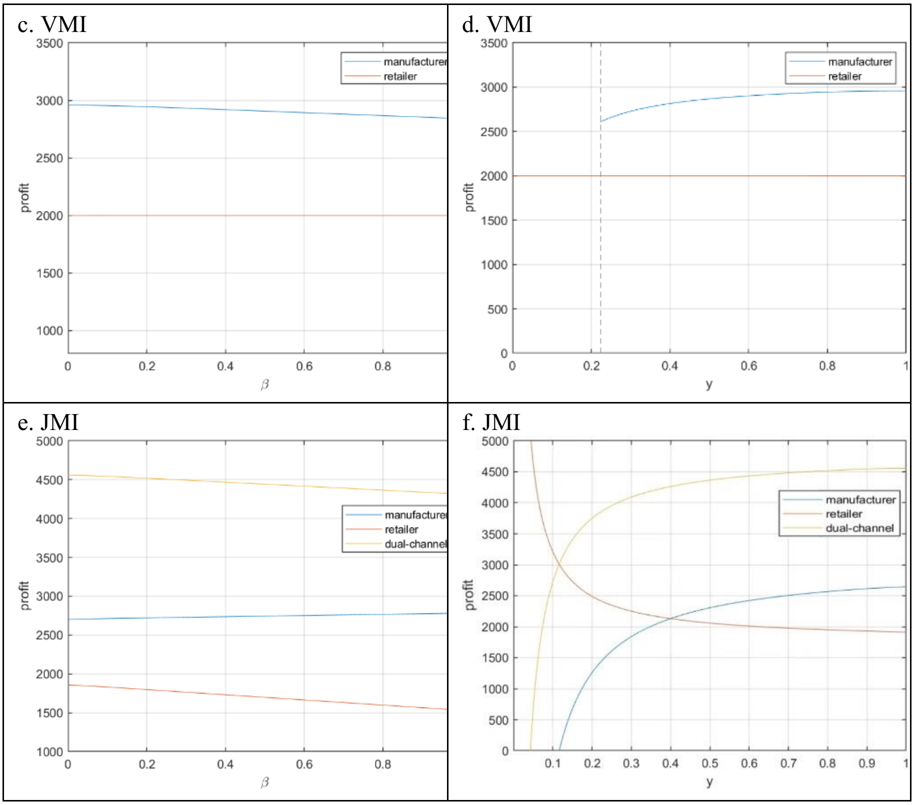



**Fig. 1.** the Relationship between β, y and Expected Profit

When the uncertainty of supply disruption risk is considered, by observing the optimal inventory expressions, it is found that inventory levels increase linearly with $\beta$, indicating a direct proportionality, while vary inversely with $y$. As show in Figure 1, it is observed that with the increase of $\beta$, the manufacturer's profit increases in the decentralized and VMI modes but decreases in the JMI mode, whereas the retailer's profit increases in the decentralized and JMI modes and remains relatively constant in the VMI mode. As $y$ increases, the manufacturer's profit increases in all three modes, while the retailer's profit increases in the decentralized inventory mode, remains largely unchanged in the VMI mode, and continuously decreases in the JMI mode.

## 4 Conclusions

This study investigated three dual-channel inventory modes considering supply disruption risks, and conducted solution, numerical analysis, sensitivity analysis on them. It was found that, under the three different inventory modes, the impact of disruption probability and the percentage of orders deliverable during disruption on inventory levels was similar, but their impact on expected profit varied. In the VMI mode, the supply chain achieves the lowest total inventory level and the highest total expected profit, while manufacturers tend to favor the decentralized inventory mode. The dual-channel supply chain inventory system lacks coordination, and future research could consider introducing supply chain contracts to achieve coordination.

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