A study of Competitive Strategies for Supplier Orders Considering Disruption Risk in Supply Chain Environment

Shengjin Ji

2461520034@qq.com

Shanghai Maritime University, Institute of Logistics Science and Engineering, Shanghai, 201306, China

Abstracts: This paper constructs a supply chain consisting of a retailer and two suppliers, discusses three strategy models, and introduces a third-party investment enterprise to further analyze the supplier's choice decision on the investment of the third-party enterprise. Finally, Matlab tool is borrowed for numerical simulation to provide corresponding decision-making suggestions for the suppliers.

Keywords: Dual supplier;Order competition strategy;Third-party investment firms; Disruption risk; Investment ratio

1. Introduction

In the information economy, the risk of supplier supply disruptions is rising as the network structure of the supply chain becomes more complex and the frequency of events such as sabotage, disease or natural disasters increases.

Most of the supply chain research under supply disruption risk is about early warning of supply disruption risk and risk management, such as Christophher, Johnson et al. and Haonan Xu study to build an early warning system for supply disruption risk, which provides countermeasures for supply chain firms to prevent disruption risk[1] .Adegoke et al. study the mitigation measures for supply chain disruption risk in the retail industry[2].Knemeyer et al. study the supply chain disruption risk caused by catastrophic events and the corresponding risk mitigation measures[3].

Most studies on the multi-source procurement ordering problem analyze the allocation of ordering quantity from the buyer's point of view, mostly ignoring the competition between suppliers[4].Juan Wang studied the problem of two suppliers competing for retailers' purchasing volume, and found that the supplier with low disruption risk adjusting its wholesale price can affect the reliability threshold of the supplier with high disruption risk, and thus can obtain more purchasing volume from retailers[5] .

In summary, this paper introduces third-party investment enterprises into the supply disruption risk reduction strategy to enrich the research on the issue of reducing supplier supply disruption risk.

IEDM 2024, February 23-25, Kuala Lumpur, Malaysia

DOI 10.4108/eai.23-2-2024.2345939

2. Model description and basic assumptions

2.1 Model description

In a secondary supply chain system consisting of a retailer and two suppliers, there are two suppliers with different risk of disruption and offering homogeneous products to supply the same retailer, the retailer purchases Qi from supplier i (i =1,2), and the price per unit of the product p as a function of the market demand Q is p =a-bQ,(a > 0, b > 0), where Q=Q1+Q2 , and the inverse The demand function is: p= a-bQ1-bQ2 (a, b are constants both greater than 0), and there is competition among suppliers for the quantity purchased.

2.2 Model assumptions

Assumption 1: The probability that supplier i does not experience supply disruptions θi is high and the unit production cost Ci is high, i.e., θ1>θ2 , C1>C2 , and θi∈(0, 1), a setting that is common in the literature[6];

Assumption 2:No shortage costs are incurred when suppliers experience supply disruptions;

Hypothesis 3: Investments to reduce the risk of supply disruptions are independent of investments to reduce unit production costs, i.e., investments to reduce the risk of supply disruptions do not have the effect of reducing unit production costs[7];

Assumption 4: When a third-party investment firm invests in a supplier, it is assumed that the probability that the supplier does not experience a supply disruption, θi, increases with a probability of 100%,i.e.[8], the probability of a supplier disruption remains unchanged in the absence of the third-party investment;

Assumption 5: The probability of supply disruption changes in the same form for both third-party firms when they work with suppliers 1or 2.

Other parameters involved in the text and their meanings are shown in Table 1:

Table 1. Parameter Symbol Definitions

parameters	define
$ш_i$	Wholesale price per unit of product
c_i	Production costs per unit of product
θ_i	Initial probability of uninterrupted supply from supplier i before third-party investment, i.e., initial supply reliability
θ_{i3}	Probability of uninterrupted supply for supplier i
α_i	Investment ratio of third-party investment firms
A_{0i}	Critical Investment Ratio for Vendor i to Third Party Collaboration
π_r	Retailer's profit
πs_i	Supplier i's profit
πc	Profits from third-party investment enterprises
π	Profitability of the supply chain

3. Model construction and solution

In this paper, we will discuss the supply chain game model in which the retailer is the dominant player and the supplier is the follower, and the supplier is a static game, which is in line with the reality that large retailers tend to have the dominant power in purchasing. The order of the game is that the retailer makes the purchasing volume decision first, and then the supplier makes the corresponding wholesale price decision.

3.1 Lack of strategy on the part of both suppliers in the event of a supply disruption

The probability that supplier 1 does not interrupt is θ_1 and the probability that supplier 2 does not interrupt the supply is θ2 when neither supplier adopts a strategy, then the probability when both supplier 1 and supplier 2 do not interrupt is $\theta_1\theta_2$, and the probability when supplier 1 interrupts and supplier 2 does not interrupt is $(1-\theta_1)\theta_2$, and similarly the probability when supplier 2 interrupts and supplier 1 does not interrupt is $(1-\theta_2)\theta_1$, and the probability that interruptions occur in supply from both suppliers is $(1-\theta_1\theta_2)\theta_1$, and the probability that interruption of supply occurs from both suppliers is $(1-\theta_1)(1-\theta_1\theta_2)$. probability is $(1-\theta_1)(1-\theta_2)$. Then there are expected profit functions for the retailer and supplier, respectively:

$$\begin{aligned}\pi_{\mathrm{r}} &= \theta_1\theta_2\left(pQ_1+pQ_2-\omega_1Q_1-\omega_2Q_2\right)+\left(1-\theta_1\right)\theta_2\left(pQ_2-\omega_2Q_2\right)\\&+\left(1-\theta_2\right)\theta_1\left(pQ_1-\omega_1Q_1\right)\end{aligned} \tag{1}$$

$$\pi_{si}=\theta_i\left(\omega_i-c_i\right)Q_i \tag{2}$$

By backward induction, the optimal wholesale price of the supplier, and the optimal purchase quantity of the retailer from the supplier are obtained:

$$\omega_1^*=\frac{c_2\theta_2-a\theta_2+2a+2c_1-a\theta_1\theta_2}{4-\theta_1\theta_2} \tag{3}$$

$$\omega_2^*=\frac{c_1\theta_1-a\theta_1+2a+2c_2-a\theta_1\theta_2}{4-\theta_1\theta_2} \tag{4}$$

$$Q_1^*=\frac{c_1\theta_1\theta_2-a\theta_1\theta_2-2c_1+2a+c_2\theta_2-a\theta_2}{2b\left(1-\theta_1\theta_2\right)\left(4-\theta_1\theta_2\right)} \tag{5}$$

$$Q_2^*=\frac{c_2\theta_1\theta_2-a\theta_1\theta_2-2c_2+2a+c_1\theta_1-a\theta_1}{2b\left(1-\theta_1\theta_2\right)\left(4-\theta_1\theta_2\right)} \tag{6}$$

Substituting Eqs. (3)-(6) into Eqs. (1) and (2) yields the profits of the retailer, the supplier, and the supply chain, respectively:

$$\pi_r^*=\frac{b\theta_1T_1^2+b\theta_2T_2^2-2b\theta_1\theta_2T_1T_2}{1-\theta_1\theta_2} \tag{7}$$

$$\pi_{s1}^*=\frac{\theta_1\left[\theta_2\left(c_2-a\right)+\left(\theta_1\theta_2-2\right)\left(c_1-a\right)\right]^2}{\left(2b-2b\theta_1\theta_2\right)\left(4-\theta_1\theta_2\right)^2} \tag{8}$$

$$\pi_{s2}^{*} = \frac{\theta_2\left[\theta_1(c_1-a)+(\theta_1\theta_2-2)(c_2-a)\right]^2}{(2b-2b\theta_1\theta_2)(4-\theta_1\theta_2)^2} \tag{9}$$

$$\pi^{*} = \pi_r^{*} + \pi_{s1}^{*} + \pi_{s2}^{*} \tag{10}$$

Among them: $T_1 = \frac{2a-c_2\theta_2+a\theta_2-2c_1}{2b(4-\theta_1\theta_2)}, T_2 = \frac{2a-c_1\theta_1+a\theta_1-2c_2}{2b(4-\theta_1\theta_2)}$

From equations (3) and (4), we can get $\frac{\partial\omega_j}{\partial\theta_i}<0$, the wholesale price of supplier i and the probability of uninterrupted supply of supplier i are inversely proportional.

When the third-party investment enterprise invests to reduce the interruption risk of supplier i (i ≠ j; i, j= 1,2), according to the study of Ou Jian[9], the probability of non-interruption of supplier i after the third-party investment is set to be $\theta_{i3} = 1-\phi(\alpha_i)(1-\theta_i)$,where $\phi(\alpha_i)=\frac{d}{d+\alpha_i}$, $\phi(\alpha_i)$ is a decreasing function about αi, d is a constant, and the third-party enterprise distributes the revenue of the two parties after the cooperation according to the investment ratio of α_i ; the probability of non-interruption of the supply of supplier j, θ_j , remains unchanged. The model is denoted by superscript "RN", and the profit functions of the retailer and the supplier are:

$$\begin{aligned}\pi_r^{RN} &= \theta_{i3}\theta_j\left(pQ-\omega_i^{RN}Q_i^{RN}-\omega_j^{RN}Q_j^{RN}\right)+(1-\theta_{i3})\theta_j\left(pQ_j^{RN}-\omega_i^{RN}Q_j^{RN}\right)\\ &+(1-\theta_j)\theta_{i3}\left(pQ_i^{RN}-\omega_i^{RN}Q_i^{RN}\right)\end{aligned} \tag{11}$$

$$\pi_{si}^{RN} = (1-\alpha_i)\theta_{i3}\left(\omega_i^{RN}-c_i\right)Q_i^{RN} \tag{12}$$

$$\pi_{sj}^{RN} = \theta_j\left(\omega_j^{RN}-c_j\right)Q_j^{RN} \tag{13}$$

$$\omega_i^{RN^*} = \frac{c_j\theta_j-a\theta_j+2a+2c_i-a\theta_{i3}\theta_j}{4-\theta_{i3}\theta_j} \tag{14}$$

$$\omega_j^{RN^*} = \frac{c_i\theta_{i3}-a\theta_{i3}+2a+2c_j-a\theta_{i3}\theta_i}{4-\theta_{i3}\theta_j} \tag{15}$$

$$Q_i^{RN^*} = \frac{c_i\theta_{i3}\theta_j-a\theta_{i3}\theta_j-2c_i+2a+c_j\theta_j-a\theta_j}{2b(1-\theta_{i3}\theta_j)(4-\theta_{i3}\theta_j)} \tag{16}$$

$$Q_j^{RN^*} = \frac{c_j\theta_{i3}\theta_j-a\theta_{i3}\theta_j-2c_j+2a+c_i\theta_{j3}-a\theta_{i3}}{2b(1-\theta_{i3}\theta_j)(4-\theta_{i3}\theta_j)} \tag{17}$$

The profits of the retailer, the supplier and the supply chain are obtained as:

$$\pi_r^{RN^*} = \frac{b\theta_{i3}M_1^{\,2}+b\theta_jM_2^{\,2}-2b\theta_{i3}\theta_jM_1M_2}{1-\theta_{i3}\theta_j} \tag{18}$$

$$\pi_{si}^{RN^*} = (1-\alpha_i)\frac{\theta_{i3}\left[\theta_j(c_j-a)+(\theta_{i3}\theta_j-2)(c_i-a)\right]^2}{(2b-2b\theta_{i3}\theta_j)(4-\theta_{i3}\theta_j)^2} \quad (19)$$

$$\pi_{sj}^{RN^*} = \frac{\theta_j\left[\theta_{i3}(c_i-a)+(\theta_{i3}\theta_j-2)(c_j-a)\right]^2}{(2b-2b\theta_{i3}\theta_j)(4-\theta_{i3}\theta_j)^2} \quad (20)$$

$$\pi^{RN^*} = \pi_r^{RN^*} + \pi_{si}^{RN^*} + \pi_{sj}^{RN^*} \quad (21)$$

Of which: $M_1 = \frac{2a-c_j\theta_j+a\theta_j-2c_i}{2b(4-\theta_{i3}\theta_j)}, M_2 = \frac{2a-c_i\theta_{i3}+a\theta_{i3}-2c_j}{2b(4-\theta_{i3}\theta_j)}$

3.2 Disruption risk reduction strategies for both suppliers

The probability of the non-disruption after the investment $\theta_{i3} = 1-\phi(\alpha_i)(1-\theta_i)$, d is a constant, the probability of the non-disruption of supply of both suppliers changes, and the third-party firm allocates the benefits of the cooperation between the two parties according to the investment ratio αi.With the superscript "RR" to indicate the model, the retailer and the supplier's profit function are:

$$\begin{aligned}\pi_r^{RR} &= \theta_{13}\theta_{23}\left(pQ-\omega_1^{RR}Q_1^{RR}-\omega_2^{RR}Q_2^{RR}\right)+(1-\theta_{13})\theta_{23}\left(pQ_2^{RR}-\omega_2^{RR}Q_2^{RR}\right)\\&+(1-\theta_{23})\theta_{13}\left(pQ_1^{RR}-\omega_1^{RR}Q_1^{RR}\right)\end{aligned} \quad (22)$$

$$\pi_{s1}^{RR} = (1-\alpha_1)\theta_{13}\left(\omega_1^{RR}-c_1\right)Q_1^{RR} \quad (23)$$

$$\pi_{s2}^{RR} = (1-\alpha_2)\theta_{23}\left(\omega_2^{RR}-c_2\right)Q_2^{RR} \quad (24)$$

The supplier's optimal wholesale price, the retailer's optimal purchase quantity is:

$$\omega_1^{RR^*} = \frac{c_2\theta_{23}-a\theta_{23}+2a+2c_1-a\theta_{13}\theta_{23}}{4-\theta_{13}\theta_{23}} \quad (25)$$

$$\omega_2^{RR^*} = \frac{c_1\theta_{13}-a\theta_{13}+2a+2c_2-a\theta_{13}\theta_{23}}{4-\theta_{13}\theta_{23}} \quad (26)$$

$$Q_1^{RR^*} = \frac{c_1\theta_{13}\theta_{23}-a\theta_{13}\theta_{23}-2c_1+2a+c_2\theta_{23}-a\theta_{23}}{2b(1-\theta_{13}\theta_{23})(4-\theta_{13}\theta_{23})} \quad (27)$$

$$Q_2^{RR^*} = \frac{c_2\theta_{13}\theta_{23}-a\theta_{13}\theta_{23}-2c_2+2a+c_1\theta_{13}-a\theta_{13}}{2b(1-\theta_{13}\theta_{23})(4-\theta_{13}\theta_{23})} \quad (28)$$

Get the profits of the retailer, the supplier, and the supply chain, respectively:

$$\pi_r^{RR^*} = \frac{b\theta_{13}K_1^2+b\theta_{23}K_2^2-2b\theta_{13}\theta_{23}K_1K_2}{1-\theta_{13}\theta_{23}} \quad (29)$$

$$\pi_{s1}^{RR} = (1-\alpha_1)\frac{\theta_{13}\left[\theta_{23}(c_2-a)+(\theta_{13}\theta_{23}-2)(c_1-a)\right]^2}{(2b-2b\theta_{13}\theta_{23})(4-\theta_{13}\theta_{23})^2} \quad (30)$$

$$\pi_{s2}^{RR^*}=(1-\alpha_2)\frac{\theta_{23}\left[\theta_{13}(c_1-a)+(\theta_{13}\theta_{23}-2)(c_2-a)\right]^2}{(2b-2b\theta_{13}\theta_{23})(4-\theta_{13}\theta_{23})^2} \tag{31}$$

$$\pi^{RR^*}=\pi_r^{RR^*}+\pi_{s1}^{RR^*}+\pi_{s2}^{RR^*} \tag{32}$$

Of which: $K_1=\dfrac{2a-c_2\theta_{23}+a\theta_{23}-2c_1}{2b(4-\theta_{13}\theta_{23})};K_2=\dfrac{2a-c_1\theta_{13}+a\theta_{13}-2c_2}{2b(4-\theta_{13}\theta_{23})}$

4. Analysis of relevant findings

Corollary 1: The risk of supply disruption has a greater impact on purchasing volumes than wholesale prices.

Proof: the previous assumption that θ1>θ2, c1>c2 from the formula (1-3), (1-4) $\Delta\omega=\omega_1^*-\omega_2^*=\dfrac{(c_1-c_2)(2-\theta_1)}{4-\theta_1\theta_2}>0$, that is, the wholesale price of supplier 1 is higher than that of supplier 2, $\omega_1>\omega_2$,and $\theta_i\in(0,1),\theta_1^2\theta_2^2-5\theta_1\theta_2+4>0$, there:

$$\Delta Q=\frac{c_2(2-\theta_2)+c_1(\theta_1-2)+a(\theta_1-\theta_2)+\theta_1\theta_2(c_1-c_2)}{2b\left(\theta_1^2\theta_2^2-5\theta_1\theta_2+4\right)}>\frac{c_2(\theta_1-\theta_2)+a(\theta_1-\theta_2)+\theta_1\theta_2(c_1-c_2)}{2b\left(\theta_1^2\theta_2^2-5\theta_1\theta_2+4\right)}$$

>0

This means that Supplier 1 with a low risk of disruption but a high wholesale price receives more purchases than Supplier 2 with a high risk of disruption but a low wholesale price. confirming the inference that purchases are more sensitive to the risk of supply disruption than to the wholesale price.

Corollary 2: There exists a critical investment ratio for suppliers to receive investment when working with third party investment firms α_i^0

Proof: Due to $\dfrac{\partial(\pi_c+\pi_{s1})}{\partial\theta_1}>0$, after the third-party investment enterprise invests in supplier 1, as the investment return ratio α1 of the third-party investment enterprise increases, the probability of uninterrupted supply θ1 of supplier 1 increases, and the total profit of supplier 1 after cooperating with the third party increases. The profit of supplier 1 before the third party investment is π_{s1} , the profit of supplier 1 after the investment is π_{s1}^R , From the equation, we can get the critical investment ratio of supplier 1 cooperating with the third party α_1^0 as well as the strategy of choosing cooperation: when 0 ≤α1 $<\alpha_1^0$,supplier 1 accepts to cooperate with the third-party enterprise, and at this time, both parties can be benefited; when α1 $\geq\alpha_1^0$, although the total profit of the supplier 1 and the third-party enterprise is increasing, but due to α's increases, the profit allocated to the third-party investor increases, and the profit of supplier 1 decreases compared with that before the cooperation, and then supplier 1 rejects the third-party investment. The above example of Supplier 1 proves that the same is true for Supplier 2's cooperation with the third-party investment enterprise.

5. Numerical examples

In this paper, numerical simulation is carried out with the help of MATLAB tool, based on the existing literature, so that a = 200, b = 4, c1 = 6, c2 = 5, d = 0.1, θ1 = 0.5, θ2 = 0.5. Substituting the values into (29), (30), and (31), the optimal investment ratio of the supplier under the reduction of the risk of supply disruption, and the equilibrium of optimal purchasing volume and profit under the three models are obtained through calculation. Solution.

Table 2. Equilibrium solutions for purchasing volume and profit under three decisions

strategic decision		α_i	Q	π
No strategy			21.500	959.800
RN	s_1	A1=0.147	20.400	1200.000
RN	s_2	A2=0.171	20.400	1244.500
RR		A1=0.131 A2 = 0.149	20.400	1418.000

Under the strategy of reducing risk of disruption for both suppliers, as shown in Fig. 1, the profit of the supply chain increases and then levels off as the investment ratio α_1 and α_2 increase, and the profit of the supply chain under the strategy of reducing the risk of disruption for both suppliers is more favorable（Fig.1）. As shown in Fig.2, the total purchasing volume of supplier 1 and supplier 2 tends to increase as the investment ratios α_1 and α_2 increase（Fig.2）.

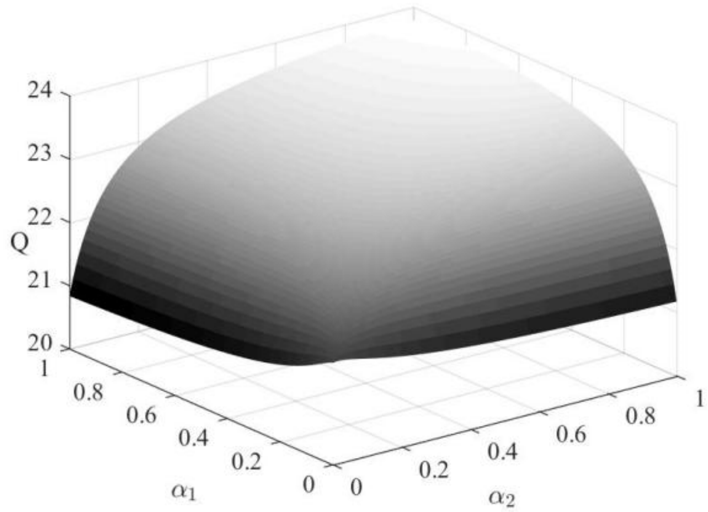

Figure 1 Variation of supply chain profit with investment ratio

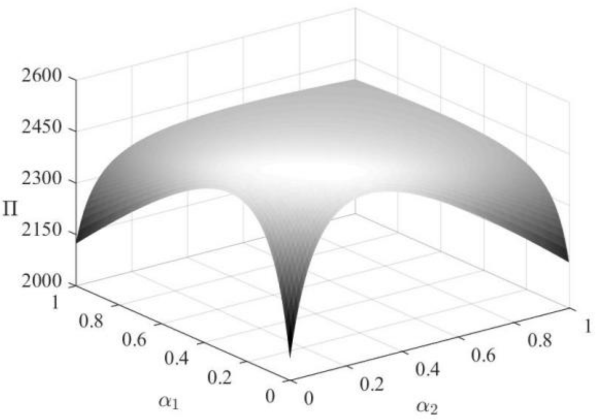

Figure 2 Variation of total procurement with investment ratio

In summary, the probability of supply disruption is greater than the wholesale price on the procurement volume;the strategy of reducing the risk of supply disruption by both suppliers is significantly better than the strategy of reducing the risk of supply disruption by a single supplier, both from the perspective of total purchasing volume and better supply chain profitability.

6. Conclusion

It is found that the impact of wholesale prices on purchasing volumes is smaller than the impact of supply disruption risk on purchasing volumes when the presence of supply disruption risk is taken into account. There is a critical investment ratio when a supplier cooperates with a third party: when the probability of the supplier's supply being uninterrupted is large, i.e., when the reliability is high, the supplier should reject the third-party investor's investment, regardless of the range of the investment ratio α1 ; on the contrary, when the probability of the supplier's supply being uninterrupted is small, the supplier can accept the third-party investor's investment.

This paper enriches the research on the problem of suppliers' order competition strategy. The supply chain profit of two suppliers competing for order quantity is better than the supply chain profit when both of them reduce the interruption risk strategy than when a single supplier reduces the supply interruption risk strategy, and this research has some implications for suppliers with order competition.

References

[1]Haonan Xu. Research on OEM/ODM Supply Chain Decision Making Considering Supply Risk[J/OL]. China Management Science:1-20 [2024-02-08].

[2]Ma S, Li G, Liu M. Procurement competition in the presence of IoT-enabled B2B E-commerce[J].

Electronic Commerce Research and Applications, 2022, 49: 101091.
[3]Linton T,Vakil B. Coronavirus Is Proving We Need More Resilient Supply Chains[J]. Harvard Business Review, 2023.
[4]Oke A, Gopalakrishnan M. Managing Disruption in Supply Chain：A case Study of a Retail Supply Chain[J].International Journal of Production Economics，2009（118）:168-174.
[5] Knemeyer A M, Zinn W, Eroglu C. Proactive Planning for Catastrophic Events in Supply Chain[J].Journal of Operations Management，2009，27（2）:141-153.
[6]Zhu Changlei, Liang Liang. Decision-making on the optimal number of suppliers for small and medium-sized enterprises［J］. Forecasting, 2011. 30(4):36-41.
[7]Qi L.Supplier Competition and its Impact on Firm's Sourcing Strategy[J].Omega，2015（55）
[8]Amico A ,Verginer L ,Casiraghi G , et al.Adapting to disruptions: Managing supply chain resilience through product rerouting.[J].Science advances,2024,10(3):eadj1194-eadj1194.
[9]Tomas B ,Agne Z ,Artiom V , et al.Measures for the viable agri-food supply chains: A multi-criteria approach[J].Journal of Business Research,2023,155(PA):