Research on Supply Chain Emergency Coordination Strategies under Asymmetric Market Demand Disruptions and Price Sensitivity Coefficient Disruptions

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Abstract—**Focusing on a supply chain system that market demand and price sensitivity coefficient are disrupted simultaneously and market demand disruption is private for the retailer, this paper studies how to coordinate the supply chain to respond to the disruptions by supposing that the supplier is the principal , the retailer is the agent and supplier offers a linear revenue sharing contracts menu for retailer. Furthermore, the paper investigates the information value of demand disruption for supply chain, then analyses deeply how demand disruption influences the profits of supply chain, the supplier and the retailer. The above study shows that asymmetric disruption information between supply chain members would change the optimal ordering quantity and production plans of the supplier, which will further lead to the profit losses supply chain.**

Keywords- Asymmetric information; Market demand disruption; Price sensitivity coefficient; Principal-agent model

I. INTRODUCTION

In recent years, the coordination relations between global enterprises are becoming more closely with the rapid development of global economy. Therefore, when unexpected events happen, the information communication and sharing are becoming more important. In ideal state, supply chain members should honestly make the information public to the other members, to cope with the impacts caused by emergencies together and avoid profits falling sharply. However, supply chain members often conceal the disruption information of supply chain for private profits. The information concludes : market demand, production cost, purchasing cost of retailer, etc. In this way, the supply chain information becomes asymmetric, then the supply chain profits would suffer losses. In the same time, the supply chain members unknown real information would suffer loss of profits. For example, the severe flooding in Thailand in 2011 made the entire industry chain of HDD bloodied and the global supply of hard drives shortage, and hard drives had no market but price; Another example is the outbreak of H7N9 avian influenza event in China in 2013, it made the demand of fowls rapidly declined, the trading price of fowls fell sharply and a large number of poultry farmers bankrupted. After the explosion in Tianjin port in 2015, the poor environment led to a sharp increase in the demand for masks, which made them out of stock. On April 16, 2018, the us department of commerce announced that it would ban us companies from selling parts, goods, software and technology to zte for the next seven years, making a huge impact in a short time. According to this, considering asymmetric disruptions between supply chain members after emergency and investigating the optimal strategies of supply chain under asymmetric information has been the common concerned issues for global enterprises and managers.

Sheffi and Rice F(2005)[1] respectively elaborated the impact of emergencies on the supply chain from the four aspects of the preparation, occurrence, first reaction, initial impact and overall impact of emergencies, and proposed the strategies to prevent the occurrence of emergencies from the perspectives of improving the elasticity and flexibility of the supply chain. Lei D, Li J, Liu Z (2012)[2] investigates how the asymmetric information influences on the profits of supply chain members and the whole supply chain and how information values effects the supply chain profits by the implication of principle-agent model when market demand disruptions and production cost disruptions are private respectively. Babich V, Li H, Ritchken Petal(2013)[3] researches on how the buyback contact impacts the coordination of supply chain system, and the results shows that the optimal buyback contact for supplier allows the arbitrary allocation of the retailer's profits. Hussain (2016)[7] studied different influencing mechanisms of supply chain operation from sustainability and service factors, and further studied supply chain coordination contract. Xian Zhang(2013)[8] researches how the asymmetric information influences coordination of supply chain and seeks the responding management strategies with the supplier and retailer as supply chain leader respectively when the occurrence of emergency makes the market demand and production cost asymmetric. Jian-zhong Zhou, Xiu-hong Chen(2013)[9] investigates how the asymmetric market demand and production cost disruptions impacts the supply chain system according to the situation of linear and nonlinear demand functions, based on the

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Stackelburg game, which is dominated by the manufacturer. Wenqiang Shi, Lang Liu, Wenchuan Li(2015)[10] considered the simultaneous fluctuation of market demand and production cost caused by emergencies and studied the coordination problem of emergency quantity elasticity contract of secondary supply chain composed of single retailer and single supplier when the information of production cost is asymmetric. Yu-quan Cui, Xian Zhang(2016)[11] supply chain under asymmetric information is studied under the emergency of the emergency management and information value, analyzed the asymmetric information on the effect of emergency management and the corresponding management measures, found the most healthy birth under the asymmetric information output is less than the most healthy birth yield under the symmetric information, supply chain system reduced profits and generate the information value, analyzed the asymmetric information of supply chain system under the law of value as well as the influence factors; Ning Guo, Peng Guo(2017)[12] by using the method of system dynamics to study the triple closed-loop supply chain system, manufacturers, retailers and third-party recycler to coordinate multiple factors such as demand, price, cost at the same time the emergency risk of disturbance, but also consider the frontal government policy environment and the enterprise face emergencies active initiative; Li-ning Jiang Liping Liu(2018)[13] designed the full-unit quantity discount contract and limited-value linear price contract to study the problems of coordinated response between suppliers and retailers when sudden events cause sudden changes in price sensitivity of demand.

The above literatures have not considered the disruption of price sensitivity coefficient and the application of principle-agent theory to solve the asymmetric disruptions. However, in the actual situation, not only the market demand and production cost would be disrupted, but also the price sensitivity coefficient would be changed with the other factors disrupted. So we consider the case that emergency causes market demand and price sensitivity coefficient disrupted simultaneously and the latter is asymmetric information in supply chain. In view of the above, we build the principle-agent model in order to seek the optimal strategies of supply chain under asymmetric information in response to the emergency.

II. MODEL ASSUMPTIONS

We consider a two echelon supply chain consisting of one supplier and one retailer. In this supply chain system, before the sales season starts, according to the sales data of previous years and the market demand forecasting the retailer determines the order quantity Q, then orders products from supplier according to the order quantity. The supplier starts to production after accepting orders, and completes the production within the required time and sends the products to the retailer. In this process, the information between supplier and retailer is symmetric. Before emergency the information in supply chain system is completely symmetric, but when emergency happens, market demand and price sensitivity coefficient are disrupted and the disruption information is asymmetric between the supplier and the retailer. In this situation, the retailer knows exactly about the market demand disruptions, but the supplier cannot know the real information (the other information in supply chain is still symmetric). Therefore, we assume that the supplier is the principal and the retailer is the agent. The supplier is responsible for providing contract menus for the retailer to choose, the retailer only can choose to accept or reject. We also assume that the supplier and the retailer form a revenue sharing contract.

We assume that the relations between market demand d and production price p is known, i.e. $d = D - kp$, where k is price sensitivity coefficient, D is market size. Assume the production cost is c, the profit of supply chain system is $\overline{f}^{sc} = (D - kp)(p - c)$, and it takes the maximum at $p^* = (D + kc)/2k$. The retailer's optimal order quantity is $Q^* = (D - kc)/2$, the ultimate profit of supply chain system is $\overline{f}^{sc}_{\max}(Q^*) = (D - kc)^2 / 4k$. When emergency happens, the optimal order quantity of supply chain would change from Q^* to $Q^\wedge$. When market demand increases, e.t. $Q^* < Q^\wedge$, the deviation cost is $\lambda_1 (\lambda_1 > 0)$; When market demand decreases, e.t. $Q^* > Q^\wedge$, the deviation cost is $\lambda_2 (\lambda_2 > 0)$.

We assume market demand disruption information $\Delta D \in \{\overline{\Delta D}, \underline{\Delta D}\}$, and $\overline{\Delta D} > \underline{\Delta D}$, only the retailer knows the exact information. But the supplier knows the probability of $\Delta D = \overline{\Delta D}$ is θ, the probability of $\Delta D = \underline{\Delta D}$ is $1-\theta$. We assume the price sensitivity coefficient Δk is fixed. θ is a prior probability. According to the sales data of previous years or market demand forecasting, the supplier can achieve the value of θ.

In the case of market demand disruption equals $\overline{\Delta D}(\underline{\Delta D})$, we call him $\overline{\Delta D}(\underline{\Delta D})$--retailer. The supplier's and the retailer's decision procedure are as follows: 1) After emergency, the retailer observes the market demand disruptions ΔD; 2) The supplier is responsible for providing a linear revenue sharing contract menu $\{w(\overline{\Delta D}), Q(\overline{\Delta D}), \overline{\varphi}; w(\underline{\Delta D}), \ Q(\underline{\Delta D}), \underline{\varphi}\}$ for retailer, and the retailer only can choose to accept or reject; 3) If the retailer chooses to accept one contract of contract menu, the supplier has to sale the order quantity of $Q(\overline{\Delta D})(Q(\underline{\Delta D}))$ to the retailer according to lower wholesale price $w(\overline{\Delta D})(w(\underline{\Delta D}))$. At the end of the sales season, the retailer needs to return $\overline{\varphi}(\underline{\varphi})$ times earnings to the supplier, and retains $1-\overline{\varphi}(1-\underline{\varphi})$ $(0 \le \overline{\varphi}, \underline{\varphi} \le 1)$ times earnings. Therefore, the supplier should reasonably set the wholesale price, order quantity and revenue sharing shares in order to maximize the profits of the supplier, whatever the retailer selects one kind of contracts. In order to meet the general situation, we assume that the reservation utility of the supplier is 0. For simplifying the calculation, we use $\overline{w}, \underline{w}, \overline{Q}, \underline{Q}$ to replace $w(\overline{\Delta D}), w(\underline{\Delta D}), Q(\overline{\Delta D}), Q(\underline{\Delta D})$.

In the case of asymmetric demand disruption information and price sensitivity coefficient disruption, the supplier ' s decision issues can be formulated as follows:

$$\max_{\{\overline{w},\overline{Q},\overline{\varphi};\underline{w},\underline{Q},\underline{\varphi}\}} f^m=\theta\Big[\overline{Q}\big(\overline{\varphi}p+(1-\overline{\varphi})\overline{w}-c\big)-\lambda_1\cdot\left(\overline{Q}-Q^*\right)^+-\lambda_2\left(Q^*-\overline{Q}\right)^+\Big]+(1-\theta)\Big[\underline{Q}\big(\underline{\varphi}p+(1-\underline{\varphi})\underline{w}-c\big)-\lambda_1\left(\underline{Q}-Q^*\right)^+-\lambda_2\left(Q^*-\underline{Q}\right)^+\Big] \tag{1}$$

s.t. IR.

$$(1-\overline{\varphi})\overline{Q}\left(\frac{D+\overline{\Delta D}-\overline{Q}}{k+\Delta k}-\overline{w}\right)\ge(1-\underline{\varphi})\underline{Q}\left(\frac{D+\overline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right), \tag{2}$$

$$(1-\underline{\varphi})\underline{Q}\left(\frac{D+\underline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right)\ge(1-\overline{\varphi})\overline{Q}\left(\frac{D+\underline{\Delta D}-\overline{Q}}{k+\Delta k}-\overline{w}\right), \tag{3}$$

IC.

$$(1-\overline{\varphi})\overline{Q}\left(\frac{D+\overline{\Delta D}-\overline{Q}}{k+\Delta k}-\overline{w}\right)\ge 0, \tag{4}$$

$$(1-\underline{\varphi})\underline{Q}\left(\frac{D+\underline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right)\ge 0. \tag{5}$$

Among them, inequality (2) (3) is incentive compatible constraint, they ensure that each type of retailer does not dream of becoming another type of retailer, nor does it imitate the choices of other retailers. Inequality (4) (5) is individual rationality constraint. They guarantee that the two types of retailers would not withdraw from the supply chain system due to the negative profit.

III. EMERGENCY COORDINATION STRATEGIES FOR SUPPLY CHAIN MEMBERS WITH SYMMETRIC INFORMATION

Under asymmetric information, all information between the supplier and the retailer is symmetric. The incentive compatibility constraint (2) (3) will not play any role in the supply chain. Therefore, the supplier ' s decision problem could be simplified as:

$$\max_{Q} f(Q)=Q\left[\varphi p+(1-\varphi)w-c\right]-\lambda_1\left(Q-Q^*\right)^+-\lambda_2\left(Q^*-Q\right)^+$$

And $\Delta D\in\{\overline{\Delta D},\underline{\Delta D}\}$. Now the wholesale price w equals sales price p , so the above problem could be further simplified as:

$$\max_{Q} f(Q)=Q\left(\frac{D+\Delta D-Q}{k+\Delta k}-c\right)-\lambda_1\left(Q-Q^*\right)^+-\lambda_2\left(Q^*-Q\right)^+ \tag{6}$$

We assume that the optimal solution of function (6) is Q^{**}, which is the optimal order quantity, and p^{**} is the optimal sale price.

Lemma 1: If $\Delta D>\Delta kc$, then $Q^{**}\ge Q^*$; Otherwise, $Q^{**}\le Q^*$.

Proof：Assume if $\Delta D>\Delta kc$, then $Q^{**}<Q^*$. Then

$$\begin{aligned} f\left(Q^{**}\right)&=Q^{**}\left(\frac{D+\Delta D-Q^{**}}{k+\Delta k}-c\right)-\lambda_2\left(Q^{**}-Q^*\right)\\ &=Q^*\left(\frac{D+\Delta D-Q^*}{k}-c\right)-\lambda_2\left(Q^{**}-Q^*\right)+Q^{**}\cdot\\ &=Q^*\left(\frac{D+\Delta D-Q^*}{k+\Delta k}-c\right)+\left(Q^{**}-Q^*\right)\left[\frac{D+\Delta D}{k+\Delta k}-c+\lambda_2-\frac{Q^{**}+Q^*}{k+\Delta k}\right]<f\left(Q^*\right)\end{aligned}$$

Because function maximize at Q^{**}, thus it can be concluded that the conclusion is contrary to the assumption, and the original hypothesis is not established. So it can be concluded that when $\Delta D>\Delta kc$,$Q^{**}\ge Q^*$ establishes.

Proof finished.

Lemma 1 reveals that the change of production plan depends on the relative distance between ΔD and Δkc with demand disruption and price sensitivity coefficient disruption simultaneously. Thus, the optimal solution of the equation can be obtained based on lemma 1 , just as follows：

Theorem 1: With symmetric information, we can conclude that:

(1) If $\Delta D\le\Delta kc-\lambda_2\left(k+\Delta k\right)$,then $Q^{**}=Q^*+\dfrac{\Delta D-\Delta kc+\lambda_2\left(k+\Delta k\right)}{2}$, $p^{**}=p^*-\dfrac{\lambda_2}{2}+\dfrac{k\Delta D-\Delta kD}{2k\left(k+\Delta k\right)}$;

(2) If $\Delta kc-\lambda_2\left(k+\Delta k\right)\le\Delta D\le\Delta kc+\lambda_1\left(k+\Delta k\right)$,then $Q^{**}=Q^*$, $p^{**}=p^*+\dfrac{\lambda_2}{2}+\dfrac{2k\Delta D-\Delta k\left(D+kc\right)}{2k\left(k+\Delta k\right)}$;

(3) If $\Delta D\ge\Delta kc+\lambda_1\left(k+\Delta k\right)$, then $Q^{**}=Q^*+\dfrac{\Delta D-\Delta kc-\lambda_1\left(k+\Delta k\right)}{2}$, $p^{**}=p^*+\dfrac{\lambda_1}{2}+\dfrac{k\Delta D-\Delta kD}{2k\left(k+\Delta k\right)}$.

From theorem 1, we can know that with the change of ΔD, under symmetric information the change of optimal orders are as follows:

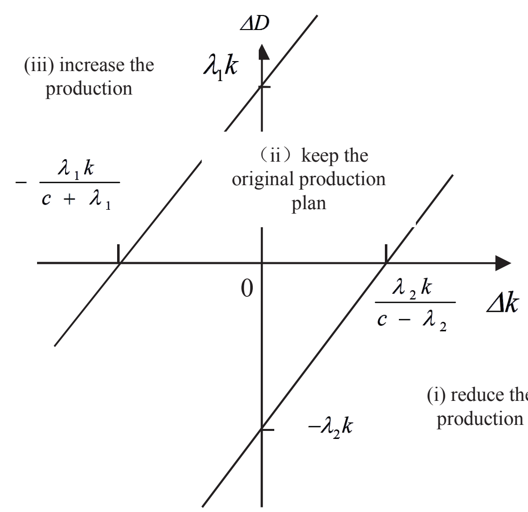

Figure 1. The Change of optimal productions with asymmetric information

From Figure 1, we know that under symmetric information when the value of ΔD is in region (i) in theorem 1, the supplier need to reduce the production due to the decrease of market demand, in order to avoid more profit loss. When the value of ΔD is in region (ii), because the range of increase or decrease of the market demand ΔD is small, it can be ignored. So the supplier does not need to change the production plan and keep the original production plan to ensure his own interests are not affected by loss. When the value of ΔD is in region (iii), the supplier would scale up the production due to the sharp increase in market demand to meet the needs of market.

IV. EMERGENCY COORDINATION STRATEGIES OF SUPPLY CHAIN MEMBERS WITH ASYMMETRIC INFORMATION

Substitute inequality (2) into inequality (5), we can conclude that：

$$\left(1-\overline{\varphi}\right)\overline{Q}\left(\frac{D+\overline{\Delta D}-\overline{Q}}{k+\Delta k}-\overline{w}\right)\geq\left(1-\underline{\varphi}\right)\underline{Q}\left(\frac{D+\overline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right)>\left(1-\underline{\varphi}\right)\underline{Q}\cdot\left(\frac{D+\underline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right)\geq 0$$

It can be known that inequality (4) can always be strictly satisfied, so the constraint condition (4) can be excluded from the supplier's problem.

Through analysis, we know that $\overline{\Delta D}$ --retailer has an incentive to claim that the demand disruption he observed is $\overline{\Delta D}$. So we can apply the constraint condition (2) (5) to solve the supplier's problem, then apply constraint (3) to verify the solutions. To seek the optimal solutions of the supplier's problem, we need to combine constraint condition (2) with condition (5). Otherwise, the supplier will increase wholesale price $\overline{w}\left(\underline{w}\right)$, and the constraint conditions can be satisfied. At the same time, the supplier's profit will be increased $\theta\overline{Q}\overline{w}$ or $\left(1-\theta\right)\underline{Q}\underline{w}$, then it makes a contradiction. Therefore, we can conclude that：

$$\left(1-\overline{\varphi}\right)\overline{Q}\left(\frac{D+\overline{\Delta D}-\overline{Q}}{k+\Delta k}-\overline{w}\right)=\left(1-\underline{\varphi}\right)\underline{Q}\left(\frac{D+\overline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right) \tag{7}$$

$$\left(1-\underline{\varphi}\right)\underline{Q}\left(\frac{D+\underline{\Delta D}-\underline{Q}}{k+\Delta k}-\underline{w}\right)=0 \tag{8}$$

Substitute Eq.(8) into Eq.(7), then $\left(1-\overline{\varphi}\right)\overline{Q}\left(\frac{D+\overline{\Delta D}-\overline{Q}}{k+\Delta k}-\overline{w}\right)=\left(1-\underline{\varphi}\right)\cdot\ \underline{Q}\frac{OD}{k+\Delta k}$

Where $OD=\overline{\Delta D}-\underline{\Delta D}$. Substitute Eq. (7) (8) into function (1), the supplier’ s decision issues can be simplified as：

$$\max_{\{\overline{Q},\overline{\varphi};\underline{Q},\underline{\varphi}\}} f^m=\theta\left[\overline{Q}\left(\frac{D+\overline{\Delta D}-\overline{Q}}{k+\Delta k}-c\right)-\left(1-\underline{\varphi}\right)\underline{Q}\cdot\frac{OD}{k+\Delta k}-\lambda_1\left(\overline{Q}-Q^*\right)^+-\lambda_2\left(Q^*-\overline{Q}\right)^+\right]+(1-\theta)$$
$$\left[\underline{Q}\left(\frac{D+\underline{\Delta D}-\underline{Q}}{k+\Delta k}-c\right)-\lambda_1\left(\underline{Q}-Q^*\right)^+-\lambda_2\left(Q^*-\underline{Q}\right)^+ \tag{9}$$

Lemma 2: Assume that $\left(\overline{Q}_d^{SB},\underline{Q}_d^{SB}\right)$ is the optimal solution of function (9), then：

(i) If $\overline{\Delta D}>\Delta kc$, then $\overline{Q}_d^{SB}\geq Q^*$; Otherwise, $\overline{Q}_d^{SB}\leq Q^*$.

(ii) If $\underline{\Delta D}>\Delta kc+\left(1-\underline{\varphi}\right)\alpha$, then $\underline{Q}_d^{SB}\geq Q^*$; Otherwise, $\underline{Q}_d^{SB}\leq Q^*$.

where, $\alpha=\dfrac{\theta}{1-\theta}OD$.

Proof：The proof of conclusion (i) is similar to the proof of Qi，atl(2004)[4].

(ii)Suppose if $\underline{\Delta D}>\Delta kc+\left(1-\underline{\varphi}\right)\alpha$，$\underline{Q}_d^{SB}<Q^*$. Then

$$f_{sd}\left(\overline{Q}_d^{SB},\underline{Q}_d^{SB}\right)=\theta\left[\overline{Q}_d^{SB}\left(\frac{D+\overline{\Delta D}-\overline{Q}_d^{SB}}{k+\Delta k}-\left(1-\underline{\varphi}\right)\underline{Q}\frac{OD}{k+\Delta k}-\lambda_1\left(\overline{Q}_d^{SB}-Q^*\right)^+-\lambda_2\left(Q^*-\right.\right.\right.$$
$$\left.\left.\left.\overline{Q}_d^{SB}\right)^+\right]+(1-\theta)\left[\underline{Q}_d^{SB}\left(\frac{D+\overline{\Delta D}-\underline{Q}_d^{SB}}{k+\Delta k}-c\right)-\lambda_2\left(Q^*-\underline{Q}_d^{SB}\right)^+\right.$$
$$\leq\theta\left[\overline{Q}_d^{SB}\left(\frac{D+\overline{\Delta D}-\overline{Q}_d^{SB}}{k+\Delta k}-c\right)-\lambda_1\left(\overline{Q}_d^{SB}-Q^*\right)^+-\lambda_2\left(Q^*-\overline{Q}_d^{SB}\right)^+\right]+(1-\theta)\left[f_{\max}^{sc}\left(Q^*\right)-\lambda_2\cdot\right.$$
$$\left.\left(Q^*-\overline{Q}_d^{SB}\right)^+\right]-\left(1-\underline{\varphi}\right)\theta\underline{Q}\cdot\frac{OD}{k+\Delta k}<f_{sd}\left(\overline{Q}_d^{SB},Q^*\right)$$

In the end, we can achieve the conclusion that $f_{sd}\left(\overline{Q}_d^{SB},\underline{Q}_d^{SB}\right)<\ f_{sd}\left(\overline{Q}_d^{SB},Q^*\right)$, which conflicts with that $\left(\overline{Q}_d^{SB},\underline{Q}_d^{SB}\right)$ is the optimal solution of f^m. Therefore, the hypothesis is not set up and the original hypothesis is overthrown.

Proof finished.

Theorem 2: Assume that $\left\{\left(\overline{Q}_d^{SB},\overline{w}_d^{SB}\right),\left(\underline{Q}_d^{SB},\underline{w}_d^{SB}\right)\right\}$ is the optimal contract of supply chain members with asymmetric market demand disruptions, then

(i) If $\underline{\Delta D}>\Delta kc+\left(1-\underline{\varphi}\right)\alpha+\lambda_1\left(k+\Delta k\right)$, then

$$\begin{cases}\overline{Q}_d^{SB}=Q^*+\dfrac{\overline{\Delta D}-\Delta kc-\lambda_1\left(k+\Delta k\right)}{2},\\ \overline{w}_d^{SB}=p^*+\dfrac{k\overline{\Delta D}-\Delta kD}{2k\left(k+\Delta k\right)}+\dfrac{\lambda_1}{2}-\dfrac{1-\underline{\underline{\varphi}}}{1-\varphi}\cdot\dfrac{OD}{k+\Delta k}\cdot\\ \left(1-\dfrac{OD+\left(1-\underline{\varphi}\right)\alpha}{D+\overline{\Delta D}-\left(c+\lambda_1\right)\left(k+\Delta k\right)}\right),\\ \underline{Q}_d^{SB}=Q^*+\dfrac{\underline{\Delta D}-\Delta kc-\lambda_1\left(k+\Delta k\right)-\left(1-\underline{\varphi}\right)\alpha}{2},\\ \underline{w}_d^{SB}=p^*+\dfrac{k\left(\underline{\Delta D}+\left(1-\underline{\varphi}\right)\alpha\right)-\Delta kD}{2k\left(k+\Delta k\right)}+\dfrac{\lambda_1}{2}.\end{cases}$$

(ii)If $\Delta kc-\lambda_2\left(k+\Delta k\right)+\left(1-\underline{\varphi}\right)\alpha<\underline{\Delta D}\leq\Delta kc+\left(1-\underline{\varphi}\right)\alpha+\lambda_1\left(k+\Delta k\right),\overline{\Delta D}>\Delta kc+\lambda_1\cdot\left(k+\Delta k\right)$, then

$$\begin{cases} \overline{Q}_d^{SB} = Q^* + \dfrac{\overline{\Delta D} - \Delta kc - \lambda_1 (k+\Delta k)}{2}, \\ \overline{w}_d^{SB} = p^* + \dfrac{k\overline{\Delta D} - \Delta kD}{2k(k+\Delta k)} + \dfrac{\lambda_1}{2} - \dfrac{1-\underline{\varphi}}{1-\overline{\varphi}} \dfrac{OD}{k+\Delta k} \cdot \\ \dfrac{D-kc}{D+\overline{\Delta D}-(c+\lambda_1)(k+\Delta k)}, \end{cases}$$

$$\underline{Q}_d^{SB} = Q^*, \underline{w}_d^{SB} = p^* + \frac{2\underline{\Delta D}k - \Delta k(D+kc)}{2k(k+\Delta k)}.$$

(iii)If $\underline{\Delta D} > \Delta kc - \lambda_2(k+\Delta k) + (1-\underline{\varphi})\alpha,$ $\Delta kc - \lambda_2(k+\Delta k) < \overline{\Delta D} \le \Delta kc + \lambda_1(k+\Delta k)$,then $\overline{Q}_d^{SB} = \underline{Q}_d^{SB} = Q^*, \overline{w}_d^{SB} = \underline{w}_d^{SB} = p^* + \dfrac{2\underline{\Delta D}k - \Delta k(D+kc)}{2k(k+\Delta k)};$

(iv)If $\underline{\Delta D} \le \Delta kc - \lambda_2(k+\Delta k) + (1-\underline{\varphi})\alpha$ and $\overline{\Delta D} > \Delta kc + \lambda_1(k+\Delta k)$, then

$$\begin{cases} \overline{Q}_d^{SB} = Q^* + \dfrac{\overline{\Delta D} - \Delta kc - \lambda_1 (k+\Delta k)}{2}, \\ \overline{w}_d^{SB} = p^* + \dfrac{k\overline{\Delta D} - \Delta kD}{2k(k+\Delta k)} - \dfrac{\lambda_2}{2} - \dfrac{1-\underline{\varphi}}{1-\overline{\varphi}} \cdot \dfrac{OD}{k+\Delta k} \cdot \\ \dfrac{D+\underline{\Delta D}-(c-\lambda_2)(k+\Delta k)-(1-\underline{\varphi})\alpha}{D+\overline{\Delta D}-(c+\lambda_1)(k+\Delta k)}, \end{cases}$$

$$\begin{cases} \underline{Q}_d^{SB} = Q^* + \dfrac{\underline{\Delta D} - \Delta kc + \lambda_2 (k+\Delta k) - (1-\underline{\varphi})\alpha}{2}, \\ \underline{w}_d^{SB} = p^* + \dfrac{k\left(\underline{\Delta D} + (1-\underline{\varphi})\alpha\right) - \Delta kD}{2k(k+\Delta k)} - \dfrac{\lambda_2}{2}. \end{cases}$$

(v)If $\underline{\Delta D} \le \Delta kc - \lambda_2(k+\Delta k) + (1-\underline{\varphi})\alpha$ and $\Delta kc - \lambda_2(k+\Delta k) < \overline{\Delta D} \le \Delta kc + \lambda_1(k+\Delta k)$, then

$$\begin{cases} \overline{Q}_d^{SB} = Q^*, \\ \overline{w}_d^{SB} = p^* + \dfrac{k\left(\overline{\Delta D} - \Delta kc\right) - \Delta kD}{2k(k+\Delta k)} - \dfrac{1-\underline{\varphi}}{1-\overline{\varphi}} \cdot \dfrac{OD}{k+\Delta k} \cdot \\ \left(1 + \dfrac{\underline{\Delta D} - \Delta kc + \lambda_2(k+\Delta k) - (1-\underline{\varphi})\alpha}{D-kc}\right), \end{cases}$$

$$\begin{cases} \underline{Q}_d^{SB} = Q^* + \dfrac{\underline{\Delta D} - \Delta kc + \lambda_2 (k+\Delta k) - (1-\underline{\varphi})\alpha}{2}, \\ \underline{w}_d^{SB} = p^* + \dfrac{k\left(\underline{\Delta D} + (1-\underline{\varphi})\alpha\right) - \Delta kD}{2k(k+\Delta k)} - \dfrac{\lambda_2}{2}. \end{cases}$$

(vi) If $\overline{\Delta D} \le \Delta kc - \lambda_2(k+\Delta k)$, then

$$\begin{cases} \overline{Q}_d^{SB} = Q^* + \dfrac{\overline{\Delta D} - \Delta kc + \lambda_2 (k+\Delta k)}{2}, \\ \overline{w}_d^{SB} = p^* + \dfrac{k\overline{\Delta D} - \Delta kD}{2k(k+\Delta k)} - \dfrac{\lambda_2}{2} - \dfrac{1-\underline{\varphi}}{1-\overline{\varphi}} \cdot \dfrac{OD}{k+\Delta k} \cdot \\ \dfrac{D+\underline{\Delta D}-(c-\lambda_2)(k+\Delta k)-(1-\underline{\varphi})\alpha}{D+\overline{\Delta D}-(c-\lambda_2)(k+\Delta k)}, \end{cases}$$

$$\begin{cases} \underline{Q}_d^{SB} = Q^* + \dfrac{\underline{\Delta D} - \Delta kc + \lambda_2 (k+\Delta k) - (1-\underline{\varphi})\alpha}{2}, \\ \underline{w}_d^{SB} = p^* + \dfrac{k\left(\underline{\Delta D} + (1-\underline{\varphi})\alpha\right) - \Delta kD}{2k(k+\Delta k)} - \dfrac{\lambda_2}{2}. \end{cases}$$

With asymmetric demand disruption, changes of the optimal order quantity are shown as Figure 2 with the change of demand disruptions $\overline{\Delta D}$ and $\underline{\Delta D}$:

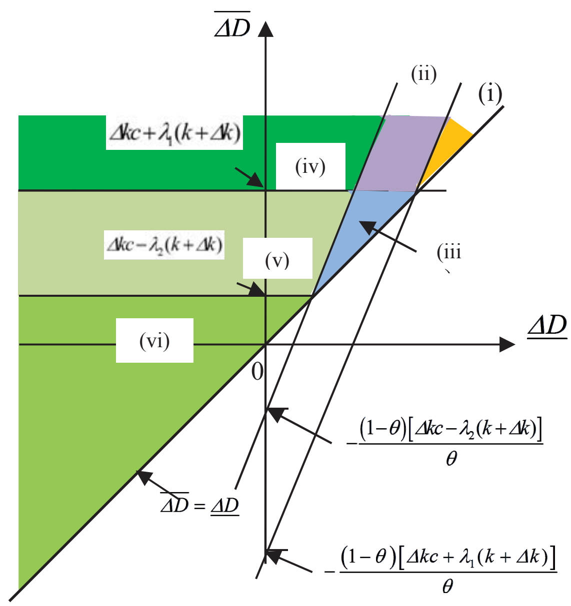

Figure2. The changes of optimal productions with asymmetric information

From the analysis of figure 2, the results show that after the occurrence of unexpected events, although market demand disruptions are asymmetric between the supplier and the retailer with marker demand and price sensitivity coefficient disrupted in a certain degree, but also the original order quantity of the supplier still has some robustness. The following two conclusions can be drawn:

Corol1ary 1: From theorem 2 (iii), with asymmetric demand disruptions, the supplier can provide the same contract for the two types retailers, e.t. $\overline{\Delta D}$ – retailer and $\underline{\Delta D}$ – retailer.

For the two types retailers, if the demand disruption is not large, e.t. $\underline{\Delta D} \ge \Delta kc + (1-\underline{\varphi})\alpha - \lambda_2 \cdot (k+\Delta k), \Delta kc - \lambda_2(k+\Delta k) \le \overline{\Delta D} \le \Delta kc + \lambda_1(k+\Delta k)$, the supplier will not change the original order quantity, although he does not know the exact market demand disruption. In this case, the supplier would provide the same contract $\left(Q^*, p^* + \frac{2\underline{\Delta D}k - \Delta k\left(D+kc\right)}{2k\left(k+\Delta k\right)}\right)$ for two type retailers. For instance, because the extra profits through changing the production plan and screening process are not sufficient to compensate for the loss of the high deviation cost and screening cost, the supplier would not use the contract to screen the type of retailers.

With asymmetric information, if the demand disruption is $\overline{\Delta D}$, the supplier will keep the original order quantity in theorem1. Otherwise, the supplier would decrease order quantity in response to the risk of asymmetric information. The explanation is as follows: the supplier does not expect $\overline{\Delta D}$ – retailer to imitate the contract choice of $\underline{\Delta D}$ – retailer, so he will pay information rents for $\overline{\Delta D}$ – retailer as incentives, in order to make him do the good choice for the supplier.

Corollary 2: For $\underline{\Delta D}$ – retailer, the order quantity with asymmetric information is not higher than the order quantity with symmetric information.

Corollary 2 shows that if the demand disruption is $\underline{\Delta D}$, the supply chain would suffer loss of profit. It means that in this case, the supplier would take on more risk, so the supplier would reduce order quantity to make up for loss of profits. With asymmetric information, $\overline{\Delta D}$ – retailer use private information to grab information rents $IR_d = \underline{Q}_d^{SB} OD / k$ from the supplier for ever.

V. INFORMATION VALUE OF MARKET DEMAND DISRUPTION

Next we will investigate the influence of the demand disruption on the profit of the supply chain system, the supplier and the retailer. With symmetric and asymmetric information, the influence of the information value on the profits of each member in supply chain is completely different. With symmetric information, the supplier achieves all the profits of the supply chain. With asymmetric information, the supplier $\overline{\Delta D}$ – will pay the information rents $IR_d = \underline{Q}_d^{SB} OD / k$ for the retailer. When the supplier is $\overline{\Delta D}$ – supplier, the supplier would lose Δf_{sd} due to $\underline{Q}_d^{SB} \neq Q^{**}$. At this time, the information value is $\theta IR_d + (1-\theta)\Delta f_{sd}$ for the supplier. With symmetric information, the profits earned by the supplier could not be zero. However, with asymmetric information, the profit of $\underline{\Delta D}$ – retailer is still zero, and the $\overline{\Delta D}$ – retailer will obtain the information rent IR_d from the supplier, which is the information value of $\overline{\Delta D}$ – retailer.

For $\underline{\Delta D}$ – retailer, the order quantity of supply chain with asymmetric is different with the order quantity with symmetric information. So the information value of supply chain is $(1-\theta)\Delta f_{sd}$. Compare theorem 2 with theorem 1, the profit loss Δf_{sd} of supply chain is as follows:

Theorem 3: Assume the market demand of product is $\underline{\Delta D}$, the profit loss of supply chain are:

(a) In theorem 2 (i) (vi), $\Delta f_{sd} = \frac{\left[(1-\underline{\varphi})\alpha\right]^2}{4(k+\Delta k)}$.

(b) In theorem 2 (ii), if $\Delta kc + \lambda_1(k+\Delta k) < \underline{\Delta D} \le \Delta kc + (1-\underline{\varphi})\alpha + \lambda_1(k+\Delta k)$, then $\Delta f_{sd} = \frac{\left[\underline{\Delta D} - \Delta kc - \lambda_1(k+\Delta k)\right]^2}{4(k+\Delta k)}$; Otherwise, $\Delta f_{sd} = 0$.

(c) In theorem 2 (iii), $\Delta f_{sd} = \frac{\left[(1-\underline{\varphi})\alpha\right]^2 - \left[\underline{\Delta D} - \Delta kc + \lambda_2(k+\Delta k)\right]^2}{4(k+\Delta k)}$.

(d) In theorem 2(iv), if $\Delta kc + \lambda_1(k+\Delta k) < \underline{\Delta D} \le \Delta kc - \lambda_2(k+\Delta k)$, then $\Delta f_{sd} = \frac{\left[(1-\underline{\varphi})\alpha\right]^2}{4(k+\Delta k)} + (\lambda_1+\lambda_2)\frac{\left[(k+\Delta k)(\lambda_1-\lambda_2) + \Delta kc - 2\underline{\Delta D}\right]}{4}$; If $\Delta kc - \lambda_2(k+\Delta k) < \underline{\Delta D} \le \Delta kc + \lambda_1(k+\Delta k)$, then $\Delta f_{sd} = \frac{\left[(1-\underline{\varphi})\alpha\right]^2 - \left[\underline{\Delta D} - \Delta kc + \lambda_2(k+\Delta k)\right]^2}{4(k+\Delta k)}$; If $\underline{\Delta D} \le \Delta kc - \lambda_2(k+\Delta k)$, then $\Delta f_{sd} = \frac{\left[(1-\underline{\varphi})\alpha\right]^2}{4(k+\Delta k)}$.

In order to deeply analyze the characteristics of the information value, firstly the market demand disruption is determined at $\underline{\Delta D}(\overline{\Delta D})$, then the change of the information value is analyzed when the market demand disruption $\underline{\Delta D}(\overline{\Delta D})$ changes. Next we will discuss the impact of the information value on the change of $\underline{\Delta D}$ when $\overline{\Delta D_0} > \Delta kc + \lambda_1(k+\Delta k)$, at this time $\underline{\Delta D}$ is fixed at $\overline{\Delta D_0}$, and analyze the impacts of the change of values on the information value. Figure 3 shows how the market demand disruption $\underline{\Delta D}$ influences the information value when $\overline{\Delta D} = \overline{\Delta D_0}$. When $\underline{\Delta D}$ is very small, e.t. $\Delta kc - \lambda_2(k+\Delta k) < \underline{\Delta D} \le \Delta kc + \lambda_1(k+\Delta k)$ or $\underline{\Delta D} \le \Delta kc - \lambda_2(k+\Delta k)$, the variation tendency of information value is similar to figure 3.

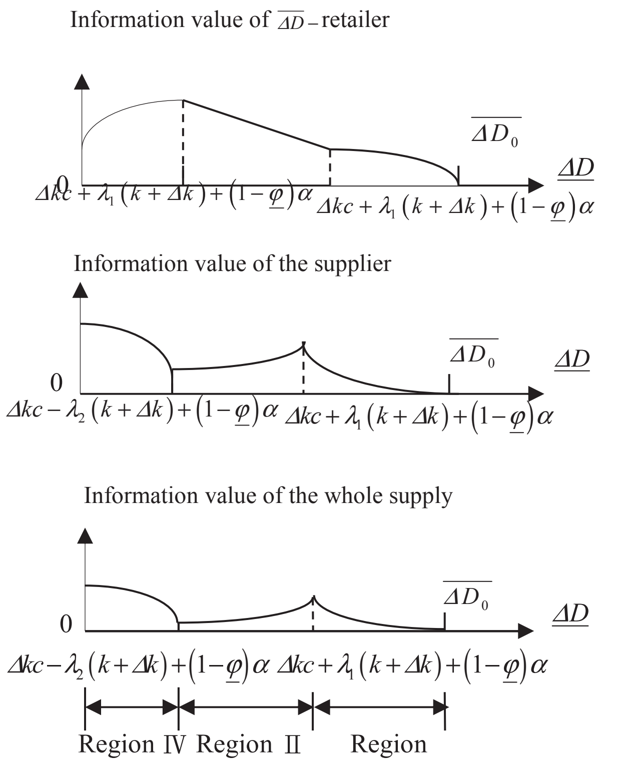

Figure3. the variation tendency of information value with the change of $\underline{\Delta D}$

Figure 3 reflects the variation tendency of demand disruption value when $\underline{\Delta D}$ increases from 0 to $\overline{\Delta D_0}$. As is shown in figure 3, in general, the information value will decrease with the increase of $\underline{\Delta D}$ value for $\overline{\Delta D}$ -retailer, the supplier and the whole supply chain. However, when the information value of $\overline{\Delta D}$ -retailer is in region Ⅱ, it increases progressively with the increase of $\underline{\Delta D}$. For the supplier and the whole supply chain, the information increases slightly in region Ⅱ with the increase of $\underline{\Delta D}$. This is because the information value is determined by the production plan of the supplier, the demand disruption and price sensitivity coefficient .etc. Every change of the information value reflects the changes of production plans of the supplier. It also reflects that how the supplier rebalance the market deviation, the value of information and profits of the supplier with asymmetric demand disruptions.

VI. THE NUMERICAL SIMULATION

Suppose a supply chain consists of retailers, distributors and manufacturers, size of the market D =3000, cost of production c =10, coefficient of sensitivity of price k =50, deviation cost λ_1 =2, λ_2 =4, The probability that the supplier knows that market demand disturbance ΔD equals $\overline{\Delta D}$ is θ =0.5, price sensitivity coefficient disturbance Δk =10, income sharing φ =0.6. For simplicity, table 1 lists the parameters and indicators of the supply chain in three states.

TABLE I Various parameters and indicators in the supply chain under different states

	Demand disturbance	**The sales price**	**Best order quantity**	**Supply chain profit**
Normal supply chain	N/A	35	1250	31250
Supply chain with symmetrical Information	△D=-160	39.33	1000	29333
	△D=100	32.83	1250	28541
	△D=300	33.5	1290	30315
Supply chain with asymmetric information	$\overline{\Delta D}$=325 $\underline{\Delta D}$=250	33.71 33.08	1303 1243	30894.13 28688.44
	$\overline{\Delta D}$=250 $\underline{\Delta D}$=200	33.08 34.5	1265 1250	29200.37 30625
	$\overline{\Delta D}$=100 $\underline{\Delta D}$=0	31.17 32.83	1250 1250	26458.25 28541.25
	$\overline{\Delta D}$=300 $\underline{\Delta D}$=-100	33.5 27.83	1290 1190	30315 21221.63
	$\overline{\Delta D}$=200 $\underline{\Delta D}$=-100	34.5 27.83	1250 1210	30625 21574.3
	$\overline{\Delta D}$=-150 $\underline{\Delta D}$=-200	28.75 25.66	1245 1210	23343.75 18955.86

VII. CONCLUSION

This paper studies the coordination strategy and profit loss analysis of supply chain members when market demand and price sensitivity coefficients are disturbed simultaneously when market demand is disturbed by retailers' private information. According to the above analysis, we can draw the following conclusions: 1) When the demand disruption of supply chain is symmetric, the supply chain system has some robustness. In some cases, the supplier can keep the original production plan; 2) With asymmetric information, the asymmetric demand disruption between the supplier and the retailer will change the production plan of the supplier, the order quantity also changes. Furthermore, the profits of supply chain system will suffer the loss of profit; 3) Whatever the information value of demand disruption changes, it reflects strategic decisions of supply chain members in production plans.

Other contracts mentioned at Cachon have been widely applied on supply chain. Whether under these contract menus the conclusions are still valid needs to be further investigated. We assume that the relationship between market demand and retailer price is linear and the marginal cost is zero. The further research direction is other types of functions. In addition, multiple suppliers or multiple retailers in supply chain could be further considered under asymmetric information. At the same time, we can consider other methods to solve the asymmetry of disruption information.

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