CSCanada
Management Science and Engineering
Vol. 11, No. 1, 2017, pp. 9-13
DOI:10.3968/9472

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

Coordinating a Supply Chain Consisted of One Supplier and One Retailer When Demand Disruption Happens

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Supported by Research Fund for the Doctoral Program of Higher Education of China (20110185110022).

Received 10 December 2016; accepted 12 March 2017
Published online 20 March 2017

Abstract

In this paper, a supply chain consisted of one supplier and one retailer is studied. The retailer sells the product to customers by using e-commerce platform and customers receive the product offline. Distributing product is outsourced by the retailer. The supply chain is coordinated under the revenue-sharing contract in the static case. The supplier observes that the market scale change after the production plan in the supply chain is formulated. In centralized supply chain, the supplier only needs to adjust the retail price if the change of the market scale is in a certain range. The supplier needs to adjust the retail price and production quantities if the change is large enough. In decentralized decision, the supply chain cannot be coordinated. This means that the original revenue-sharing contract cannot coordinate the disrupted supply chain. An improved revenue-sharing contract is put forward to coordinate the disrupted supply chain. The research shows that the improved contract can coordinate the original supply chain and the disrupted supply chain, which means that the contract has robustness when facing the market scale disruption. Finally, some numerical examples are also given.

Key words: Supply chain coordination; E-commerce; Demand disruption; Supply chain contract

Zhang, J., & Chen, H. (2017). Coordinating a Supply Chain Consisted of One Supplier and One Retailer When Demand Disruption Happens. *Management Science and Engineering*, *11*(1), 9-13. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/9472 DOI: http://dx.doi.org/10.3968/9472

INTRODUCTION

The e-commerce market grows rapidly all over the world in recent years. E-commerce market in Europe is a relatively mature market and evolves constantly. However, disruptions such as natural disasters, terrorism attacks, major public health events, financial crisis, machine faults and strikes may affect business operation and supply chain management. An originally-coordinated supply chain cannot be coordinated because of some disruptions, and the survival of the supply chain members can be influenced by other disruptions. For example, a large number of airports in the United States were forced to close because of "9 • 11" terrorism attacks. Raw material supply in many companies all over U.S.A. was delayed because of the accident. Some supply chains are almost damaged due to this disruption and it results in a heavy loss. Large companies like Ford are also influenced by disruptions. Supply of engines and drive parts of Ford suspends for a long time due to the slow response of its procurement system, which makes five companies affiliated with Ford in North America close temporarily.

Disruptions will make market demand change greatly. For example, the spread of foot-and-mouth disease makes the demand for beef in Europe decrease dramatically, which affects the operation of the beef supply chain in Europe. The demand for tents and moving shelters increases dramatically in the disaster areas after the Wenchuan Earthquake, 2008, and a lot of enterprises manufacturing tents have to work overtime in order to meet the demand, which affects the operation of their supply chain system. Recently, with the development of e-commerce, online shopping is widely spread all over China. Customers buy what they want online and evaluate the products after they receive them offline. According to some statistics, total sales volume in Taobao and Tmall, two companies subordinated to Alibaba, is about 19.1 billion RMB on 11th November, 2012, which has great impact on the supply chain system. Retailers need to preorder a large number of products in order to meet the huge coming demand and the logistics system is greatly influenced by logistics activities such as purchasing, storing, transporting and distributing.

As can be seen above, supply chain members' behavior, total supply chain profit and the survival of enterprises in supply chains can be affected by disruptions. The impact is so serious that it is necessary to study the strategy about how to coordinate supply chains when facing disruptions and this has been paid much attention by many companies and academic world.

A supply chain consisting of one supplier and one retailer is studied in this paper. The rest of this paper is organized as follows. The related researches are reviewed in Section 2. Benchmark model is established in Section 3. Section 4 coordinates the centralized supply chain with demand disruption. How to coordinate the decentralized supply chain with demand disruption is studied in Section 5 and an improved revenue-sharing contract is presented in this section. Numerical studies are illustrated in Section 6. Section 7 concludes this paper and some possible research opportunities in the future are also discussed.

1. LITERATURE REVIEW

Researches related to this paper are known as disruption management. The concept "disruption management" is firstly put forward by Clausen (2001). It is used to solve the operations of Continental Airlines when it faces emergency. A conceptual model to analyze supply chain disruptions is put forward by Kleindorfer et al. (2005). A two-stage supply chain with demand disruption is studied by Xu (2003), Qi (2004) and Huang (2006), and the quantity discount contract is used to coordinate the supply chain. Giannoccaro (2004) studies a three-stage supply chain coordination by using revenue-sharing contract. Tomlin (2006) discusses a supply chain in which there exist two suppliers and one manufacturer when the supply chain faces disruption risks. Xu (2006) studies supply chain coordination when the production cost function is a convex function. Xiao (2005, 2008) studies a supply chain with one-manufacturer and two-retailers when the demand disruption occurs and extends the study to a more complex problem in which there exists competition between the two retailers. Lei (2012) examines how to coordinate a two-stage supply chain under asymmetric information with a linear contract when demand and cost disruptions happen simultaneously.

Compared with previous studies, there are some differences in this paper. Firstly, it analyzes a supply chain under e-commerce, a new background. We analyze the impact of the market scale on the e-commerce supply chain. Secondly, there exists retailer's sales cost in the supply chain. Thirdly, this paper examines the effect of the revenue-sharing contract in supply chain coordination, which is also different from previous studies.

2. BENCHMARK MODEL

This paper examines a supply chain composed of one supplier (she) and one retailer (he), in which the supplier is the price leader and the retailer is the price follower. The transaction between the supplier and the retailer is done under symmetric information, which means that the supplier knows the retailer's cost structure and profit function, and vice versa. The supplier sells a kind of short-life-cycle product to the retailer according to a production plan which is based on market forecast. The retailer sells the product online and customers receive the product offline. The retailer outsources his product distribution business to a third-party logistics company. The retailer decides whether or not to buy the product according to the revenue-sharing contract the supplier offers.

Suppose that p is the retail price and the demand function that the retailer faces is a nonlinear function, i.e., $d=Dp^{-2k}$. D is the market scale and c_s is the supplier's unit production cost. The retailer's unit sales cost is c_r which includes the unit cost of using e-commerce platform and the unit cost of distributing his product. The unit retail price is p and k ($k>0$) is the price sensitivity coefficient. Q is the realized demand under the retail price p. The demand function is $Q=Dp^{-2k}$ and the retail price is $p=(D/Q)^{\frac{1}{2k}}$. The total profit of the supply chain is

$$\overline{f}(Q)=Q\left[(D/Q)^{\frac{1}{2k}}-c_s-c_r\right]. \tag{1}$$

According to the first-order condition, we obtain that the optimal retail price is

$$\overline{p}=\frac{2k(c_s+c_r)}{2k-1}, \tag{2}$$

the optimal production quantity is

$$\overline{Q}=D\left[\frac{2k-1}{2k(c_s+c_r)}\right]^{2k}, \tag{3}$$

and the optimal supply chain profit is

$$\overline{f}(\overline{Q})=\frac{D(c_s+c_r)}{2k-1}\left[\frac{2k-1}{2k(c_s+c_r)}\right]^{2k}. \tag{4}$$

Lemma 1. The supply chain composed of one supplier and one retailer can be coordinated under the revenue-sharing contract (w,ϕ), where $w=\phi(c_s-\frac{1-\phi}{\phi}c_r)$ and $0<\phi<1$.

PROOF. By substituting $w=\phi(c_s-\frac{1-\phi}{\phi}c_r)$ ($0<\phi<1$) into the supplier's profit function, i.e., $f_s=(1-\phi)\overline{p}\cdot\overline{Q}+(w-c_s)\overline{Q}$, we easily obtain that $f_s=(1-\phi)\cdot\overline{f}(\overline{Q})$. It shows that the revenue-sharing contract (w,ϕ) coordinates the supply chain (Burguera, 2003; Cachon, 2005).

3. COORDINATING CENTRALIZED SUPPLY CHAIN WHEN DEMAND DISRUPTION OCCURS

Centralized supply chain is a system which its decisions are made by the same decision-maker, the supplier. The supplier observes that demand disruption occurs after her production plan is formulated. It results in the change of the market scale. The disruption is captured by the term of ΔD if and only if $D+\Delta D>0$, which ensure it is meaningful in the real world. Thus, the discussions followed are based on the condition mentioned above.

After the disruption occurs, the demand function is $d=(D+\Delta D)p^{-2k}$. The realized demand is $Q=(D+\Delta D)p^{-2k}$ and the retail price is $p=(\frac{D+\Delta D}{Q})^{\frac{1}{2k}}$. The corresponding total supply chain profit function is written as

$$f(Q)=Q\left[(\frac{D+\Delta D}{Q})^{\frac{1}{2k}}-c_s-c_r\right]-b_1(Q-\overline{Q})^+-b_2(\overline{Q}-Q)^+ . \quad (5)$$

The parameters $b_1>0$ and $b_2>0$ in Equation (5) are the marginal cost related to the change of the market scale and $(x)^+=\max\{0,x\}$. b_1 is the extra increased unit cost due to increase production plan and b_2 is the extra unit disposal cost due to selling the remained products in the secondary market at the price lower than the marginal production cost when the supply is greater than the demand. In order to further discuss the impact of the demand disruption on the original production plan, we put forward Lemma 2.

Lemma 2. When the demand disruption occurs, we assume that Q^* is the optimal production quantity which maximizes the supply chain profit function shown in Equation (5). Then, $Q^*\geq\overline{Q}$ if $\Delta D>0$, and $Q^*\leq\overline{Q}$ if $\Delta D<0$.

Lemma 2 illustrates the following results. If the market scale increases, the supply needs to increase production quantities. If the market scale decreases, the supplier needs to decrease production quantities.

According to Lemma 2, if $\Delta D>0$, then $Q^*\geq\overline{Q}$. Thus, optimizing the total supply chain profit function $f(Q)$ is equal to optimize the strictly concave function

$$f_1(Q)=Q\left[(\frac{D+\Delta D}{Q})^{\frac{1}{2k}}-c_s-c_r\right]-b_1(Q-\overline{Q}), \quad (6)$$

subject to $Q^*\geq\overline{Q}$.

If $\Delta D<0$, then $Q^*\leq\overline{Q}$. Thus, optimizing the total supply chain profit function $f(Q)$ is equal to optimize the strictly concave function

$$f_2(Q)=Q\left[(\frac{D+\Delta D}{Q})^{\frac{1}{2k}}-c_s-c_r\right]-b_2(\overline{Q}-Q) \quad (7)$$

subject to $Q^*\leq\overline{Q}$.

Theorem 1 is obtained by using the methodology similar to Xu (2003, 2006) and Qi (2004), which shows the optimal decisions in the centralized supply chain when the demand disruption occurs.

Theorem 1. When the market scale disruption occurs and the demand function is $d=(D+\Delta D)p^{-2k}$, the supplier in the centralized supply chain needs to adjust the optimal retail price and the optimal production quantities in order to optimize the total supply chain profit and coordinate the supply chain. According to different disruptions, the optimal retail price p^* and the optimal production quantity Q^* are shown as follows:

$$p^*=\begin{cases}\overline{p}+\frac{2kb_1}{2k-1}, & \text{if } \Delta D>D\left[(1+\frac{b_1}{c_s+c_r})^{2k}-1\right];\\ \overline{p}(1+\frac{\Delta D}{D})^{\frac{1}{2k}}, & \text{if } D\left[(1-\frac{b_2}{c_s+c_r})^{2k}-1\right]\leq\Delta D\leq D\left[(1+\frac{b_1}{c_s+c_r})^{2k}-1\right];\\ \overline{p}-\frac{2kb_2}{2k-1}, & \text{if } \Delta D<D\left[(1-\frac{b_2}{c_s+c_r})^{2k}-1\right].\end{cases} \quad (8)$$

$$Q^*=\begin{cases}(D+\Delta D)\left[\frac{2k-1}{2k(c_s+c_r+b_1)}\right]^{2k}, & \text{if } \Delta D>D\left[(1+\frac{b_1}{c_s+c_r})^{2k}-1\right];\\ D\left[\frac{2k-1}{2k(c_s+c_r)}\right]^{2k}, & \text{if } D\left[(1-\frac{b_2}{c_s+c_r})^{2k}-1\right]\leq\Delta D\leq D\left[(1+\frac{b_1}{c_s+c_r})^{2k}-1\right];\\ (D+\Delta D)\left[\frac{2k-1}{2k(c_s+c_r-b_2)}\right]^{2k}, & \text{if } \Delta D<D\left[(1-\frac{b_2}{c_s+c_r})^{2k}-1\right].\end{cases} \quad (9)$$

Theorem 1 shows the following results. When disruptions make the market scale change, there exists robustness in the original production plan. When ΔD is in certain range, the original production quantity does not need to be changed but the corresponding retail price needs to be adjusted in order to compensate for the extra cost derived from the disruption. If ΔD exceeds certain value, the original production quantity needs to be adjusted and the corresponding retail price also needs to be adjusted according to the change of the market scale. It is also shown that the original revenue-sharing contract cannot coordinate the supply chain when the demand disruption occurs. We need to redesign the contract in order to coordinate the supply chain, which will be discussed in the next section.

If the supplier does not notice the impact of the disruption and continues to use the original retail price ($\tilde{p}=\overline{p}$) when the realized demand in the supply chain is $d=\tilde{Q}=(D+\Delta D)\tilde{p}^{-2k}$ and the retail price is $\tilde{p}=(\frac{D+\Delta D}{Q})^{\frac{1}{2k}}$, the total supply chain profit in this case is

$$\tilde{f}(\tilde{Q})=(D+\Delta D)(\bar{p}-c_s-c_r)\bar{p}^{-2k}-b_1(\tilde{Q}-\bar{Q})^+-b_2(\bar{Q}-\tilde{Q})^+. \quad (10)$$

Thus, we obtain that

$$\tilde{f}(\tilde{Q})=\begin{cases}\left[(D+\Delta D)(\bar{p}-c_s-c_r)-b_1\Delta D\right]\bar{p}^{-2k}, if\,\Delta D>0;\\ \left[(D+\Delta D)(\bar{p}-c_s-c_r)+b_2\Delta D\right]\bar{p}^{-2k}, if\,\Delta D<0.\end{cases} \quad (11)$$

4. COORDINATING DECENTRALIZED SUPPLY CHAIN WHEN DEMAND DISRUPTION HAPPENS

Decentralized decision means that each member in the supply chain does his business according to his own maximum profit. In the centralized decision, when the market scale change, the optimal strategy for the retailer is to choose the retail price p^* and the procurement quantity Q^*. In decentralized decision, if the supply chain members sign an appropriate contract which also makes the retailer choose p^* and Q^*, the decentralized supply chain obtains the optimal supply capacity which is equal to that in the centralized supply chain. This means that the supply chain is coordinated. The revenue-sharing contract is used to coordinate the decentralized supply chain.

Let $T(Q)=b_1(Q-\bar{Q})^+ + b_2(\bar{Q}-Q)^+$. Concerning a given revenue allocation ratio $\phi(0<\phi<1)$, the supplier offers the retailer an improved revenue-sharing contract in which the wholesale price is $w(Q)=\phi(c_s-\frac{1-\phi}{\phi}c_r+\frac{T(Q)}{Q})$.

Theorem 2. When the market scale change in the decentralized supply chain, the supply chain can be coordinated by the revenue-sharing contract $(w(Q),\phi)$ and the optimal total supply chain profit can be allocated between the supplier and the retailer in any given ratio.

PROOF. Concerning a given revenue allocation ratio $\phi(0<\phi<1)$, the retailer's profit function under the improved revenue-sharing contract $(w(Q),\phi)$ is shown below.

$$f_r(Q)=\phi(\frac{D+\Delta D}{Q})^{\frac{1}{2k}}Q-w(Q)Q-c_rQ\,.$$

By substituting $w(Q)$ into the equation mentioned above, we easily obtain that $f_r(Q)=\phi f(Q)$. Thus, the supply chain is coordinated by the contract and the optimal supply chain profit can be allocated between the supply chain members in any given allocation ratio by adjusting the parameter ϕ. This means that the improved revenue-sharing contract $(w(Q),\phi)$ can coordinate the decentralized supply chain. Furthermore, if ΔD=0, then b_1=b_2=0. The supply chain profit function in this case is $f(Q)=\bar{f}(Q)$ and the wholesale price is $w(Q)$=w. This means that the improved revenue-sharing contract $(w(Q),\phi)$ can coordinate the supply chain when the disruption of the market scale does not occur. In other words, there exists anti-disruption ability in the improved contract.

5. NUMERICAL STUDIES

When the market scale disruption takes place, the optimal production quantity and the optimal retail price in the supply chain will be influenced, and the optimal supply chain profit and the allocation of the profit between the supply chain members will also be influenced. We will analyze the effect of the demand disruption on the supply chain performance, the supplier's profit and the retailer's profit by using numerical examples in this section.

Let D=1,500 , c_s=3, c_r=1 and k=1. The supplier and the retailer sign an agreement in which the supplier takes 40% of the total channel revenue and the retailer takes the remainder part. This means that ϕ=0.6. In the static case, it is shown that the supplier's optimal production quantity is $\bar{Q}=23.44$, the optimal retail price is $\bar{p}=8$ and the optimal supply chain profit is $\bar{f}=93.75$.

Suppose that b_1=0.5 and b_2=0.2. When the market scale changes, there exist two types of demand disruption in the supply chain. We analyze two different strategies, the original strategy and the adjusted strategy, which are used in the supply chain after the demand disruption takes place. If the supplier does not recognize the impact of the disruption on the supply chain and does not make timely decision, he will continue to use the original retail price strategy which is called as the original strategy. We compare supply chain performance under the original strategy with that under the improved revenue-sharing contract, which is shown in Table 1.

Table 1
Supply Chain performance Under Demand Disruption

Case	ΔD	$\tilde{p}$	p^*	$\tilde{Q}$	Q^*	$\tilde{w}$	w^*	$\tilde{f}$	f^*
1	500	8	9	31.25	24.69	1.4	1.42	121.09	122.83
2	400	8	9	29.69	23.46	1.4	1.40	115.63	117.27
3	300	8	8.76	28.13	23.44	1.4	1.4	110.16	111.65
4	-100	8	7.73	21.88	23.44	1.4	1.4	87.19	87.39
5	-200	8	7.6	22.51	20.31	1.4	1.40	80.63	80.84
6	-300	8	7.6	20.78	18.75	1.4	1.42	74.06	74.26

Note. $\tilde{x}$ is the original strategy and x^* is the adjusted strategy.

As it can be seen from Case 1 and Case 2 in Table I, the optimal retail prices are the same while the optimal wholesale prices and the optimal production quantities need to be adjusted. The retail price here is larger than the original retail price. It shows the following results. If the disruptions of the market scale satisfy certain conditions, the retailer does not need to adjust the retail prices while the supplier needs to increase the production quantity and the wholesale price. This can balance the supplier's profit when facing enlarged market demand. As is shown in Case 3 and Case 4, both the optimal production quantities and the optimal wholesale prices are the same while the optimal retail prices need to be adjusted. This means that there exists robustness in the optimal production quantity decided at first and the revenue-sharing contract when dealing with the disruptions. When the demand increases, the retailer increases the retail price in order to balance the impact of the disruption. The retail price here is larger than the original retail price. When the demand decreases, the retailer decreases the retail price in order to balance the impact of the disruption. The retail price here is lower than the original retail price. The supplier does not need to adjust the production quantity and the wholesale price in both cases. As can be seen from Case 5 and Case 6, the optimal retail prices are the same while the optimal wholesale prices and the optimal production quantities need to be adjusted. The retail price here is lower than the original retail price. It shows the following results. If the disruptions of the market scale satisfy certain conditions, the retailer does not need to adjust the retail prices while the supplier needs to decrease the production quantity and increase the wholesale price. This can decrease the supplier's loss when facing shrunk market demand. Last but not least, when the demand disruptions occur, the total supply chain profits under the improved revenue-sharing contract are always larger than those under the original price strategy. It illustrates that there are better performances in using the revenue-sharing contract when dealing with the disruptions.

CONCLUSION

A one-supplier-one-retailer supply chain is studied in this paper when the market scale change. In centralized decision, the supplier needs to increase the production quantity when the market demand increases. The supplier needs to decrease the production quantity when the market demand decreases. There exists robustness in the original production plan. In other words, when the disruptions satisfy a given condition, the original production quantity does not need to be adjusted and the supplier only needs to adjust the corresponding retail price in order to deal with the demand disruptions. The retail price and the production quantity need to be adjusted when the demand disruptions exceed certain value. An improved revenue-sharing contract is used to coordinate the decentralized supply chain, which can maximize the total supply chain profit. It is noted that the results derived in this paper also illustrates the generality of the revenue-sharing contract. Finally, some numerical examples are also given to analyze the supply chain performance when the original price strategy in basic model and the adjusted price strategy in the demand disruption are carried out respectively.

There are abundant opportunities in the future. For example, it is interesting to study more complex supply chain when the information of profit and cost between the participants is asymmetric. It is worth coordinating the same supply chain system when the demand disruption and the supplier's production cost disruption occur simultaneously. Another direction is to study the problem which the demand function the retailer face is an exponential and more complex function. More complex supply chain structure with other disruptions is also worth studying.

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