How to Coordinate a Two-Echelon Supply Chain under O2O Business Model When Retailer Faces Disruptions

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Abstract. A two-echelon supply chain under O2O business model, a new kind of supply chain, is studied in this paper, in which it is composed of one supplier (she) and one O2O retailer (he). The supplier finds that demand disruption and retailer’s sales cost disruption happen simultaneously after her production plan is formulated. How to maximize the total supply chain profit in the centralized and the decentralized decisions is analyzed, which is a new problem compared with the previous studies. The results obtained are as follows. The supplier needs to adjust the retail price if the disruptions satisfy a given condition. If the disruptions satisfy other conditions, the supplier needs to adjust both the retail price and the production quantity. In the decentralized decision, an improved revenue-sharing contract, a new supply contract, can coordinate the disrupted supply chain. Finally, some numerical examples are given to show the results.

Introduction

The development of e-commerce grows rapidly around the world in recent years. It profoundly changes customers’ consumption habit, which also has a significant impact on the production and operation of traditional manufacturers and retailers. In this setting, O2O (Online to Offline/Offline to Online) business model, a new business model, is put forward by some high-tech companies. They suggest that companies in the future should integrate online business with offline business. With the broad utilization of information technology, O2O business model becomes localized and begins to integrate with mobile devices at the end of 2013, which means that a new era of O2O business model is coming. For example, Tmall, an e-retailer affiliated to Alibaba, begins to cooperate with Intime Department Store in 2013. Many e-commerce companies such as Taobao, Tmall, Amazon, Dangdang and Jingdong Shopping Center become O2O retailers when they sell products online and improve their customers’ shopping experience in online and offline channel. They are exactly the subjects we focus on.

However, disruptions such as public health events, natural disasters and machine faults can influence supply chain operation. An initially-coordinated supply chain cannot be coordinated because of some disruptions, and whether supply chain members can survive or not is influenced by other disruptions. For
example, the spread of plague caused by H7N9 in China makes the demand of chicken for food decrease dramatically. The spread of foot-and-mouth disease makes the demand for beef in Europe decrease dramatically. With the development of e-commerce, shopping online is widely spread throughout China. According to some statistics, the total sales volume in Tmall is about 120.7 billion RMB on 11th November 2016, which greatly influences the operation of its online and offline supply chain system. The e-retailer needs to order a large number of different products in advance in order to meet the huge demand, and its logistics system is greatly affected by activities such as storing, transporting and distributing.

As it can be seen above, supply chain profit, supply chain operation and supply chain members’ decision can be affected by different disruptions. The impact is so profound that it is important to discuss how to coordinate supply chain when disruptions happen\[1\]. Scholars and companies home and abroad have paid much attention to this problem.

**Literature Review**

Current research related to O2O business model focuses on recommendation system and how to improve e-commerce service. Tsai et al. (2013) find that retailers implementing O2O business model can better understand their customers\[2\]. Chen et al. (2013) believe that improvements in recommendation system can attract more online customers\[3\]. Hsieh et al. (2014) put forward a kind of BP neural network algorithm containing many factors, which is used to better match consumers’ need\[4\]. There are other studies about the development of O2O business model in China. For example, Hong (2013) and Zhao (2014a) examine the role of O2O business model in the marketing of local fresh produce and the development of regional economy\[5,6\]. Zhao (2014b) analyze the O2O business model in Wanda Group, a Chinese leading real estate company\[7\].

Studies closely related to this paper are called as disruption management. Clausen (2001) firstly puts forward disruption management\[8\]. How to coordinate supply chain with different disruptions is discussed by Qi et al. (2004)\[9\], Xu et al. (2003, 2006)\[10,15\] and Huang et al. (2006)\[11\]. Lei et al. (2012) examine how to coordinate a two-stage supply chain under asymmetric information with a linear contract\[12\]. Zhang et al. (2015, 2016) investigate different two-echelon supply chains under O2O business model, respectively\[14,16\].

Compared with previous studies, there are three major differences in this paper. Firstly, a single-channel supply chain under O2O business model, a new kind of supply chain, is established. Secondly, the discussion is different from Xu et al. (2003, 2006), Qi et al. (2004) and Zhang et al. (2015, 2016). We analyze the impact of two elements, the market scale and the retailer’s sales cost, on supply chain coordination. Thirdly, this paper examines the role of the revenue-sharing contract in how to coordinate a new disrupted supply chain.

**Coordinating the Centralized Supply Chain When Disruptions Happen**

**Benchmark Model**

This paper examines a supply chain comprising of one supplier (she) and one O2O retailer (he). To expand his market share and increase his profit, the retailer
sells a kind of short-life-cycle product to consumers on an O2O e-commerce website, and customers evaluate the online shopping experience at the website after they receive the product offline. The problem is considered as a Stackelberg game in which the supplier is the price leader and the O2O retailer is the price follower. The transaction between the supplier and the retailer is realized under symmetric information. The supplier sells the product to the retailer according to her market forecast. The retailer outsources his product distribution business to a third-party logistics company. The retailer decides whether or not to sell the products according to the revenue-sharing contract the supplier provides.

Suppose that the retail price is \( p \) and the demand function is a nonlinear function, i.e., \( d = D p^{-k} \). The market scale is \( D \) and the supplier’s unit production cost is \( c_s \). The O2O retailer’s unit sales cost is \( c_r \) which includes the unit cost of distributing his product and the unit cost of using the O2O e-commerce website. The retail price is \( p \) and the price sensitivity coefficient is \( k(k > 0) \). Then, the market demand is \( Q = D p^{-k} \) and the retail price is \( p = (D/Q)^{1/k} \). The total profit of the supply chain is

\[
\bar{f}(Q) = Q \left( \frac{D}{Q} \right)^{1/k} - c_s - c_r \quad (1)
\]

From the first-order optimality condition, the optimal retail price in the supply chain is

\[
\bar{p} = \frac{2k(c_s + c_r)}{2k - 1}, \quad (2)
\]

the optimal production quantity is

\[
\bar{Q} = D \left[ \frac{2k - 1}{2k(c_s + c_r)} \right]^{1/k}, \quad (3)
\]

and the optimal supply chain profit is

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

Lemma 1. The supply chain which is comprised of one supplier and one O2O retailer can be coordinated under the revenue-sharing contract \((w, \phi)\) where \( w = \phi(c_s - \frac{1-\phi}{\phi} c_r) \) (\( 0 < \phi < 1 \)), if \( f_s = (1-\phi) \cdot \bar{f}(\bar{Q}) \) with \( 0 < \phi < 1 \) or \( f_r = \phi \cdot \bar{f}(\bar{Q}) \) with \( 0 < \phi < 1 \). \( f_s \) is the optimal supplier’s profit and \( f_r \) is the optimal O2O retailer’s profit.

**Coordinating the Centralized Supply Chain When Disruptions Happen**

Centralized supply chain is a system in which its decisions are made by the supplier, the decision-maker. She finds that the market scale disruption and the retailer’s sales cost disruption happen simultaneously after her production plan is formulated. Those disruptions are captured by the terms of \( \Delta D \) and \( \Delta c_r \), respectively, if and only if \( D + \Delta D > 0 \) and \( c_r + \Delta c_r > 0 \), where the disruption of the
market scale is \( \Delta D \) and the retailer’s sales cost disruption is \( \Delta c_r \). It ensures that they are practical in the real world. Thus, the following discussions are based on the conditions mentioned above.

After the disruptions happen, the market demand is \( Q = (D + \Delta D)p^{-\Delta} \) and the retail price is \( p = \left(\frac{D + \Delta D}{Q}\right)^{-\Delta} \). Then, the total supply chain profit function concerning the disruptions is written as

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

(5)

\( b_1 \) and \( b_2 \) in the above equation are the marginal costs related to the change of the market scale and \( (x)^+ = \max\{0, x\} \). \( b_i (b_i > 0) \) is the extra increased unit cost due to increasing production quantity and \( b_2 \) (\( b_i > 0 \)) 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. To further discuss the impact of the disruptions mentioned above on the initial production plan, we put forward Lemma 2 below.

Lemma 2. If the market scale disruption and the retailer’s sales cost disruption happen simultaneously, we assume that \( Q^* \) is the optimal production quantity which maximizes the supply chain profit function shown in Equation (5). Then, the following results hold: if \( \Delta D > D \left[ (1 + \frac{\Delta c_r}{c_s + c_r})^{\Delta} - 1 \right] \), then \( Q^* \geq \overline{Q} \); if \( \Delta D < D \left[ (1 + \frac{\Delta c_r}{c_s + c_r})^{\Delta} - 1 \right] \), then \( Q^* \leq \overline{Q} \).

Lemma 2 illustrates the following results. When the disruption of the market scale exceeds a given value, the supplier needs to increase the production quantity; while the disruption of the market scale satisfies the other condition, the supplier needs to decrease the production quantity.

According to Lemma 2, when \( \Delta D > D \left[ (1 + \frac{\Delta c_r}{c_s + c_r})^{\Delta} - 1 \right] \), \( Q^* \geq \overline{Q} \). Then, optimizing the total supply chain profit function \( f(Q) \) is equal to optimize the strictly concave function

\[
f_1(Q) = Q \left(\frac{D + \Delta D}{Q}\right)^{\frac{1}{\Delta}} - c_r - c_s - \Delta c_r \right) - b_1(Q - \overline{Q})
\]  

subject to \( Q \geq \overline{Q} \).

When \( \Delta D < D \left[ (1 + \frac{\Delta c_r}{c_s + c_r})^{\Delta} - 1 \right] \), \( Q^* \leq \overline{Q} \). Then, optimizing the total supply chain profit function \( f(Q) \) is equal to optimize the strictly concave function

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

subject to \( Q \leq \overline{Q} \).
By using the methodology similar to Xu et al. (2003), Qi et al. (2004) and Huang et al. (2006), Theorem 1 is obtained which illustrates the optimal decisions in the centralized supply chain when the disruptions happen.

Theorem 1. When the demand disruption and the retailer’s sales cost disruption happen simultaneously and the market demand function is \( Q = (D + \Delta D)p^{-1} \), the supplier, the decision-maker in the centralized O2O supply chain, needs to change the retail price and the production quantities in order to maximize the total supply chain profit. According to different disruptions, the optimal retail price \( p^* \) and the optimal production quantity \( Q^* \) are shown as follows:

\[
p^* = \begin{cases} 
\pi + \frac{k(\Delta c_r + b_1)}{2k - 1}, & \text{if } \Delta D > D \left[ (1 + \frac{\Delta c_r + b_1}{c_r + c_r})^2 - 1 \right]; \\
\pi + \frac{k(\Delta c_r - b_1)}{2k - 1}, & \text{if } \Delta D < D \left[ (1 + \frac{\Delta c_r - b_1}{c_r + c_r})^2 - 1 \right]; \\
\pi + \frac{\Delta D}{D}, & \text{if } D \leq \Delta D \leq D \left[ (1 + \frac{\Delta c_r + b_1}{c_r + c_r})^2 - 1 \right]; \\
\end{cases}
\]

(8)

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

(9)

Theorem 1 illustrates the following results. When the demand disruption and the retailer’s sales cost disruption happen simultaneously, there exists robustness in the initial production plan. When \((\Delta D, \Delta c_r)\) is in a given interval, the supplier does not need to change the initial production quantity but she needs to change the corresponding retail price in order to compensate for the extra cost derived from the disruptions. The optimal retail price is only influenced by the disruption of the market scale and is not correlated to the disruption of the retailer’s sales cost. If \((\Delta D, \Delta c_r)\) exceeds the given interval, the supplier needs to change both the production quantity and the retail price according to the disruption of the market scale and the disruption of the retailer’s sales cost. However, the optimal retail price in this scenario is only related to the retailer’s sales cost disruption and is not related to the demand disruption. It is also shown that the initial revenue-sharing contract cannot coordinate the supply chain when the disruptions happen, and we need to redesign a new contract in order to coordinate the new disrupted supply chain.

Next, we discuss a problem which the equilibrium price in the basic case is adopted in the supply chain when the disruptions happen. The similar problem is also investigated by Qi (2004) and Huang (2006).

When the market demand in the supply chain is \( d = \hat{Q} = (D + \Delta D)p^{-1} \), the supplier, the decision-maker in the supply chain, does not notice the impact of the disruptions and continues to use the retail price in the basic case, i.e., \( \hat{p} = p \). Then, the total supply chain profit in this scenario is

\[
\hat{f}(\hat{Q}) = \hat{Q}(\hat{p} - c_r - \Delta c_r) - b_1(\hat{Q} - \hat{Q})^2 - b_2(\hat{Q} - \hat{Q})^3,
\]

(10)
and we have
\[
T(Q) = \begin{cases} 
((D + \Delta D) (\bar{p} - c, - \Delta c) + b_2 \Delta D) \bar{p} - 1, & \text{if } \Delta D > 0; \\
((D + \Delta D) (\bar{p} - c, - \Delta c) - b_1 \Delta D) \bar{p} - 1, & \text{if } \Delta D < 0.
\end{cases}
\] (11)

**Coordinating the Decentralized Supply Chain When the O2O Retailer Faces the Disruptions**

In the centralized decision, when the market scale disruption and the retailer’s sales cost disruption happen simultaneously, the optimal strategy for the O2O retailer is to choose the retail price \( p^* \) and the procurement quantity \( Q^* \). In the decentralized decision, if the two parties in the supply chain sign an appropriate contract which also makes the O2O retailer choose \( p^* \) and \( Q^* \), then the optimal supply capacity in the decentralized O2O supply chain is equal to that in the centralized O2O supply chain. This means that the supply chain is coordinated. The revenue-sharing contract is used to coordinate the decentralized O2O supply chain.

Let \( r(Q) = h_1 (Q - \bar{Q}) + h_2 (Q - \bar{Q})^+ \). Given a revenue allocation ratio \( \phi (0 < \phi < 1) \), the supplier provides the O2O retailer with an improved revenue-sharing contract in which the wholesale price is
\[
w(Q) = \phi \left[ c, - \frac{1 - \phi}{\phi} (c, + \Delta c) + \frac{r(Q)}{Q} \right].
\]

**Theorem 2.** When the disruption of the market scale and the disruption of the retailer’s sales cost disruption occur simultaneously in the decentralized O2O supply chain, the supply chain can be coordinated by the revenue-sharing contract \( (w(Q), \phi) \), where the wholesale price is
\[
w(Q) = \phi \left[ c, - \frac{1 - \phi}{\phi} (c, + \Delta c) + \frac{r(Q)}{Q} \right].
\]

The optimal total supply chain profit can be allocated between the two supply chain members in any ratio at the same time.

**Proof.** Given a revenue allocation ratio \( \phi (0 < \phi < 1) \), the retailer’s profit function under the revenue-sharing contract \( (w(Q), \phi) \) is shown below.
\[
f_2(Q) = \phi \left( \frac{D + \Delta D}{Q} \right) Q - w(Q)Q - (c, + \Delta c)Q
\]
\[
= \phi \left( \frac{D + \Delta D}{Q} \right) Q - \phi \left[ c, - \frac{1 - \phi}{\phi} (c, + \Delta c) + \frac{r(Q)}{Q} \right] Q - (c, + \Delta c)Q
\]
\[
= \phi \left( \frac{D + \Delta D}{Q} \right) Q - \phi (c, + c, + \Delta c)Q - \phi \cdot r(Q) = \phi \cdot f(Q)
\]

Hence, the supply chain is coordinated, and the optimal channel profit can be allocated between the two parties in any allocation ratio by changing the parameter \( \phi \). This means that the improved revenue-sharing contract \( (w(Q), \phi) \) coordinates the decentralized O2O supply chain. It is noted that if \( \Delta D = 0 \) and \( \Delta c = 0 \), then \( h_1 = h_2 = 0 \). The total supply chain profit function in this case is \( f(Q) = T(Q) \) and the wholesale price is \( w(Q) = w \), which means that the improved contract \( (w(Q), \phi) \) can coordinate the O2O supply chain when the disruptions do
Numerical Studies

When the supplier finds that the market scale and the retailer’s sales cost change simultaneously, the optimal production quantity, the optimal retail price and the optimal supply chain profit in the disrupted supply chain will be affected. We will analyze the impact of the disruptions on the pricing strategy of the two supply chain members and the supply chain performance by using some numerical examples.

Let $D = 1600$, $c_s = 5$, $c_r = 2$ and $k = 1$. The supplier and the O2O retailer sign an agreement in which the supplier takes 40% of the total supply chain profit and the retailer takes the remained part, i.e., $\phi = 0.6$. In the basic scenario, we obtain that the supplier’s optimal production quantity is $\bar{Q} = 8.16$, the optimal retail price is $\bar{p} = 14$ and the optimal supply chain profit is $f(\bar{Q}) = 57.14$.

Suppose that $\Delta D = [-350, 450]$, $\Delta c_r = [-0.6, 0.6]$, $b_1 = 0.8$ and $b_2 = 0.5$. If the market scale and the retailer’s sales cost change simultaneously, there exist four basic scenarios in the supply chain. We adopt two different price strategies, the original price strategy and the adjusted price strategy, after the disruptions take place. We will compare the supply chain performances under the original strategy with those under the improved revenue-sharing contract, which is shown in Table 1.

As it can be seen from Case 1 and Case 3 in Table 1, when the market scale increases and the retailer’s sales cost decreases, the optimal production quantities decided by the supplier are greater than those in the basic case and the supplier deals with the disruptions by increasing the corresponding production quantity and the corresponding wholesale price. The production quantities under the adjusted strategy are less than those under the original strategy, which means that the supplier only needs to adjust a little part of the corresponding production quantities if she deals with the disruptions. The supplier can reduce the relevant disposal cost by adopting the adjusted strategy. The O2O retailer increases the corresponding retail prices in order to cope with the disruptions in both cases. As it can be seen from Case 2, Case 4, Case 5 and Case 7 in Table 1, the optimal production quantities remain the same when the supplier adopts the adjusted strategy, while the supplier needs to change both the optimal wholesale prices and the optimal retail prices in those cases according to the disruptions. It illustrates that the original optimal production quantity is not affected after the disruptions happen. In other words, if the disruptions satisfy certain conditions, there exists robustness in the initial production plan when both the market scale and the retailer’s sales cost increase/decrease simultaneously. When both the market size and the retailer’s sales cost increase simultaneously, the supplier needs to decrease the corresponding optimal wholesale prices, and the retailer needs to increase the corresponding optimal retail prices in order to cope with the disruptions. When both the market size and the retailer’s sales cost decrease simultaneously, the supplier needs to increase the corresponding optimal wholesale prices and the retailer needs to decrease the corresponding optimal retail prices in order to cope with the disruptions. As can be seen from Case 6 and Case 8 in Table 1, when the market scale decreases and the retailer’s sales cost increases, the optimal production quantities decided by the supplier are less than those in the basic case, and the supplier deals with the disruptions by decreasing
the corresponding production quantity and the corresponding wholesale price. The supplier also can reduce the corresponding loss by adopting the adjusted strategy, which can maximize the total supply chain profit. The O2O retailer needs to decrease the corresponding retail prices in order to cope with the disruptions in both cases. Furthermore, it is noted that the total supply chain profits under the improved revenue-sharing contract are always greater than those under the original price strategy when the disruptions happen simultaneously. It illustrates that there are better performances in using the revenue-sharing contact when dealing with the disruptions.

Table 1. Supply Chain Performances under Different Disruptions.

<table>
<thead>
<tr>
<th>Case</th>
<th>Δσ</th>
<th>Δc</th>
<th>The retail price</th>
<th>The production quantities</th>
<th>The wholesale price</th>
<th>The total supply chain profit</th>
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<tr>
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<td>p'</td>
<td>Q</td>
<td>Q'</td>
</tr>
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<td>450</td>
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<td>10.46</td>
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</tr>
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<td>8.16</td>
</tr>
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<tr>
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<td>8.11</td>
</tr>
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</tr>
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<td>14</td>
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<td>6.38</td>
<td>6.20</td>
</tr>
</tbody>
</table>

Note. x is the original strategy and x' is the adjusted strategy.

Conclusion

This paper studies how to coordinate one-supplier-one-O2O-retailer supply chain in centralized and decentralized decisions when the market scale and the retailer’s sales cost change simultaneously. In the centralized decision, the supplier needs to increase the production quantities in order to meet the increased market demand when the disruption of the market scale and the retailer’s sales cost disruption satisfy a given condition. The supplier needs to decrease the production quantities in order to meet the shrunk market demand when the disruptions satisfy other conditions. There exists robustness in the initial production quantity when making the centralized decision. In other words, when the disruptions satisfy a given condition, the supplier does not need to change the initial production quantity she formulates and she only needs to change the corresponding retail price in order to compensate for the disposal cost originated from the disruptions. Furthermore, the supplier needs to change both the production quantity and the retail price if the disruptions exceed a particular interval. An improved revenue-sharing contract is used to coordinate the decentralized O2O supply chain, which can maximize the total supply chain profit. Finally, some numerical examples are given to investigate the supply chain performances when the original price strategy in the basic case and the adjusted strategy in the disruptions are adopted.
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