The Value of Hybrid MTS/MTO Supply Chain Sharing Demand Forecasts under Big Data

Yu Cao 1, Kan Wu 1,*, Hanli Hu 2

1 Business School, Central South University, Changsha 410083, China
2 School of Economics & Management, Changsha University of Science & Technology, Changsha 410114, China

*Kan_wu@csu.edu.cn

Abstract. Big data technology provides convenience for all entities in the supply chain to obtain demand forecasts and share the information. This article considers a supply chain composed of a manufacturer and two competitive retailers and analyzes the value of sharing demand information in the supply chain. In this supply chain, the manufacturer has a hybrid MTS/MTO production system and sells products to the MTS retailer and the MTO retailer. Both the manufacturer and the retailers have private demand information. We established a no-information sharing model, a full information-sharing model, and two partial-information sharing models, to study the value of sharing information. The results show that the full information sharing strategy cannot benefit all entities. However, if the demand forecasts of the two retailers are very different and lower than the manufacturer’s forecast, sharing information between the manufacturer and the retailer who has high demand prediction can benefit all entities.

Keywords: supply chain, information sharing, MTO, MTS

1. Introduction

Make to Stock (MTS) and Make to Order (MTO) are two typical production modes in enterprise production. In order to make full use of production capacity and respond to the different demands of customers, more and more enterprises and supply chains adopt a hybrid MTO/MTS production mode.

Though the demand is usually uncertain, big data technology provides a way for each entity of the supply chain to obtain market volatility and share the information. The demand information obtained by each entity will directly affect the enterprise’s pricing, ordering, and production decisions. Sharing
demand information can improve the accuracy of market demand forecasts of various entities, which is very important to the supply chain. Generally, sharing information can promote the improvement of supply chain performance from two aspects. Firstly, it helps manufacturers match supply and demand, thereby reducing the costs of oversupply or undersupply. Secondly, it improves the accuracy of demand forecasts, then better to realize demand management and make pricing decisions.

The existing research on sharing demand information can mainly be divided into two categories. The first category explored the value of supply chain sharing demand information, specifically studying the motivation of sharing information under different supply chain structures and the impact of sharing information on supply chain decision[1]. The second category focused on the design of incentive contracts for sharing demand information in the supply chain[2]. However, none of them considered the differences in production systems. Only a few scholars studied the issue of sharing information in the supply chain of different production systems. Yue and Liu[3]and Mishra et al[4] studied the motivation of manufacturers and retailers to share demand forecasts under different production modes (MTS and MTO). They found that in MTO mode, unconditional sharing of forecasts of retailers and manufacturers would benefit the manufacturer but harm retailers; and in MTS mode, manufacturers can obtain higher benefits in the form of saving inventory holdings and shortage costs when sharing demand forecasts. As far as we know, information sharing under the hybrid MTO/MTS supply chain production model has not been studied.

In order to analyze the value of sharing demand information under the hybrid MTO/MTS supply chain production system, we consider a supply chain consisting of a manufacturer and two competing retailers. The manufacturer has a hybrid MTS/MTO production system and sells products to MTS retailers and MTO retailers. Both the manufacturer and the retailers make decisions based on demand prediction, which is private information. We establish four models: no information sharing, complete information sharing, manufacturer and MTS retailer information sharing, and manufacturer and MTO retailer information sharing models to study the pricing and production decisions of the supply chain under different information sharing situations. We analyze the value of sharing information by comparing the final decision with or without information sharing.

2. Model settings
We study the information sharing problem of a secondary supply chain composed of one manufacturer \((m)\) and two retailers, namely, MTS retailer \((s)\) and MTO retailer \((o)\). The MTO retailer places an order with the manufacturer before production. After receiving the order, the manufacturer produces it and delivers to the retailer at a price \(w_o\). The retailer sells it to the market at a price \(p_o\). The MTS retailer purchases products from the manufacturer at a price \(w_s\) after the manufacturer produces it, and then sells it to the market at a price \(p_s\). Currently, there are two situations: oversupply or undersupply. When the supply exceeds the demand, the remaining products will be treated as residual values \(s\). When supply is short, there will be out-of-stock cost \(h\). In the market, competition occurs between MTS and MTO retailers. With reference to the research of Arya and Mittendorf[5], set the
demand as: $d_s = a - p_s + tp_o$ and $d_o = a - p_o + tp_s$, where $d_s$ and $d_o$ is the market demand of MTS and MTO retailer, respectively; $a$ is the basic demand of the entire market; $t$ represents the cross-price elasticity coefficient of the two retailers, showing their competition intensity in the market; $p_s$, $p_o$ stands for the selling price of MTS and MTO retailer, respectively. From the demand function, we obtain that product demand is inversely proportional to its own price and directly proportional to the price of competitors.

Demand is uncertain as affected by the economy and business market. Assume that the basic market demand obeys a normal distribution, that is $a \sim N(\mu, \sigma^2)$. The forecasts of the manufacturer, MTS retailer, and MTO retailer are $f_m$, $f_s$ and $f_o$, where $f_i - a \sim N(0, \sigma^2_i)$ ($i = \{m, s, o\}$). Referring to the research of Mishra et al[4], we can get the mean and variance of the posterior distribution, which are defined as $a_i := E[a | f_i]$ , $\sigma_{wi} := Var[a | f_i]$ , $a_{ij} := E[a | f_i, f_j]$ , $\sigma_{w_{ij}} := Var[a | f_i, f_j]$ , $a_{ww} := E[a | f_s, f_o, f_m]$ and $\sigma_{ww} := Var[a | f_s, f_o, f_m]$, where $i, j = m, s, o, i \neq j$.

3. Model analysis

3.1. Without information sharing

In this case, neither the manufacturer nor the two retailers share the information. The manufacturer can decide the wholesale price $w_s$ and $w_o$ based on its own predicted value $f_m$ of basic demand. However, the two retailers can decide the retail price $p_s$ and $p_o$ based on their predicted value $f_s$, $f_o$ and the $w_s$, $w_o$ given by the manufacturer. The profit functions of the manufacturer, MTS retailer, and MTO retailer as follows:

$$\pi_s = (p_s - w_s)(E[a | f_s, w_s] - p_s + tp_o), \quad \pi_o = (p_o - w_o)(E[a | f_o, w_o] - p_o + tp_s),$$

$$\pi_m = (w_o - c)(E[a | f_m] - E[p_o | f_m] + tE[p_s | f_m]) + \int_{0}^{\infty} (a + tp_o - p_s)(w_o - c)f(a)da$$

$$- \int_{0}^{\infty} (a + tp_o - p_s)(w_o - c)f(a)da$$

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where $\pi_s$, $\pi_o$ and $\pi_m$ represents the profit of the MTS retailer, MTO retailer, and manufacturer, respectively; $Q_i$ represents the manufacturer MTS’s production quantity. Therefore, we can get the optimal decision of the supply chain as proposition 1.

**Proposition 1** Without information sharing, the optimal strategies of the supply chain are:
From Proposition 1 we get, in order to prevent vicious bidding between retailers, the manufacturer will set the same wholesale price for MTS and MTO retailers. The wholesale price is directly proportional to the manufacturer’s final forecast of demand and inversely proportional to the intensity of competition. The manufacturer will increase MTS production when forecasting demand is high, and the inaccuracy of the forecast will cause the MTS production to deviate from the situation when the forecast is accurate, and the more inaccurate the forecast, the more deviation. Specifically, if the inventory handling cost is higher than the out-of-stock cost, the inaccuracy of the forecast will reduce the MTS production volume. Otherwise, the MTS production volume will be increased. The two retailers can fully obtain the manufacturer’s forecast information from the manufacturer’s wholesale price, so their pricing strategy will be affected by both their own forecast and the manufacturer’s forecast.

Therefore, the optimal profit of each entity in the supply chain can be obtained.

\[
\pi^N_m = \frac{(4a_m + 2ta_m - (2 + t)a_m - c(2 - t - r^2))^2}{4(4 - r^2)^3}, \quad \pi^N_o = \frac{(4a_m + 2ta_m - (2 + t)a_m - c(2 - t - r^2))^2}{4(4 - r^2)^3},
\]

\[
\pi^N_w = \frac{(a_m - c(1 - t))(a_m + a_m - a_m - c(1 - t))}{2(2 + t)(1 - t)} - \sigma_m ((s + h)L(r) + hr) , \quad \text{where} \quad r = \frac{1}{4 - 2t} \Phi^{-1}\left(\frac{s}{s + h}\right),
\]

\[
L(x) = \int_x^\infty (z - x)d\Phi(z).
\]

3.2. Full information sharing

In full information sharing mode, the manufacturer and the two retailers share demand forecast information with each other. All entities in the supply chain make decisions based on the predicted values of \(f_m, f_s\) and \(f_o\); the retailer can also make decisions based on the manufacturer’s wholesale price information. We can get the profit function of each main entity of the supply chain under complete information sharing as follows:

\[
\pi^F_r = (p_r - w_r)(E[a \mid f_s, f_o, f_m, w_o] - p_o + tp_o) \quad \pi^F_m = (p_m - w_m)(E[a \mid f_s, f_o, f_m, w_o] - p_o + tp_o) \quad \pi^F_o = (p_o - w_o)(E[a \mid f_s, f_o, f_m, w_o] - p_o + tp_o)
\]

\[
\pi^F_w = (w_o - c)(E[a \mid f_s, f_o, f_m] - E[p_o \mid f_s, f_o, f_m] + tE[p_o \mid f_s, f_o, f_m]) + \int_{\pi^F_w}^{\infty} (a + tp_o - p_o)(w_o - c)f(a)da
\]

\[
- h \int_{\pi^F_w}^{\infty} (Q_o - (a + tp_o - p_o))f(a)da - \int_{\pi^F_w}^{\infty} (a + tp_o - p_o - Q_o)f(a)da
\]

We can also get the optimal decision of the supply chain in full information sharing mode, as shown in Proposition 2.
**Proposition 2** Under full information sharing, the optimal strategy of the supply chain is:

\[
\begin{align*}
\epsilon_{s}^{*} &= \frac{a_{om} + c}{2 - 2t}, \\
Q_{s}^{*} &= \frac{a_{om} + \sigma_{aim} \Phi^{-1} \left( \frac{s}{s + h} \right) - c(1 - t)}{4 - 2t}, \\
P_{s}^{*} &= \frac{(3 - 2t) a_{om} + c - ct}{4 - 6t + 2t^2}.
\end{align*}
\]

According to Proposition 2, the optimal profit of each entity in the supply chain can be obtained.

\[
\begin{align*}
\pi_{s}^{*} &= \frac{(a_{om} - c(1 - t))^2}{4(2 - t)^2}, \\
\pi_{m}^{*} &= \frac{(a_{om} - c(1 - t))^2}{2(2 - t)(1 - t)} - \sigma_{aim} \left( (s + h) L(r) + hr \right).
\end{align*}
\]

### 3.3. Information sharing with the MTS retailer or MTO retailer

In this case, the manufacturer only shares information with the MTS retailer or MTO retailer. The manufacturer decides the wholesale price based on the predicted value \( f_{m} \) and \( f_{i} \), where \( i = 1 \) stands for MTS retailer and \( i = 2 \) for MTO retailer. Then the MTS retailer(MTO retailer) decides the retail price based on the wholesale price, and the MTO retailer(MTS retailer) decides the retail price based on the forecast value \( F_{o} \) \(( F_{i} \) and wholesale price information. The profit function of each main entity of the supply chain is as follows:

\[
\begin{align*}
\pi_{s}^{*} &= (p_{s} - w_{s})(E[a | f_{s}, w_{s}, f_{m}, l_{im}, w_{i}]) - p_{s} + t p_{s}, \\
\pi_{m}^{*} &= (p_{m} - w_{m})(E[a | f_{m}, w_{m}, f_{im}, l_{im}, w_{i}]) - p_{m} + t p_{m},
\end{align*}
\]

\[
\begin{align*}
\pi_{i}^{*} &= (w_{i} - c)(E[a | f_{i}, w_{i}, f_{im}, l_{im}, w_{i}]) - E[a | f_{i}, w_{i}, f_{im}, l_{im}, w_{i}] + \int_{0}^{c}(a + t p_{o} - p_{i})(w_{i} - c)f(a) da \\
&= \frac{h}{Q_{o} - p_{o} + p_{i}} \int_{0}^{\infty} (Q_{i} - (a + t p_{o} - p_{i})) f(a) da.
\end{align*}
\]

The sequence of events still is, under the information forecasting and sharing, the manufacturer first decides the wholesale price and production quantity, and then the two retailers decide their retail prices individually. Through calculation, the optimal decision of the supply chain under the profit maximization can be obtained, as shown in Proposition 3.

**Proposition 3** In information sharing between the manufacturer and the MTS retailer, the optimal decision of the supply chain is:

\[
\begin{align*}
\epsilon_{s}^{*} &= \frac{a_{om} + c - ct}{2 - 2t}, \\
Q_{s}^{*} &= \frac{a_{om} + \sigma_{aim} \Phi^{-1} \left( \frac{s}{s + h} \right) - c(1 - t)}{2(1 - t)(4 - t^2)}, \\
P_{s}^{*} &= \frac{3(2 - t) a_{om} + (1 - t)(2 t a_{om} + c(2 + t))}{2(1 - t)(4 - t^2)}, \\
P_{s}^{*} &= \frac{(2 + (3 - 2t) a_{om} + (1 - t)(4 t a_{om} + c(2 + t))}{2(1 - t)(4 - t^2)}.
\end{align*}
\]

According to Proposition 3, we can get the profits of manufacturers and retailers as follows

\[
\begin{align*}
\pi_{s}^{*} &= \frac{(2 - t) a_{om} + 2 t a_{om} - c(2 - t t^2))^2}{4(4 - t^2)^2}, \\
\pi_{m}^{*} &= \frac{(4 a_{om} - 2 - t) a_{om} - c(2 - t t^2))^2}{4(4 - t^2)^2}, \\
\pi_{s}^{*} &= \frac{(a_{om} - c(1 - t))(a_{om} - c(1 - t))}{2(2 - t)(1 - t)} - \sigma_{aim} \left( (s + h) L(r) + hr \right).}
\]

\[
\pi_{m}^{*} = \frac{4(4 - t^2)^2}{4(4 - t^2)^2}.
\]
4. The value of information sharing

To further analyze the value of information sharing, we compare the situation of no information sharing with full information sharing, sharing with the MTS retailer, and sharing with the MTO retailer, then we obtain Results 1, 2, and 3.

Result 1: Full information sharing strategy cannot benefit all entities.

To benefit the retailer, then $a_m + a_{som} > 2\max\{a_{som}, a_m\}$; to benefit the manufacturer, then $2a_{som} > a_m + a_{sm}$. Result 1 shows that the full information sharing strategy is not beneficial to all entities. This is because satisfying the conditions that are beneficial to the manufacturer ($a_m < \min\{f_s, f_m\}$) and these to the two retailers ($a_m > \max\{f_s, f_m\}$) are mutually exclusive under complete information sharing. When $a_m < \min\{f_s, f_m\}$, it indicates that the manufacturer’s market demand forecast is lower than the retailer’s expectations without information sharing, so lower wholesale prices will be set, and information sharing will increase the manufacturer’s expectations of the market, thereby increasing the wholesale price and its profits while reducing the retailers’ profits. However, when $a_m > \max\{f_s, f_m\}$, it indicates that under no information sharing, the manufacturer has a higher expectation of demand and set a higher wholesale price, forcing retailers to set higher sales prices and leading to a decline in demand, which is unfavorable to both the manufacturer and retailer. Through information sharing, the manufacturer will lower the wholesale price to make the retailer profit, while the retailer will increase its demand forecast that prompts to increase the retail price, resulting in a decline in demand, which is not good for the manufacturer. In short, when the information forecasts of the manufacturer and retailer are inconsistent, information sharing will prompt them to change their pricing decisions, but it will always harm the profit of one party.

Result 2: If $E[f_s | f_m, f_m] \leq f_s \leq E[f_s | f_m]$, then sharing information with the MTS retailer is beneficial to all entities.

Result 2 shows that when the MTS retailer’s expectation of demand ($f_s$) is higher than the demand expectation ($E[f_s | f_m, f_m]$) under the full information sharing and lower than the demand forecast ($E[f_s | f_m]$) under the information sharing only with the manufacturer, the manufacturer and the MTS retailer share information, which are favorable to all entities. This means that the manufacturer passes the forecast information of high demand to the MTS retailer through the wholesale price, making the MTS retailer have a higher expectation of demand after sharing the information with the manufacturer ($f_s \leq E[f_s | f_m]$), at this time the manufacturer will set a high wholesale price, the MTS retailer also sets higher retail price due to high demand, both of which can profit from increasing product sales prices. And the condition $E[f_s | f_m, f_m] \leq f_s$ indicates that the demand forecast of the MTO retailer is extremely low, resulting in that complete information sharing reversely reduces the supply chain’s demand forecast as a whole. Therefore, if the manufacturer only shares information with MTS, MTO can learn from the manufacturer’s wholesale price to obtain high demand information, thereby increasing its own retail price and increasing profit. So when the MTO demand forecast is low, sharing information between the manufacturer and the MTS retailer can improve the profits of all entities.

Result 3: If $E[f_s | f_m, f_m] \leq f_s \leq E[f_s | f_m]$, then sharing information with the MTO retailer is beneficial to all entities.
Like Result 2, if the MTO retailer’s demand forecast becomes higher after sharing the information with the manufacturer, both can obtain higher profits by increasing the wholesale price and the retail price. When the MTS retailer's demand forecast is very low, that is, the MTS retailer's expected demand after fully sharing the information is lower than that under no information sharing. The manufacturer can only share the information with the MTO retailer, which can send a signal of high demand to the MTS retailer, prompting it to increase the retail price, thereby obtaining more profits. In summary, both Results 2 and 3 show that when the manufacturer increases the demand expectations of one retailer when sharing information, and when the other retailer's demand expectation is very low, the manufacturer can share information with the first retailer to improve the income of all entities in the supply chain.

5. Conclusions
In the context of big data, various entities in the supply chain can obtain forecasts of market demand through their own channels and methods, and share the forecast information through big data technology. But in the hybrid MTO/MTS supply chain, it is uncertain whether and how sharing demand can create value. Therefore, this article considers a supply chain composed of one manufacturer and two retailers (MTS and MTO), and studies the optimal decisions of a hybrid MTO/MTS supply chain and the value of sharing demand information. The result shows that the supplier’s pricing and production volume depend on the supplier’s final forecast of demand. The variance of the posterior distribution will cause the MTS production volume to deviate from expectations, and the direction of deviation depends on the cost of oversupply and undersupply.

Our analysis of the value of information shows that full information sharing strategy cannot benefit all entities. This may be because full information sharing will lead the manufacturer to occupy an absolutely advantageous position in the supply chain. By setting wholesale prices to gain more profits, it reversely reduces the retailers' profits. Only when the manufacturer’s information sharing can increase the MTO (MTS) retailer’s demand expectations, and the MTS (MTO) retailer’s demand expectation is so low that the demand expectations under complete information sharing are lower than those without information sharing, there will be a wholesale price contract, allowing the manufacturer to share information with the MTO (MTS) retailer to improve the profits of all entities.

Our study assumes that shared demand information is true, and false information is not considered. In reality, there may be situations in which demand is exaggerated in order to obtain a lower wholesale price. In the future, we can further discuss the sharing and contract design with the existence of false information motivation.

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