# Research on VMI supply chain coordination based on revenue sharing contract

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**Abstract:** Taking VMI system composed of retailer and supplier as the research object, taking supply chain coordination as the optimization goal, considering product The revenue sharing model after the surplus value subsidy is introduced demand uncertainty and no shortage of goods, a revenue sharing model under stackelberg game is constructed, and a price subsidy strategy is introduced. Finally, a numerical example is given to show that the introduction of price subsidy strategy can effectively realize the coordination of supply chain.

## 1. Introduction

With the integration of global manufacturing and economy, the competition among enterprises has gradually turned into the competition between chains and networks. To judge whether an enterprise is competitive or not, we should not only see its own strength, but also its ability to integrate resources. Rapid response ability and efficient customer response ability have become the decisive factors for the survival and development of enterprises. Through the cooperation among supply chain enterprises, the supply chain flexibility can be improved, the consumer demand can be effectively satisfied, and the bullwhip effect of the supply chain can be reduced. In the traditional system, the marketing and production organizations in the vertical supply chain are managed completely separately, and the supply chain members make separate manufacturing and retail plans [1].In this inventory management mode, the buyer and the supplier have their own inventory, inventory objectives and control strategies, and lack of information communication with each other, each monopolizes the inventory information, so the distortion and delay of demand information is inevitable. And of lack of information communication between each other, causing a demand information distortion and lag time, making the inventory demand information in supply chain from downstream to upstream of the transfer process has been gradually exaggerated, produce the "bullwhip effect", thus increasing the overall supply chain inventory levels and weaken the whole competition strength of the supply chain. The goal of supply chain management is to provide the maximum customer value with the minimum cost through the close cooperation among trading partners, which requires that the activities of enterprises in each link of the supply chain should be carried out simultaneously. Inventory management functions should also be integrated as needed, rather than Shared. Obviously, the traditional inventory control methods can’t meet the needs of supply chain management. Vendor Managed Inventory (VMI) refers to that the supplier monitors the Inventory level of users and periodically carries out replenishment decisions including order quantity, shipment and related operations [2]. VMI reflects the idea of supply chain integration, is conducive to the organic integration of logistics, capital flow and information flow, and plays a positive role in promoting information sharing, bullwhip effect and improving the level of supply chain cooperation [3].

Moreover, the global consideration based on cooperation and trust can also reduce the overall inventory level of the supply chain. Its advantages are becoming more and more prominent in the fierce competitive environment, and many large companies at home and abroad are beginning to realize the importance of reducing the supply chain inventory. In addition, he grants the supplier full control and management of inventory. Vendor-managed inventory provides transparency of sales data and inventory levels to suppliers [4]. Vendor-managed inventory has broken the traditional mode of separate inventory management. In order to obtain the lowest cost for both retailers and suppliers, the supplier manages the retailer's inventory under a common agreement, and continuously monitors the implementation of the agreement and modifies the content of the agreement.

VMI strategy can effectively reduce the supply chain cost, improve the supply chain flexibility, so as to improve the overall competitiveness of the supply chain. However, in the traditional model, since suppliers bear inventory management and related costs, the effect of revenue increase is not as obvious as that of retailers who directly enjoy the cost reduction. This mode of cooperation in which benefits and responsibilities are not unified is unstable [5]. Suppliers may also increase their own management and processing costs by bearing the inventory costs of customers. How to ensure the mutual benefit of supply chain members is the power source for the implementation of VMI, and the use of revenue sharing mechanism to coordinate the supply chain under VMI has become one of the research hotspots [6].

## 2. Model Structure

This paper considers a secondary supply chain consisting of a risk-neutral supplier and a risk-neutral retailer. It is assumed that the product is not allowed to be out of stock, that market demand is uncertain, and that it obeys a normal distribution with an average constant, that is, $d \sim N(\mu, \sigma^2)$.Because random demand is always greater than or equal to 0, we're going to assume a big number is μ, a small number is σ.In a VMI environment, the vendor manages inventory and assumes risk, taking into account the vendor's carrying costs. The retailer is responsible for the sale, regardless of the retailer's selling expenses. Each variable is defined as follows:

p Retail price
c Unit production cost of a product
d Product demand
h The unit carrying cost of the product
e The wholesale price of the product
q Inventory of goods
F (x) Cumulative distribution function of demand
F (x) The probability density function of demand
$\Phi\ (x)$ The cumulative distribution function of the standard normal distribution
ϕ (x) The probabililty density function of the standard normal distribution

Assuming that both suppliers and retailers are rational, then p>e>c>h. In the state of traditional integrated supply chain, inventory is managed by the supplier, and the profit of the supplier can be expressed as:

$$R_s(q) = e * Emin(q, d) - h \int_0^q F(x)dx - cq \quad (1)$$

The retailer's profit can be expressed as:

$$R_r(q) = (p - e) * [q - \int_0^q F(x)dx] \quad (2)$$

The total profit of the supply chain is:

$$R_t(q) = (p - c)q - (p + h) \int_0^q F(x)dx \quad (3)$$

Take the derivative of equation (3) and set the derivative to zero, then we can get: $\mathrm{F(x)} = \frac{p-c}{p+h}$

Then the optimal inventory replenishment quantity is:

$$q_0 = \mu + z_0\sigma \quad (4)$$

Which: $\Phi(z_0) = \frac{p-c}{p+h}$

The optimal profit of the supply chain is:

$$R_{t_0}(q_0) = (p - c)q_0 - (p + h)[\int_0^{q_0} F(x)dx] \quad (5)$$

## 2.1 A revenue sharing model based on stackelberg game

In general, retailers dominate the implementation of VMI. Therefore, the model can be regarded as a stackelberg master-slave game. The retailer first proposes a revenue sharing factor $\lambda$.For each product sold at a retail price of p, the retailer receives $\lambda$q,in order for suppliers to be sufficiently to participate, then $\mathrm{c}+\mathrm{h}<(1-\mathrm{r})\mathrm{p}$, which $\mathrm{r}<\frac{p-c-h}{p}$. The supplier will decide whether to accept or not based on this revenue and determine the quantity of inventory replenishment. Then the expected profit of the supplier can be expressed as: $R_s(\lambda)=(1-\lambda)p[q-\int_0^q F(x)dx]-cq-h\int_0^q F(x)dx$

The derivative of this expression is obtained: $\frac{\partial R_s(\lambda)}{\partial q}=(1-\lambda)p[1-F(q)]-c-hF(q)$

If the derivative is zero, the optimal inventory is obtained:

$$q_1=\mu+z_1\sigma \tag{6}$$

$$\text{which } \Phi(z_1)=\frac{(1-\lambda)p-c}{(1-\lambda)p+h} \tag{7}$$

The expected profit of the supplier is: $R_s(\lambda)=(1-\lambda)p[q_1-\int_0^{q_1} F(x)dx]-cq_1-h\int_0^{q_1} F(x)dx$

The derivative of equation (7) is obtained: $\frac{\partial z_1}{\partial \lambda}=-\frac{c+h}{(1-\lambda)^2 p\phi(z_1)}<0$

That is, the optimal inventory supply decreases with the increase of $\lambda$, when $\lambda=0$.

The inventory selected by the supplier reaches the maximum, in this moment $q_1=q_0$.

Although the supply chain has the largest overall revenue, the retailer's revenue is zero. Retailers should optimize their profits according to the choice of suppliers: $R_r(\lambda)=\lambda p[q_1-\int_0^{q_1} F(x)dx]$

Take the derivative of the above equation to get the optimal solution $\lambda^*$ and the retailer's profit $R_r{}^*(\lambda^*)$,At this time, the optimal inventory is:

$$q_1{}^*=\mu+z_1{}^*\sigma \tag{8}$$

while $\Phi(z_1{}^*)=\frac{(1-\lambda^*)p-c}{(1-\lambda^*)p+h}$.The profit of the supplier is:

$$R_s{}^*(\lambda)=(1-\lambda^*)p[q_1{}^*-\int_0^{q_1{}^*} F(x)dx]-cq_1{}^*-h\int_0^{q_1{}^*} F(x)dx \tag{9}$$

The derivative of equation (9) is obtained: $\frac{\partial R_s(\lambda^*)}{\partial \lambda^*}=-p[q_1{}^*-\int_0^{q_1{}^*} F(x)dx]<0$

That is, the profit of the supplier decreases with the increase of the sharing coefficient, because the optimal inventory supply quantity selected by the supplier also decreases with the increase of the sharing coefficient, and the total profit of the supply chain also decreases with the increase of the sharing coefficient. In order to achieve the coordination of the supply chain, that is, the overall profit of the supply chain is optimal, the sharing coefficient $\lambda^*$ is zero, which is impossible in the game. Therefore, it is necessary to introduce new contracts to coordinate the supply chain.

## 2.2 The revenue sharing model after the surplus value subsidy is introduced

This section introduces surplus value subsidy on the premise of revenue sharing coefficient, that is, the retailer subsidizes the cost of one unit $\theta$ to the supplier for the unsold products, which $\theta<(1-\lambda)\mathrm{p}$, That is, the residual subsidy is less than the Shared benefit. At this point, the profit function of the supplier is:

$$R_s(\theta,\lambda)=(1-\lambda)p[q-\int_0^q F(x)dx]-cq-h\int_0^q F(x)dx+\theta\int_0^q F(x)dx \tag{10}$$

The derivative of equation (10) is obtained: $\frac{\partial R_s(\theta,\lambda)}{\partial q}=(1-\lambda)p[1-F(q)]-hF(q)+\theta F(q)-c$

If the derivative is zero, then The optimal inventory is:

$$q_2=\mu+z_2\sigma \tag{11}$$

Which:$\Phi(z_2) = \frac{(1-\lambda)p-c}{(1-\lambda)p+h-\theta}$

In order to maximize the overall profit of the supply chain, the supply chain achieves coordination, then $q_2 = q_0$, which is $\frac{(1-\lambda)p-c}{(1-\lambda)p+h-\theta} = \frac{p-c}{p+h}$, $\theta = \frac{p\lambda(h+c)}{p-c}$

The profit function of the supplier is:$R_s(\theta,\lambda) = (1-\lambda)p[q_0 - \int_0^{q_0} F(x)dx] - cq_0 - h\int_0^{q_0} F(x)dx + \frac{p\lambda(h+c)}{p-c}\int_0^{q_0} F(x)dx$

The profit function of the retailer is: $R_r = \lambda p[q_0 - \int_0^{q_0} F(x)dx] - \frac{p\lambda(h+c)}{p-c}\int_0^{q_0} F(x)dx$

## 3. Analysis and Discussion

We assume that $\mu = 200, \sigma = 20, p = 60, c = 10, h = 5, e = 30$. Which can be obtained in the traditional VMI mode that $z_0 = 0.74$, the optimal stock replenishment $q_0 = 214.8$,the optimal expected profit $R_{t_0}(q_0)$ =9548.55, the value range of the revenue sharing coefficient is $\lambda \in [0,0.75]$, Figure 1 shows the impact of the change of the revenue sharing coefficient on the members of the supply chain. In order to maximize their profits, the retailer would chooses a revenue share that benefits them, in this situation $\lambda^* = 0.75$,the retailer's profit is $R_r = 8640$,the supplier's profit is $R_s = 840$,the total profit is $R_t = 9480$, In such a competitive state, the retailer's choice of revenue share makes the overall profit of the supply chain decrease by $\Delta = 68.55$

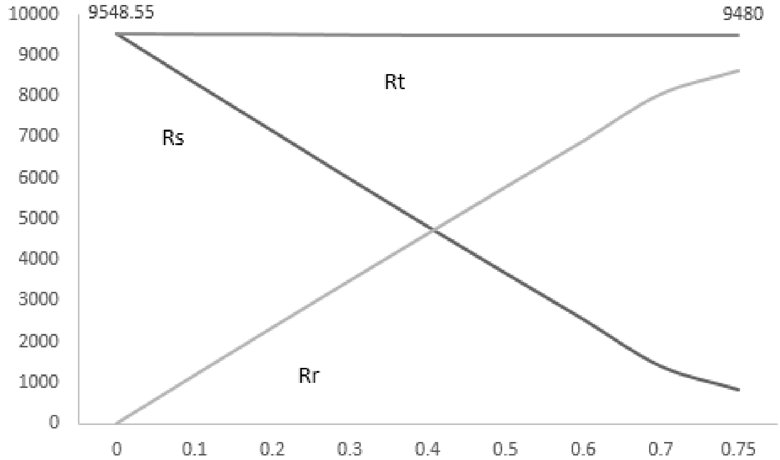


Figure 1. profit changes of supply chain members under the revenue sharing contract

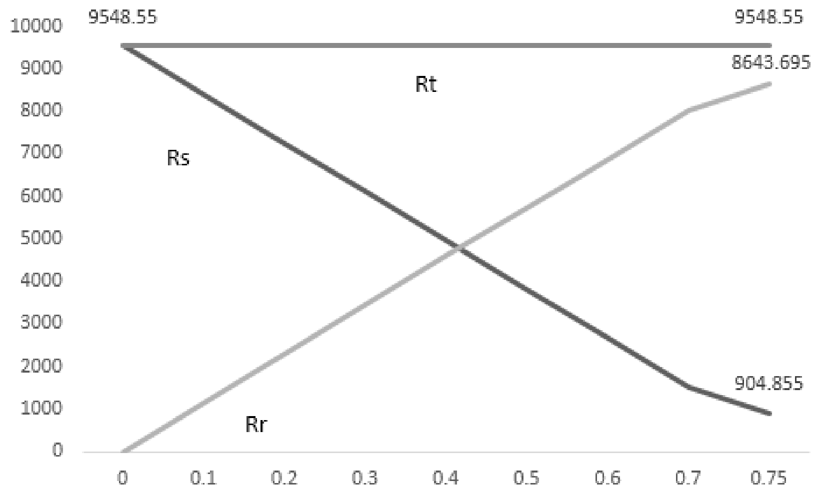


Figure 2. profit changes of supply chain members under the revenue sharing contract with residual value subsidy

The above simple contract model will enable retailers to choose a larger share of revenue, thus reducing the overall profit of the supply chain.After the introduction of surplus value subsidy, the impact of the change of revenue sharing coefficient on the members of the supply chain can be seen from figure 2. The retailer subsidizes the cost of one unit θ to the supplier for the unsold products, to ensure the coordination of the supply chain, the subsidizes the residual value $\theta = \frac{p\lambda(h+c)}{p-c}$, From the analysis in the previous part, it can be concluded that $\lambda^* = 0.75$ is the optimal revenue share selected by the retailer, $\theta = 13.5$, the retailer's optimal expected profit $R_r = 8643.695$, the supplier's optimal expected profit $R_s = 904.855$,the total profit $R_t = 9548.55$, Figure 2 also verifies that the profit of suppliers decreases with the increase of sharing coefficient, while the profit of retailers increases with the increase of sharing coefficient.In this case, the profits of both retailers and suppliers have increased, and the enthusiasm of both suppliers and retailers has been mobilized. In this case, the supply chain has been coordinated, and this contract model has greater practical application value.

## 4. Conclusion

In this paper, the overall profit models of suppliers, retailers and supply chains under traditional VMI are first obtained.Then, the revenue sharing model of stackelberg game is obtained, and the conclusion is that this game cannot reach the coordination of supply chain.On this basis, the surplus value subsidy coefficient is introduced.Finally, a case study shows that the surplus value subsidy can coordinate the supply chain.This paper also has some shortcomings, such as only considering the case of single supplier but retailer.Issues worthy of further study in the future include :(1) consideration of multiple retailers;(2) considering the situation of permitted shortage, introduce the cost of shortage;Consider the supplier's cost of sales.

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