Option Contract for a Retailer-Led Supply Chain with Uncertain Demand and Selling Price

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Abstract. This paper considers a two-echelon (supplier & retailer) supply chain under random market needs, where the retailer has the predominance in the supply chain, and the selling price is completely hinge on market demand. We employ an option contract to coordinate the supply chain, and discuss the impact of the demand sensitivity on the optimal order/assembly quantity and contact parameters for the purpose of improving supply chain performance. The conclusion of this paper is the supply chain can be coordinated through option contract, and the option premium is inversely correlated with the exercise price under supply chain coordiantion. Given the option price is constant under supply chain coordination, the strike price increases with the demand sensitivity .

Keywords: Option contract; supply chain coordination; stochastic demand; uncertain selling price

1 INTRODUCTION

Nowadays, the market environment faced by enterprises has undergone great changes, where the complexities and uncertainties of market are increasing constantly. As a result, more and more businesses realize that they can get more potential profits and enhance their competitiveness by coordinating operation decisions among enterprises or supply chains. Up to now, there is a lot of work done on supply chain coordination, involving a variety of contracts [1-2], and option contract is one of the most important ones [3]. For instance, Arani et al. [4] coordinated a retailer–producer supply chain by combining an choice system and a revenue-sharing system. Biswas and Avittathur [5] discovered that it was possible to coordinate single-supplier-multi-buyer supply chain networks through option contracts and eliminate channel conflicts caused by synchronous price and stock competition.

In the meantime, the market relation between supply and demand changes gradually from seller-led market to buyer-led market in recent years. Some large-scale retail enterprises such as Wal-mart and large e-commerce enterprises such as Jingdong gradually occupy the dominant positions in supply chains, and they are also becoming the framers of supply chain contracts. Under this circumstances, it is intriguing to explore the coordination issue in supply chain dominated by retailers with option contract.

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Huang et al. [6-7] proved that option contract is applicative in retailer-led supply chains with risk-aversion or loss-aversion under stochastic demand. Fan et al. [8] considered an option contract supply chain with a supplier and a risk-averse who are not willing to take risks, in which the buyer acts as the leader. Chen et al. [9] found that a supply chain dominated by retailers with random demand and random yield can also be coordinated through option contract. Nevertheless, all the aforementioned papers assumed that the selling price is exogenous and constant.

In reality, not only market demand but also selling price is uncertain, and there is a correlation between them. Generally speaking, when market demand is relatively stable, the selling price generally keeps stable. When market demand is weak, selling price will be depressed to some extent. And when market demand is strong, selling price tend to be bid up to a certain degree [10]. As a result, this paper further investigates the channel coordination issue in a supply chain dominated by retailers with option contract under stochastic demand and selling price, and discusses how the demand sensitivity affects the optimal production quantity and contract parameters.

2 PROBLEM DESCRIPTION AND HYPOTHESIS

Consider a supply chain consisting of a single retailer and a single supplier, where the supplier yields a product with a short lifecycle and a long lead time, and the retailer acts as a dominant holder in the supply chain. The market demand faced by the retailer D is a stochastic variable. The selling price is exogenous but dependent on market demand. Following the literature [7], we suppose that the selling price is a monotone increasing function of market demand, namely, $p = g(D)$. Let c be the cost of manufacture and w be wholesale price. For any unmet demand, the retailer endures the shortage cost s. Since the product has a very short lifetime and is fast-depreciating, this paper did not considered the salvage value of product in order to simplify the model. In addition, this paper used subscript m represent the supplier, r represent the retailer, and s represent the complete supply chain.

3 MODEL DEVELOPMENT

3.1 Benchmark: Wholesale Price Contract

We first study the centralized case. In a central system, the supplier is made an agreement with the retailer as a team. The objective of the team is to seek an optimal order/production quantity to maximize the anticipated profit of the whole supply chain, which expressed as

$$\max_{q_s} \pi_s(q_s)$$
$$st.\quad \pi_s(q_s) = p\min\{q_s, D\} - s\max\{D - q_s, 0\} - cq_s \tag{1}$$

Where q_s is the order/production quantity of the team. And the whole supply chain's anticipated profit is

$$\pi_s(q_s)=q_s\int_{q_s}^{\infty} g(x)f(x)dx+\int_0^{q_s} xg(x)f(x)dx-s\int_{q_s}^{\infty}(x-q_s)f(x)dx-cq_s \qquad (2)$$

Since $\partial^2\pi_s(q_s)/\partial q_s^2<0$, $\pi_s(q_s)$ is a concave function of q_s.

Let $\partial\pi_s(q_s)/\partial q_s=0$. We have $\int_{q_s}^{\infty}(g(x)+s)f(x)dx=c$.

Further, let $H(y)=\int_y^{\infty}(g(x)+s)f(x)dx$, we can find that $H(y)$ is a decreasing function of y since $\partial H(y)/\partial y=-(g(x)+s)f(x)<0$. Thus, the optimal order/production quantity of the team is $q_s^*=H^{-1}(c)$

Next, we use the decentralized system of wholesale price contract as another benchmark. In this case, the target of the retailer is to decide an optimal order quantity to maximize its anticipated profit, which is expressed as

$$\begin{aligned}&\max_{q_s} \pi_{wr}(q_{wr})\\ &st.\quad \pi_{wr}(q_{wr})=p\min\{q_{wr},D\}-s\max\{D-q_{wr},0\}-wq_{wr}\end{aligned} \qquad (3)$$

Where q_{wr} is the order quantity. The retailer's anticipated profit of the retailer in the decentralized system is

$$\pi_{wr}(q_{wr})=q_{wr}\int_{q_{wr}}^{\infty} g(x)f(x)dx+\int_0^{q_{wr}} xg(x)f(x)dx-sq_{wr}\int_{q_{wr}}^{\infty}(x-q_s)f(x)dx-wq_{wr} \qquad (4)$$

Similar to the analysis process in the centralized decision, the optimal order quantity of the retailer can be obtained by $q_{wr}^*=H^{-1}(w)$. The supplier produces to order and its anticipated profit is $(w-c)q_{wr}^*$. Therefore, the anticipated profit of the entire supply chain is

$$\pi_s(q_{wr}^*)=q_{wr}^*\int_{q_{wr}^*}^{\infty} g(x)f(x)dx+\int_0^{q_{wr}^*} xg(x)f(x)dx-s\int_{q_{wr}^*}^{\infty}(x-q_{wr}^*)f(x)dx-cq_{wr}^* \qquad (5)$$

As mentioned earlier, $H(y)$ is a decreasing function of y, thus we get $q_s^*>q_{wr}^*$ since $w>c$. Consequently, the entire supply chain in the decentralized system has less anticipated profit than that in the centralized system, i.e., $\pi_s(q_{wr}^*)<\pi_s(q_s^*)$. This implies that the supply chain can be not coordinated under the wholesale price contract.

3.2 Option Contract

In this section, option contract is introduced to discuss supply chain coordination. Under option contract, the retailer, as a dominant holder of the Stackelberg game, provides an option contract (o,e) to the supplier before the selling season begins. The supplier determines the production quantity based on the forecast of market demand and the option contract provided by the retailer, which is different from the wholesale price contract. Under this mechanism, the supplier assumes the inventory, and the problem of the supplier is expressed as

$$\begin{aligned} &\max_{q_{om}} \pi_{om}(q_{om}) \\ &\text{st. } \pi_{om}(q_{om}) = e\min\{q_{om}, D\} + (o-c)q_{om} \end{aligned} \tag{6}$$

Where q_{om} is the production quantity of the supplier. The anticipated profit of the supplier is

$$\pi_{om}(q_{om}) = (o+e-c)q_{om} - e\int_0^{q_{om}} F(x)dx \tag{7}$$

Since $\partial^2\pi_{om}(q_{om})/\partial q_{om}^2 = -ef(q_{om}) < 0$,we get that $\pi_{om}(q_{om})$ is concave in q_{om}. Let $\partial\pi_{om}(q_{om})/\partial q_{om} = 0$, the optimal production quantity is $q_{om}^* = F^{-1}(o+e-c/e)$.

Accordingly, the anticipated profit of the retailer is

$$\pi_{or}(q_{om}^*) = (p-o-e+s)q_{om}^* - s\mu - (p-e+s)\int_0^{q_{om}^*} F(x)dx \tag{8}$$

As the dominant force of the supply chain, the retailer has motivation and opportunity to induce the production quantity of the supplier by formulating reasonable option contracts to coordinate the supply chain. Let $q_{om}^* = q_s^*$, we get $H^{-1}(c) = F^{-1}(o+e-c/e)$. Then, we get $o = (F(H^{-1}(c)) - 1)e + c$.

Consequently, if and only if the option contract satisfies $o = (F(H^{-1}(c)) - 1)e + c$. the supply chain in the decentralized system under option contract has equal anticipated profit to that in the centralized system. In other words, the coordination of supply chain can be carried out by option contract when $o = (F(H^{-1}(c)) - 1)e + c$. Additionally, since $F(x) \le 1$, we have $F(H^{-1}(c)) - 1 < 0$. This implies that there is a negative correlation between option price and exercise price under coordination with option contract.

4 NUMERIC ANALYSIS

In this paper, we suppose random demand D obeys uniform distribution with $F(x) \sim \mathrm{U}(0,200)$, the selling price satisfies $p = 70 + aD$. Unless otherwise specified, the other parameters are: $a = 0.1$, $c = 20$, $w = 40$, $s = 10$.

Through calculation, the optimal order volume of the retailer in the decentralized system with the wholesale price contract is 116.5, the anticipated profit of the retailer and the supplier is 2804 and 2330 respectively. Accordingly, the total anticipated profit is 5134. In centralized system, the optimal order/production volume of the team is 159.2, and the total anticipated profit is 5610. It shows the uncooperativeness of supply chain under the wholesale price contract.

What is noteworthy is that the price sensitivity coefficient directly affects the decision-making behaviours of the supply chain members. In Table 1, the greater the price sensitivity coefficient, the greater the optimal order/production quantity both in the decentralized system and in the centralized system. The higher the price sensitivity coefficient, the larger the retailer orders.

Table 1. The effect of the price sensitivity coefficient on the order/production quantity.

a	q_{wr}^*	q_s^*
0.10	116.5	159.2
0.15	123.3	162.7
0.20	129.2	165.7
0.25	134.3	168.3
0.30	138.9	170.5
0.35	142.9	172.5
0.40	146.4	174.2

As shown in Figure 1, the larger the option price, the smaller the exercise price. With option price given, the higher the price sensitivity coefficient, the higher the exercise price under supply chain coordination. This can be interpreted as the higher the price sensitivity coefficient, the higher the market risk borne by the supplier under the option contract, and the retailer needs to offer a higher exercise price in order to make up for the risk loss borne by the supplier.

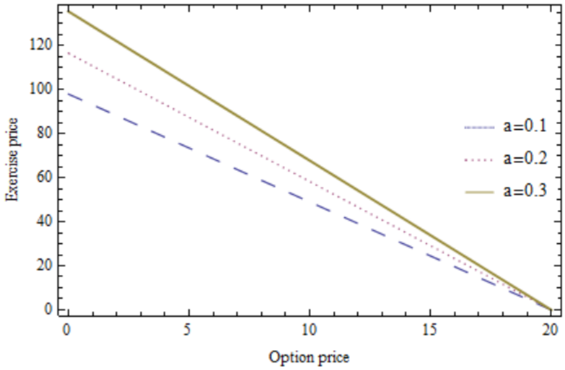

Fig. 1. The relationship between option price and exercise price under coordination.

Under supply chain coordination, the anticipated profit of the supplier is a decreasing function, whereas the anticipated profit of retailer is an increasing function. When the option price satisfies $11.0 \leq o \leq 12.5$, both the supplier and the retailer are willing to accept the option contract, and the anticipated profits of both are not lower than that under the wholesale price contract. Under such conditions, the option contract can be implemented smoothly.

5 CONCLUSIONS

This paper studies a two-echelon (supplier & retailer) under stochastic demand, in which the retailer acts as leading force in the supply chain, and the selling price is dicey and reliant on market demand. An option contract is introduced to research the supply chain coordination problem. In addition, we researched how the demand sensitivity affects the optimal order/production quantity and contract parameters. We find that the wholesale price contract cannot coordinate the supply chain, while the supply chain can be coordinated by option contract. Under supply chain coordination, there is a inverse correlation between the option price and the exercise price. If the selling price is more sensitive to market demand, the order/production volume will become larger. Moreover, the higher the demand sensitivity, the higher the exercise price under coordination. Under supply chain coordination, the anticipated profit of suppliers decreases under the option price, in the meantime, the anticipated profit of retailers increases under the option price. The results can provide decision-making and strategy formulation for operation management and coordination of retailer-led supply chains.

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