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Modeling of Capacity Reservation and Supplier Selection Based on Option Contract

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ABSTRACT

A key issue for manufacturing firms is planning for outsourced components. In this research, we have considered a manufacturer in a Make-to-Order production environment who has to outsource a special component from a set of suppliers. One selling season is considered and the manufacturer faces uncertain demand during the selling season. A good strategy for the manufacturer to balance both holding and lost sale costs is to initiate capacity reservation contracts with his suppliers. Thus, unlike the previous researches we have presented a mathematical model based on option mechanism that will help the manufacturer to select appropriate suppliers and order allocation, simultaneously. The considered option mechanism has a two part contract fee structure (option price and exercise price) and it is at the foundation of practical contracts used by different industries. A numerical example is used to illustrate the model and to investigate how option mechanism improves manufacturer's expected profit in comparison with the situation without applying the option mechanism.

1. Introduction

Nowadays, one important problems of manufacturing firms is deciding about suppliers selection and placing order to them. In this research, it is supposed that a manufacturer outsources his required component before realization of customer's demand and produces final product according to customer's preferences, like in make-to-order (MTO) environments. Like many industries (Apparel industries, for instance), the manufacturer is faced with long outsourcing lead time, short selling season, and high demand uncertainty. When the manufacturer makes an investment decision under uncertainty of demand, he might under or over-invest in orders. This is a major concern for a manufacturer since it directly leads to loss of sales or holding extra inventory.

Another drawback manufacturers may face in practice is occurrence of disruption in supplier's production system. Because of different reasons such as failure in production, political or economical issues and natural disasters like earthquake, hurricane, fire, etc, suppliers might lose their production capability [1].

A good strategy for the manufacturer to cope with these problems (under/over stocking and disruption with suppliers) is to place order of reserve components and make relation with several suppliers. Along these lines, one of appropriate mechanisms for the manufacturer is to apply option contract. With an option contract, the manufacturer will be able to adjust his order after demand recognition. This order adjustment will help the manufacturer to better cope up with demand variations. According to option contract, after the start of the selling season, when demand is realized the manufacturer would be able to place more orders if market demand is more than his initial order and if the suppliers are placed order to produce reserve components [1-3]. The manufacturer promises to pay an option price 'o_i' for each unit of capacity reserved

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for him and to pay exercise price 'e_i' for each unit he purchases in the next contingent orders to supplier 'i'. In fact, options give the manufacturer the right but not obligation, to increase initial order quantities and use reserved components [3]. Applying option contract will entitle the manufacturer to the following benefits.

- Reduced product sale risks and demand uncertainty;
- Reduced holding costs for unused products;
- Possibility for back ordering contingent extra demands with supplier's reserve production

Under this situation, regarding suppliers limited production capacity, it is precious for the manufacturer to find out how to select suppliers and how many components to order to each one. In this research to answer these questions, a model for selection of suppliers and order placement to them simultaneously, is proposed. Also, a numerical example is used to illustrate the model.

The remainder of this paper is organized as follows. The related literature is briefly presented in Section two. In Section three, the studied problem is described. Section four is devoted to the analysis of the model. Section five presents a numerical example and finally, the paper will be concluded in Section six.

2. Literature Review

Several studies have been conducted on capacity reservation orders and the option mechanisms for the improvement of the supply chain performance. Our research is related to three main components: capacity reservation, option contract and suppliers selection. Thus, in order to shed more light on the problem under study, we will here provide a brief review of the literature on capacity reservation followed by a review of studies on option contract and suppliers selection.

Numerous studies have dealt with capacity reservation and capacity outsourcing problems. Dogan [4] studied a multi-period capacity reservation contract between a manufacturer and a long-term supplier when there was uncertainty about the quantity of an input item available in the spot market.

Kouvelis and Milner [5] set up a supply chain model with a single manufacturer and a single supplier to investigate the capacity outsourcing for single and multi-period versions under the uncertainty of both demand and supply.

Kim et al. [6] built a single-period supply chain model with a single manufacturer and multiple suppliers, in which both the manufacturer and suppliers had capacity limits and the outsourcing decision of the manufacturer had to take into account the ‘capacity reservation agreements’ made in advance between the manufacturer and each supplier. Wang et al. [7] proposed a two-echelon supply chain model with one supplier and one manufacturer to study how manufacturing firms should make a trade-off between strategies of vertical integration and outsourcing.

Ozer and Wei [8] discussed two different contracts, nonlinear capacity reservation contract and advance purchase contract, to show that coordination was possible in even asymmetric demand information. Wu et al. [9] studied optimal long-term electric power capacity strategies with capacity options. They derived the optimal capacities for Generation Companies in the long-run given full knowledge of the short-term equilibria as characterized by previous literature. Erkoc and Wu [10] studied the capacity reservation contracts in fully deductible reservation fee setup and found that channel coordination was achievable only under very restrictive conditions. Jin and Wu [11] also studied the capacity reservation contract in high tech industries like semiconductor, telecommunication, etc. with deductible reservation, and showed that coordination conditions do exist when both supplier and manufacturer invest in capacity. Gupta and Weerawat [12] studied different contract mechanisms that a manufacturer whose revenues depend on order delays can use to affect its component supplier's inventory decisions. A pay to delay capacity reservation contract is analyzed by Wu et al. [13] using the concept of conditional value-at-risk.

First, they construct the manufacturer’s optimal ordering problem by using the dynamic programming approach and then the impact of risk aversion on the manufacturer’s optimal decisions is investigated. Spinler and Huchzermeier [14] have provided a game-theoretic framework to value options on capacity for production of non-storable goods or dated services. Hazra and Mahadevan [15] have modeled a scenario where a buyer reserves capacity from one or more suppliers in the presence of demand uncertainty. They explicitly derive suppliers’ capacity reservation price, which is a function of their capacity, amount of capacity reserved by the buyer and other parameters.

There are other studies [16-18] that have studied two-stage outsourcing and capacity reservation problems with demand updating. A review of capacity management literature is presented by Wu et al. [19].

Several studies have addressed option contracts used as a contract mechanism. Cachon and Lariviere [20] modeled a supply chain consisting of a retailer and a supplier in a game theoretic set-up with options. They discussed the contracts under both forced and voluntary compliance.

Barnes-Schuster et al. [21] studied the role of options in supply chain coordination in the two compliance regimes and a two-period model. Wang and Tsao [3] developed a single-period, two-stage supply contract with bidirectional options by which the buyer can adjust the initial order both upward and downward. He studied the buyer's perspective and the parameters affecting the buyer’s behavior.

Using a certain kind of option contract, Wang and Liu [2] developed a model to study channel coordination and risk sharing in a retailer-led supply chain. Their paper stems from the business practice in China consumer electronics retailing industry. Xu and Nozick [1] have applied option contract to assure supply, considering capacity disruptions at supplier's side. Gomez and Mishina [22] propose a model to analyze the impact of an option contract for two companies of a supply chain: retailer and supplier. In the proposed model, the option premium is calculated from the expected demand and from the conversion rate. Li et al. [23] investigated the role of forward commitments and option contracts between a seller (supplier) and a buyer (retailer) in the presence of asymmetric information. They investigated how alternative contracting arrangements alter the expected value of obtaining information that eliminates asymmetric information.

Also, there are lots of researches in the field of supplier selection [24],[25],[26],[27],[28]. In multiple source researches, the allocation problem as well as the selection problem, has been considered. In these researches, mainly mathematical programming models have been implemented. Some researchers in this field are: Pan [29], Benton [30], Ghodsypour [31], Cakravastia et al. [32] and Kim [33]. Our main concentration for suppliers selection in this research is on selecting suppliers and contracting with them as base or option relations, according to option mechanism. This point is explained more in the next part.

Regarding reviewed studies, the literature shows that none of the previous researches have analyzed capacity reservation contracts and suppliers selection simultaneously and based on option mechanism. Capacity reservation offers several benefits to supply chain members such as mitigating the ‘‘bull-whip effect’’, providing flexibility to handle uncertain demand and permitting better capacity planning [34]. Additionally, suppliers derive benefits from better downstream procurement planning. Making appropriate choices in procurement of capacity (specially during periods with great demand volatility), therefore, becomes crucial [15].

On the other hand, option contracts can provide trading partners with enhanced flexibility to respond to uncertain market conditions [14]. Thus, in this research we have paid attention to this important issue (capacity reservation) for the manufacturers, through option mechanism.

3. Problem Description and Assumptions

Consider a manufacturer who produces products with stochastic demand and short selling season. The market demand (X), follows a continuous distribution $F_X(x)$ with density $f_X(x)$ for $X \geq 0$. The manufacturer has to outsource a special component from a set of suppliers. Long production leadtime is supposed for the suppliers. So, the manufacturer has to order his required component (material) to the suppliers well before beginning of the selling season. For simplicity, assume that each unit of final product needs just one unit of component.

Based on option mechanism in [1,2], two kinds of relationships with a supplier are considered. The first type of relationship we refer to is a “base” supplier relationship. Base suppliers are those whom the manufacturer intends to get all of ordered parts from.

The second type of relationship we refer to is an “options” supplier relationship. With those suppliers, the manufacturer orders reserve components to be made available to him for purchase should the need arise.

In a base supplier arrangement with jth supplier there is only a per-unit cost (wj) for each part acquired. In contrast, with an option supplier there is an initial payment (oj) to the jth supplier to purchase the option and then there is a per-unit cost (ej) to exercise each option. We assume that the per-unit cost under an option agreement is always higher than under a base agreement (ej+oj>wj, for j $\in$ set of suppliers).

The manufacturer will hold ordered components to base suppliers and will produce final products after recognition of customers demand. The manufacturer may face holding or goodwill costs, at the end of the selling season. If customers demand be greater than the manufacturer's components inventory, he can backorder extra demands through reserved components with option supplier's as much as possible.

Each supplier has limited capacity for production and reservation. Also, regardless of the type of relationship, there is a fixed cost that varies based on the supplier to initiate the relationship. In this environment the problem manufacturer faces is to select base and option suppliers and determine how much component to order to them considering his/her budget constraint and suppliers production limit.

4. Model Development

Before proceeding with the analysis, let us introduce the notations used:

c:	Unit production cost (including processing or assembling operations)
v:	Unit salvage value
h:	Unit holding cost
f:	Unit goodwill cost
w_i:	Wholesale price of supplier i.
p:	Price of Manufacturer's product.
Bud:	Available budget before start of selling season.
o_i:	Payment by manufacturer to option supplier i for each unit of option (reserved component).

e_i:	Payment by manufacturer to option supplier i to use a reserve component (to exercise an option)
S_i:	$\begin{cases} 1 & \textit{if supplier i is selected for outsourcing} \\ 0 & \textit{otherwise} \end{cases}$
K_{bi}:	Capacity of supplier i for producing components under base relation.
K_{oi}:	Capacity of supplier i for producing components under option relation.
Q_{bi}:	Quantity of components ordered to supplier i with base relation.
Q_{oi}:	Quantity of components ordered to supplier i with option relation.
Q_{exi}:	Quantity of options which are exercised from option supplier i.
Z_i:	Fixed cost of initiating a relation with supplier i.
Ω:	Set of suppliers.
β:	Set of base suppliers.
O:	Set of option suppliers.
X:	Random demand in the selling season.
$f_X(x)$:	p.d.f of X
$F_X(x)$:	Cumulative density function of X.
$E\prod_M$:	Manufacturer's expected profit.

4.1. Objective Function

To write the objective function of the model, at first we should pay attention that after realization of market demand (X), the following cases might arise:

- $X \le \sum_{i=1}^{\beta} Q_{bi}$: In this case, the manufacturer will face an extra inventory of $\sum_{i=1}^{\beta} Q_{bi} - X$.
- $\sum_{i=1}^{\beta} Q_{bi} < X \le \sum_{i=1}^{\beta} Q_{bi} + \sum_{i=1}^{O} Q_{oi}$: In this case, the manufacturer will exercise some of his options to use a reserve quantity of X-$\sum_{i=1}^{\beta} Q_{bi}$, to back order for the extra demand.
- $\sum_{i=1}^{\beta} Q_{bi} + \sum_{i=1}^{O} Q_{oi} < X$: In this case, the manufacturer will exercise all of the options. A lost sale shortage of $X - \sum_{i=1}^{\beta} Q_{bi} + \sum_{i=1}^{O} Q_{oi} < X$ occurs.

Using the introduced parameters, here we present the objective function of the model:

$$
\begin{aligned}
&Max\, E\prod_M : \\
&\int_0^{\sum_{i\in\beta} Q_{bi}} [(p-c)x - \sum_{i\in\beta} w_i Q_{bi} - \sum_{i\in o} Q_i Q_{oi} \\
&+ (v-h)\left(\sum_{i\in\beta} Q_{bi} - x\right)] f(x)dx + \\
&\int_{\sum_{i\in\beta} Q_{bi}}^{\sum_{i\in\beta} Q_{bi} + \sum_{i\in o} Q_{oi}} [(\quad p-c)x - \sum_{i\in\beta} w_i Q_{bi} - \\
&\sum_{i\in o} Q_i Q_{oi} - \sum_{i\in o} e_i Q_{exi}] f(x)dx + \\
&\int_{\sum_{i\in\beta} Q_{bi} + \sum_{i\in o} Q_{oi}}^{\infty} [(\quad p-c)\left(\sum_{i\in\beta} Q_{bi} + \sum_{i\in o} Q_{oi}\right) - \sum_{i\in\beta} w_i Q_{bi} - \\
&\sum_{i\in o} (O_i + e_i) Q_{oi} - f\left(x - \sum_{i\in\beta} Q_{bi} - \sum_{i\in o} Q_{oi}\right)] f(x)dx
\end{aligned}
\tag{1}
$$

The objective function maximizes manufacturer's expected profit. The first three terms show the manufacturer's expected cost and income depending on the stochastic demand. The last part shows fixed costs of initiating relation with the suppliers.

4.2. Constraints

$$Q_{bi} \le S_i K_{bi} \qquad \forall_i \in \Omega \tag{2}$$

$$Q_{oi} \le S_i K_{oi} \qquad \forall_i \in \Omega \tag{3}$$

$$Q_{exi} \le Q_{oi} \qquad \forall_i \in \Omega \tag{4}$$

$$
\begin{aligned}
&\sum\nolimits_{i\in O} Q_{exi} = \\
&\int_{\sum_{i\in\beta} Q_{bi}}^{\sum_{i\in\beta} Q_{bi} + \sum_{i\in O} Q_{oi}} (x - \sum\nolimits_{i\in\beta} Q_{bi})\, f(x)dx + \\
&\int_{\sum_{i\in\beta} Q_{bi} + \sum_{i\in O} Q_{oi}}^{x} (\sum\nolimits_{i\in O} Q_{bi})\, f(x)dx
\end{aligned}
\tag{5}
$$

$$\sum\nolimits_{i\in\beta} w_i Q_{bi} + \sum\nolimits_{i\in O} O_i Q_{Oi} + \sum\nolimits_{i\in\Omega} S_i Z_i \le Bud \tag{6}$$

,

$$Q_{bi}, Q_{oi}, Q_{exi} \ge 0, S_i \in \{0,1\}, \qquad \forall i \in \Omega \tag{7}$$

The first two constraints show that before ordering to a base or option supplier, at first he has to be selected.
Also, this order can not be more than supplier's production or reservation capacity. The third constraint shows that the amount of options exercised from option supplier 'i' can not be more than options ordered to that supplier. The forth constraint shows sum of the expected exercised options based on stochastic demand. The fifth constraint represents manufacturer's

budget constraint at the beginning of the selling season. The last constraint shows feasible values for decision variables. In the next part we have provided a numerical example to show how we can use the model.

5. Numerical Example

Consider a manufacturer who produces MTO products like commodity electronics for a short selling season and assume that customer's demand is uniformly distributed X∼[0,M]. The manufacturer can provide his required component (material) for production before beginning of the selling season from a set of suppliers. Information about the suppliers are shown in Table 1. Also, assume that other parameters are estimated as: M=500 (unit of product), h=15$, v=25$, c=20$, p=100$, f=50$ (all of the parameters are per unit) and Bud=8000$.
All of the cost parameters (Wi, oi, ei) are per unit. After modeling the problem in GAMS software the optimal solution is obtained as:

$$Q_{b2}^{*}=60, Q_{b5}^{*}=50, Q_{b6}^{*}=90, Q_{b9}^{*}=6.8, Q_{b10}^{*}=80 \quad (8)$$

$$Q_{o2}^{*}=5, Q_{o4}^{*}=25, Q_{o5}^{*}=10, Q_{o6}^{*}=5, Q_{o9}^{*}=30, Q_{o10}^{*}=50 \quad (9)$$

So, the manufacturer has to make relation with the suppliers 2,5,6,9,10 as base suppliers and with suppliers 2,4,5,6,9,10 as option supplier. Rest of this part is devoted to analyze the effect of various parameters on the manufacturer's optimal decision and expected profit.

Tab. 1. Supplier's information

Supplier	K_{bi}	K_{oi}	Z_i	W_i	O_i	e_i
1	170	15	150	30	15	20
2	60	5	300	15	5	15
3	100	10	220	22	10	15
4	85	25	160	30	5	30
5	50	10	600	12	5	10
6	90	5	270	20	10	15
7	120	40	100	40	15	30
8	100	20	120	30	10	25
9	150	30	350	25	5	30
10	80	50	750	15	10	8

In Table 2, we can see how holding cost will affect order quantities. As it was expected, we can see that by enhancement of holding cost, the orders to the base suppliers will decrease. The amount of order reduction depends on other parameters such as goodwill cost.

Tab. 2. Effect of holding cost on orders

Supplier	H=15, without option		H=5, with option		H=15, with option		H=30, with option		H=60, with option	
	Base order	reservation	Base order	reservation	Base order	reservation	Base order	reservation	Base order	reservation
1										
2	60		60	5	60	5	60	5	60	5
3	61.818		85.682	10					25.478	10
4						25		25		25
5	50				50	10	50	10	50	10
6	90		90	5	90	5	82	5		
7										40
8								20		20
9					6.8	30		30		30
10	80		80	50	80	50	80	50	80	50

Tab. 3. Effect of goodwill cost on order quantities

Supplier	F=50, without option		F=20, with option		F=35, with option		F=50, with option		F=70, with option	
	Base order	reservation	Base order	reservation	Base order	reservation	Base order	reservation	Base order	reservation
1										
2	60		60	5	60	5	60	5	60	5
3	61.818		85.682	10						
4					11.667	25		25		25
5	50				50	10	50	10	50	10
6	90		90	5	90	5	90	5	90	5
7										
8						20				
9							6.8	30	6.8	30
10	80		80	50	80	50	80	50	80	50

Table 3 shows how goodwill cost has an effect on order quantities. Regarding budget constraint and holding cost, we can see when goodwill cost increases, the amount of order will increase as much as possible. For f=50 and f=70 we have the same solutions. This is due to other problem parameters (specially budget constraint). The next figures compare the manufacturer's expected profit after applying the option contract to the case without option mechanism. The comparisons are in terms of different values for the parameters h, f, M and Bud. As can be seen, the manufacturer's expected profit has improved in all of the cases, by applying the option contract in comparison with the case without option contract. This situation coincides with our expectations, because by option mechanism the manufacturer will be able to reduce products sale risk and make a tradeoff between holding and goodwill costs.

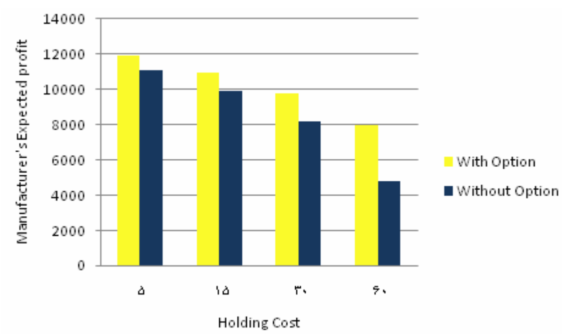

Fig. 1. Manufacturer's expected profit in terms of 'H'

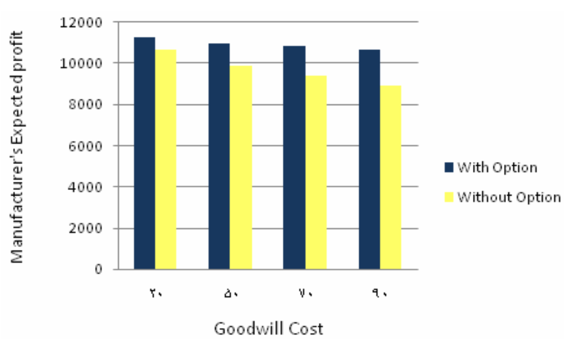

Fig. 2. Manufacturer's expected profit in terms of 'F'

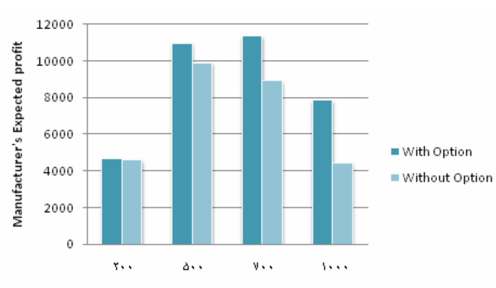

Fig. 3. Manufacturer's expected profit in terms of Demand uncertainty

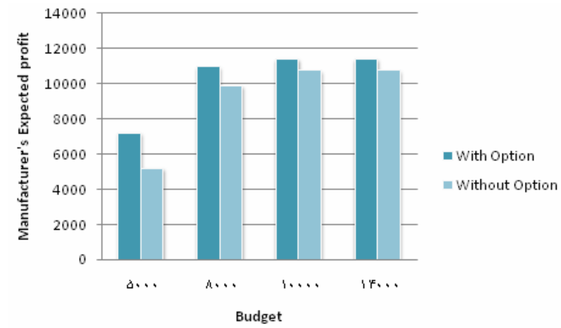

Fig. 4. Manufacturer's expected profit in terms of Budget

6. Conclusion

Nowadays, it is a common practice in manufacturing firms to have contractual agreement with suppliers that enables them to reserve capacity in advance. In this study, we developed a mathematical model that helps the manufacturers solve their capacity reservation problem, that is, how much material and/or component to order from which supplier, given capacity limits of suppliers. The proposed model was based on option contract. According to option mechanism, a supplier might be selected as a base or option or both relations. Through this strategy for components reservation, the manufacturer would be able to reduce products sale risk and holding costs. Also, the manufacturer can react against market's extra demand through reserved components. As it was shown in the numerical analysis, the manufacturer's expected profit will be improved after applying the option contract and components reservation. Future researches may include the following directions:
Analyzing the supply contract from the supplier's and the whole supply chain's perspectives. Extending the proposed model for multi components outsourcing and multi periods.

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