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Optimal decision model of heavy equipment manufacturers with the right of order quantity

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ABSTRACT

In the heavy equipment industry, manufacturers are dominant in business transactions with retailers. What products manufacturers provide is what retailers can only buy and sell. In the supply chain, the manufacturer's decisions have significant impact, it determines the efficiency and system performance of the supply chain, so study the manufacturer's decision has important theoretical and practical significance. Most of the studies assumed that retailers decide order quantity, which is consistent with the actual situation in most industries. This paper assumes that the manufacturer decided the agents' order quantity, which is different from the previous studies. Furthermore, the existing research didn't study the specific form of demand function, and only assumed the demand function as the specified demand and random demand.This paper considers the impact of transport capacity flexibility on transportation costs, and assumes that heavy equipment manufacturer has the power of order quantity decision-making, supplier productivity rate is a linear function of market demand, and market demand rate is a function of price and marketing costs. Based on demand function and the transport cost function, develop heavy equipment manufacturer's wholesale price and order quantity decision model, and analyze properties of the model. The study shows that: production startup costs, production costs, fixed transportation costs and unit inventory costs have positive impact on manufacturer's optimal wholesale price, while productivity have negative impact. Market demand rate, fixed transportation costs, production start-up costs and productivity of manufacturers have positive impact on manufacturer's optimal order quantity, while retail price and unit inventory costs have negative impact.

KEYWORDS

Heavy equipment manufacturer; Marketing cost; Order quantity; Retail price; Wholesale price.

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INTRODUCTION

In the heavy equipment industry, aviation industry, automobile industry and other industries, manufacturers have the advantages of network, technology, and the scale, and they are absolutely dominant in business transactions with retailers. What products manufacturers provide is what retailers can only buy and sell. This situation is a status of seller's market, in which manufacturers are in the dominant position.

After Harris first studied the economic order quantity (EOQ) in 1913, many scholars conduct research on EOQ[1]. Tersine et al (1995) considered the EOQ model with fully delayed order and two discounted EOQ model. They assumed that the unit shortage cost depended on the time of shortage[2]. Fazel et al (1998) established the inventory costs of the EOQ based on quantity discounts and compared with the JIT[3]. Wee (1999) built specified inventory model with assumption about quantity discount and products deterioration over time[4]. Skouri and Papachristos (2002) considered the opportunity cost of lost sales and a linear dependence on supplies costs of the order quantity, and assumed that deterioration rate is constant and delayed ordering rate was dependent on the index decreased function of the time[5]. Tripathy et al (2003) considered the EOQ model with imperfect production process, and assumed that unit production costs had positive impact on the reliability of the process, while demand rate had negative impact[6]. Berman (2006) built an EOQ model with demand shifted with inventory, in the random condition, and analyzed and solved the EOQ with demand in constant distribution and exponential distribution[7]. Wang et al (2007) assumed proportion of imperfect-quality products in each batch was fuzzy random variable and applied particle swarm optimization (PSO) to solve the proportion and tested the method's effectiveness[8]. Bjrk (2009) assumed that demand and lead times were triangular fuzzy numbers, and got analytical solution of the optimization[9]. Salameh and Jaber (2000), Eroglu and Ozdemir (2007), Maddah and Jaber (2008) and Kelle et al (2009) pet a single manufacturer's profit maximization as objective, and studied EOQ model that manufacturers conducted all inspections of materials when products had quality defects and got the optimal results[10-13].

According to the literature above, most of the studies assumed that retailers or agents decide order quantity. This assumption is consistent with the actual situation in most industries.

Different with the general study, this paper assumes that the manufacturer decided the agents' order quantity. Because manufacturers have the advantages of technology, scale and network in the heavy equipment manufacturing industry, aviation industry, automobile industry, and they are absolutely dominant in the business transactions with retailers. What products manufacturers provide is what retailers can only buy and sell. This situation is a status of seller's market.

Furthermore, these papers didn't study the specific form of demand function, and only assumed the demand function as the specified demand and random demand, then built the model, and designed the algorithm to solve it. This paper assumes that demand is a function of retail price and marketing cost, and considers the impact of transport capacity flexibility on transportation costs, then builds optimization model of the heavy equipment manufacturer, and solved it.

MODEL DESCRIPTION

(1)Model assumptions

Assuming that heavy equipment manufacturer decides order quantity, and then distributes it to the agent. After receives the equipment, the agent pays marketing cost of product sales. Manufacturer need to cover the cost of production preparation to adjust the machine, train staff and arrange materials. The manufacturer's distribution cost includes the fixed and variable transport cost. Fixed transportation cost is independent of the number of transportation, but only dependent on delivery frequency. Vehicles startup costs, driver's salary belong to fixed transportation costs. Market demand is a function of the retail price and marketing cost. α and β respectively indicate the price elasticity of demand and marketing cost elasticity of demand. Agents can understand the needs of the market from α and β. Not allowing goods shortage, so productivity must be greater than or equal to the market demand rate, assuming the relationship between productivity and market demand rate is linear determined as the following function:

$$R = u_0 D(P, M), u_0 \geq 1 \tag{1}$$

Where R, productivity; D, the demand rate; P, the retail price, M, marketing cost, u_0, the safety factor of production.

In general, order quantity is decided by the retailer or the agency. In order to reflect the characteristics of the heavy equipment manufacturing industry, this paper assumes order quantity determined by the manufacturer. There are many companies in various industries that the manufacturer determines the order quantity. For example, in equipment manufacturing industries with high degree of specialization and with high technology, heavy equipment manufacturing, aviation and the automobile industry, the market is often dominated by a few manufacturers. These industries require high startup costs, transportation costs and inventory costs, and need large-scale production in order to compensate these costs, so there is minimum production restriction. Minimum Production restrictions reduce the number of manufacturers in the whole industry, and let manufacturers gain dominance in the cooperation with agents. Therefore, in these industries, manufacturers determine order quantity to arrange production better and maximize profit (Such as Esmaeili et al., 2009; Kelle et al., 2003)[14,15]. To simplify the model analysis, this paper assumes that the order quantity decided by manufacturer is equal to the order acceptance by the agent.

(2)Decision variables

Q is the order quantity of decision of the manufacturer.

V is the wholesale price of the manufacturer's products.

(3) Input variables

k is a demand function coefficient. ($k > 0$)

u_0 is a production function coefficient. ($u_0 \geq 1$)

h_s is the manufacturer unit inventory cost.

α is the price elasticity of demand. ($\alpha > 1$)

β is marketing cost elasticity of demand. ($0 < \beta < 1, \beta + 1 < \alpha$)

A_s is the manufacturer production startup cost. (¥ /per startup)

C_s is the manufacturer production cost, which includes materials and parts procurement cost. (¥ /per unit product)

R is manufacturers productivity. (/unit time)

$D(P, M)$ is market demand rate (/unit time), and is similar to Lee and Kim (1993)[16], we assume:

$$D(P, M) = kP^{-\alpha} M^{\beta} \tag{2}$$

Where P, the sales price; M, the marketing cost.

K^C represents fixed costs of transport.

$n = s - tQ$ represents transportation variable costs, and both s and t are coefficients greater than zero. t is smaller, the flexibility of transport capacity of manufacturers stronger.

OPTIMAL STRATEGY OF HEAVY EQUIPMENT MANUFACTURER

When we analyze the manufacturer's profit function and the optimal strategy, and profit function consists of the following basic components in the relationship: the profit of the manufacturer= sales revenue - production costs - production preparation costs - inventory costs - transportation costs (fixed transportation cost and variable transportation costs). Taking the related expressions into the formula above, the profit of the manufacturer can be expressed as

$$\pi_s(V,Q) = VD - C_s D - A_s \frac{D}{Q} - 0.5 h_s Q \frac{D}{R} - K^C \frac{D}{Q} - (s - tQ)D$$

$$= kVP^{-\alpha}M^{\beta} - kC_s P^{-\alpha}M^{\beta} - A_s kP^{-\alpha}M^{\beta}Q^{-1} - 0.5h_s \frac{Q}{u_0} \tag{3}$$

$$-K^C kP^{-\alpha}M^{\beta}Q^{-1} - (s - tQ)kP^{-\alpha}M^{\beta}$$

The manufacturer's operating objective is to select the optimal order quantity Q^* and wholesale prices V^* to maximize its profit. When V is fixed, manufacturer’s profit function $\pi_s(V,Q)$ is a concave function of order quantity Q. Therefore the existence and uniqueness of the optimal Q^* allows manufacturer to maximize the profit $\pi_s(V,Q)$. Q^* can be uniquely determined by the first-order condition of manufacture’s profit function $\pi_s(V,Q)$. Seeking $\pi_s(V,Q)$ first-order condition, we get:

$$\frac{\partial \pi_s(V,Q)}{\partial Q} = A_s \frac{D}{Q^2} - 0.5h_s \frac{D}{R} + K^C \frac{D}{Q^2} + tD = 0 \tag{4}$$

We can conclude from the formula (4)

$$Q^* = \sqrt{\frac{2R(A_s + K^C)}{h_s - 2tR}} \tag{5}$$

Taking $R = u_0 D(P,M)$ into the formula (5), we conclude

$$Q^* = \sqrt{\frac{2u_0 D(A_s + K^C)}{h_s - 2tR}} \tag{6}$$

Taking the equation (6) into the equation (3), manufacturer’s profit function can be turned into:

$$\pi_s(V,Q) = VD - C_s D - sD - (A_s + K^C)D\sqrt{\frac{h_s - 2tR}{2u_0 D(A_s + K^C)}} + (t - \frac{h_s}{2R})D\sqrt{\frac{2u_0 D(A_s + K^C)}{h_s - 2tR}} \tag{7}$$

Assuming the manufacturer’s profit is equal to 0, namely $\pi_s(V,Q) = 0$, we conclude:

$$V_0 = C_s + s + (A_s + K^C)Q^{-1} - (t - \frac{h_s}{2R})Q \tag{8}$$

Because of the formula (7) is a linear increasing function of V, the optimal V^* appears at the maximum price that the agent pay for manufacturer, therefore,

$$V^{*} = FV_0 = F[C_s + s + (A_s + K^C)Q^{-1} - (t - \frac{h_s}{2R})Q] \quad \textbf{(9)}$$

In the formula (9), $F > 1$. For any given P and M, the optimal order quantity and the sales price is given by Q^* and V^*.

RESULT AND DISSCUSS

We can conclude the following proposition according to previous analysis of the optimal strategy of the heavy equipment maker.

Proposition 1: in the supply chain system which manufacturer is in dominant position, manufacturer's profit $=(F-1)D[(C_s+s)+\xi(\frac{1}{\psi}+\frac{\psi}{2R})]$, and in the formula above, $\xi=\sqrt{(A_s+K^C)(h_s-2Rt)}$, $\psi=\sqrt{2u_0D}$.

Prove:

$$\pi_s(V,Q) = VD - C_sD - sD - (A_s + K^C)\frac{D}{Q} + (t - \frac{0.5h_s}{R})QD$$

$$=(C_s+s)FD - C_sD - sD - (A_s+K^C)\frac{D}{Q} + (A_s+K^C)FDQ^{-1} + (t-\frac{0.5h_s}{R})QD - (t-\frac{h_s}{2R})FDQ$$

$$=-(1-F)(C_s+s)D - (1-F)(A_s+K^C)\frac{D}{Q} + (1-F)(t-\frac{0.5h_s}{R})QD$$

$$= -(1-F)[(C_s+s)D + (A_s+K^C)\frac{D}{Q} - (t-\frac{0.5h_s}{R})QD]$$

Taking $Q^* = \sqrt{\frac{2u_0D(A_s+K^C)}{h_s-2tR}}$ into the formula above, we conclude:

$$-(1-F)[(C_s+s)D + (A_s+K^C)D\sqrt{\frac{h_s-2tR}{2u_0D(A_s+K^C)}} - (t-\frac{0.5h_s}{R})D\sqrt{\frac{2u_0D(A_s+K^C)}{h_s-2tR}}]$$

$$=(F-1)D[(C_s+s) + \sqrt{\frac{(A_s+K^C)(h_s-2tR)}{2u_0D}} + \frac{1}{2R}\sqrt{2u_0D(A_s+K^C)(h_s-2Rt)}]$$

$$=(F-1)D[(C_s+s) + \sqrt{(A_s+K^C)(h_s-2Rt)}(\frac{1}{\sqrt{2u_0D}} + \frac{\sqrt{2u_0D}}{2R})]$$

Proposition 2: production startup costs, production costs, fixed transportation costs and unit inventory costs have positive impact on manufacturer's optimal wholesale price, while productivity have negative impact.

Proposition 2 can be proved from the solving and analysis on V^*.

Proposition 3: Market demand rate, fixed transportation costs, production startup costs and productivity of manufacturers have positive impact on manufacturer's optimal order quantity, while retail price and unit inventory costs have negative impact.

Prove: as the other properties are obvious, this paper only analyzes the relationship between the retail price and optimal order quantity.

Taking $R = u_0 k P^{-\alpha} M^{\beta}$ and $D(P,M) = kP^{-\alpha} M^{\beta}$ into the formula of manufacture's optimal order quantity, we conclude:

$$Q^* = \sqrt{\frac{2u_0 k P^{-\alpha} M^{\beta} (A_s + K^C)}{h_s - 2tu_0 k P^{-\alpha} M^{\beta}}}$$

$$\frac{\partial Q^*}{\partial P} = \frac{-h_s \alpha u_0 k P^{-\alpha-1} M^{\beta} (A_s + K^C)}{(h_s - 2tu_0 k P^{-\alpha} M^{\beta})^2 \sqrt{\frac{2u_0 k P^{-\alpha} M^{\beta} (A_s + K^C)}{h_s - 2tu_0 k P^{-\alpha} M^{\beta}}}} < 0$$

$$\frac{\partial Q^*}{\partial M} = \frac{(A_s + K^C)\beta u_0 k P^{-\alpha} M^{\beta-1} h_s}{(h_s - 2tu_0 k P^{-\alpha} M^{\beta})^2} \sqrt{\frac{h_s - 2tu_0 k P^{-\alpha} M^{\beta}}{2u_0 k P^{-\alpha} M^{\beta} (A_s + K^C)}} > 0$$

The proposition is proved.

CONCLUSIONS

This paper studies heavy equipment manufacturer's optimal decision. Different from the existing research, this paper assumes that the heavy equipment manufacturer has dominance of product order quantity decision-making. Furthermore, manufacturer's productivity is assumed as a linear function of demand rate. And it counts marketing cost into demand rate, and assumes that demand rate is a function of price and marketing cost. This paper takes the demand function and transportation cost function into consideration, and establishes the model of order quantity and wholesale price of heavy equipment manufacturer, and analyzes the nature of the model.

The study shows that: production startup costs, production costs, fixed transportation costs and unit inventory costs have positive impact on manufacturer's optimal wholesale price, while productivity has negative impact. Market demand rate, fixed transportation costs, production startup costs and productivity of manufacturers have positive impact on manufacturer's optimal order quantity, while retail price and unit inventory costs have negative impact.

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