Economic Order Quantity Model with Inventory-Based Financing

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***Abstract*-Most of the traditional models in inventory purchase ignore the financial states of enterprises and can result in infeasible practices in real systems. This paper attempts to incorporate inventory-based financing into order decisions. Instead of setting a known, exogenously determined budgetary constraint as most existing models suggest, we consider inventory management with financial constrait. Given seasonal commodities, regarding newsboy model as the archetype and Stackelberg game as analysis method, we discuss the inventory model from two aspects: enterprises purchase a single product, and they purchase multi-products. Moreover, in the case of multi-products, we discuss the model from four aspects classified according to purchasing order and whether initial capital remains or not.**

Keywords- SMEs; Economic Order Quantity; Inventory Financing

I. INTRODUCTION

There is an extensive literature on production and inventory control ignoring financial constraints in both deterministic and stochastic environments: Single-item distribution systems [1], multi-item supply chains [2, 3], material requirement planning production systems [4], just-in-time environments [5], supply chain management [6]. Similarly, there has been a large body of literature on corporate financing: description of the theory and practice of corporate finance [7], dynamic stochastic programming models for characterizing the structure of optimal cash-management policies [8, 9].

Few people in the inventory management community have tried to incorporate financial considerations into inventory decisions. Among them, Li [10] seek to model the relationship between production decisions, borrowing, and dividend policies under demand uncertainty with no restricitions on the amount of borrowing. Lederer and Singhal[11]consider the joint financing and technology choices when making manufacturing investments and show that considerable value can be added to investments through financing decisions. Birge and Zhang [12] apply the risk-neutral pricing arguments from option theory for incorporating risk into an inventory problem, but they assume infinite borrowing power. Birge [13] adapts option-pricing methods for incorporating risk into capacity-planning models. Buzacott and Zhang [14] incorporate asset-based financing into production decisions. They model the available cash in each period as a function of assets and liabilities that may be updated periodically according to the dynamics of the production activities and allow different interest rates on cash balance and outstanding loans. Zhang and Ji [15] study the inventory control problem of retailers with different initial cash. Li and Wang [16] research on decision of loan-to-value rations of seasonal inventory based logistics finance. Li and Feng [17]research on key risk control indicator of inventory financing under consigning supervision. Bai and Xu [18] study the loan-to-value ratios decision on inventory financing under the randomly-fluctuant market demand.

Thus, while there is a lot of literature on inventories and finance, there does not appear to have much research on addressing the way in which they interact in inventory-based financing. In this paper, separately standing in small and medium-sized enterprises and banks aspects, and applying for Stackelberg game theory, we present inventory purchasing models for single product and multiproduct based on inventory financing.

II. ASSUMPTION

(1) There are three parties in the business: banks, small and medium-sized enterprises(SMEs), third-party logistics(TPLs); banks commission inventories' value evaluation, management, price-monitoring and disposal to TPLs;

(2) When SMEs default, TPLs can ensure that the collaterals can always be sold with higher price to make banks suffer smaller losses.

(3) SMEs are risk neutral, the price of the product i $\left(i = A, B, C...\right)$ is c_i, sales price is p_i, treatment prices is c_i', punishment price is c_i'', and assume: $c_i'' > p_i > c_i > c_i'$

(4) During the purchase, SMEs do not know the future demand for products, only know its probability distribution. Assume that demand x for the products subjects to $\left[0, D_i\right]$ uniform distribution, with the distribution function $F(x) = x_i / D_i$ and the density function $f(x) = 1/D_i$.

(5) Banks regard initial purchase price as the assessed value for loans, loan interest rate is α, deposit interest rate is α', loan period is T. α and α' are defined as annual interest and single interest.

(6) SMEs suffer capital constraint, i.g. initial capital m_0 is not sufficient to obtain optimal order quantity. SMEs get other capital through inventory financing. In the paper, inventory financing means SMEs put the inventory purchased into TPLs' warehouses appointed by banks as a guarantee for loans.

(7) Purchase procedures are as follows: First using initial funds to purchase products i with amount q_{i0}, $c_i q_{i0} \le m_0$, and then put q_{i1} as collateral for loans to banks, $0 \le q_{i1} \le q_{i0}$. And assume $q_{i1} = kq_{i0}$, wherein, $0 \le k \le 1$. And then purchase another products $j\ (j = A, B, C...)$ with amount q_{j0} (if $i = j$, it means SMEs purchase single products, if $i \ne j$, it means multi-products.). Typically to control risk, banks provide SMEs with loans less than collateral value, e.g. with pledged quantities q_{i1} and purchase price c_i, the collateral value is $c_i q_{i1}$, but banks loan amount $tc_i q_{i1}\ (0 < t \le 1)$, wherein t means the loan-to-value ratio.

III. THE MODEL

A. Inventory Model for Single Product

In the subsection, we consider the case of one product, named A. Based on the assumption (7), SMEs first purchase q_{A0} with the initial funds, and pledge $q_{A1}\left(0 \le q_{A1} \le q_{A0}\right)$ as collateral for loans, and then further purchase product A with quantity q_{A2}.

Assumption default endogenous, i.g., when the profits with non-repayment are greater than that with repayment, SMEs choose not to repay. With non-repayment, SMEs have the quantity $q_{A2} + (1-k)q_{A0}$, With repayment, the quantity is $q_{A0} + q_{A2}$.

Lemma 1: When $x \in [0, +\infty)$, i) if $t \le c_A' / c_A(1+\alpha T)$, SMEs will repay, banks will not face the moral hazard; ii) if $t > p_A / c_A(1+\alpha T)$, SMEs will not repay; iii) if $c_A' / c_A(1+\alpha T) < t < p_A / c_A(1+\alpha T)$, SMEs repay with a certain probability. (Note: The conclusions of Lemma 1 and Lemma 2 are the same with the literature (Zhang and Ji 2006.).

By Lemma 1, we can discover that banks will face three situations at the end of period: (1) SMEs repay; (2) SMEs will not repay; (3) SMEs will repay with a certain probability. In this paper, we only consider the case of SMEs repayment.

With SMEs' repayment, banks' expected profit and SMEs' expected profit are respectively:

$$\pi_b = tcq_2(1+\alpha T) - tcq_2(1+\alpha' T). \tag{1}$$

$$E\pi_e(k) = p_A(1+tk)\frac{m_0}{c_A} - m_0 - tm_0(1+\alpha T)k + c_A''(1+tk)\frac{m_0}{c_A} - c_A''\mu - (p_A + c_A'' - c_A')\int_0^{(1+tk)\frac{m_0}{c_A}} F(x)dx \tag{2}$$

Among them, SMEs' expects profit function is proved in Appendix A.

In inventory financing, banks are dominant. According to SMEs' situation and the pledged inventory, banks first determine the loan-to-value ratio t, and then SMEs make inventory decision according to the value of t. This game can be called Stackelberg game equilibrium. To obtain the equilibrium, we first determine the game's reaction function for the second stage.

By equation (2), and then

$$k^* = \frac{D_A c_A[p_A - c_A(1+\alpha T) + c_A''] - (p_A + c_A'' - c_A')m_0}{(p_A + c_A'' - c_A')tm_0} \tag{3}$$

The optimal pledged quantities: $q_{A1} = k^* q_{A0} = \dfrac{k^* m_0}{c_A}$

The optimal order quantity:

$$q_{A0}+q_{A2}=q_{A0}+tq_{A1}=\frac{m_0}{c_A}(1+tk^*) \tag{4}$$

Equation (4) is the reaction function of t. Put k^* into equation (1), and then

$$\pi_b=(\alpha-\alpha')T\frac{D_A c_A[p_A-c_A(1+\alpha T)+c_A'']-(p_A+c_A''-c_A')m_0}{(p_A+c_A''-c_A')}$$

$$\text{Because } k=\frac{D_A c_A[p_A-c_A(1+\alpha T)+c_A'']-(p_A+c_A''-c_A')m_0}{(p_A+c_A''-c_A')tm_0}\le 1,$$

$$t\ge\frac{D_A c_A[p_A-c_A(1+\alpha T)+c_A'']-(p_A+c_A''-c_A')m_0}{(p_A+c_A''-c_A')m_0}$$

With single products and SMEs repayment, Stackelberg equilibrium is:

$$\left(t^*,k^*\right)=[\frac{D_A c_A[p_A-c_A(1+\alpha T)+c_A'']-(p_A+c_A''-c_A')m_0}{(p_A+c_A''-c_A')m_0}\le t^*\le\frac{c_A'}{c_A(1+\alpha T)},\frac{D_A c_A[p_A-c_A(1+\alpha T)+c_A'']-(p_A+c_A''-c_A')m_0}{(p_A+c_A''-c_A')t^*m_0}] \tag{5}$$

Proposition 1. With single products and SMEs repayment, banks' optimal expected profits and SMEs' optimal order quantities,

$$\pi_b^*=(\alpha-\alpha')T\frac{D_A c_A[p_A-c_A(1+\alpha T)+c_A'']-(p_A+c_A''-c_A')m_0}{(p_A+c_A''-c_A')}$$

$$q^*_A=q_{A0}+q_{A2}=\frac{m_0}{c_A}(1+tk)=\frac{D_A[p_A-c_A(1+\alpha T)+c_A'']}{p_A+c_A''-c_A'}$$

From above results, we discover that if the loan-to-value ratio is too low, SMEs may not participate because of high costs; if it is too high, SMEs may choose not to repay the debt. It should be maintained in the range shown by equation (5). Under the situation, banks will get a stable expected return.

B. Inventory Model for Multi-Products

To facilitate the analysis, assume that SMEs only purchase two products A and B, and initial capital is not enough to meet the demand for optimal order quantities. Assume SMEs is financed by inventory financing. Firstly the initial funds are used for purchasing one product, and then the product is regarded as collateral to obtain loans from banks to purchase another product. Compared with purchasing single products, purchasing multi-products will face two problems: one is how to decide proper purchase order, and the other one is how to decide order quantities. In view of this, the paper discusses inventory model from the following four cases.

1) Product A First and Initial Capital Surplus

Assume that SMEs first purchase product A and initial funds have surplus, namely, $c_A q_{A0}<m_0$, initial funds left are used for purchasing product B with quantities q_{B0}; q_{A0} is used as collateral for loans to purchase another quantities q_{B1} of product B, so the total quantities of products B is $q_{B0}+q_{B1}$, and $q_{B1}=\frac{tc_A q_{A0}}{c_B}\left(0<t\le 1\right)$.

Lemma 2: When $x\in[0,+\infty)$, i) if $t\le c_A'/c_A(1+\alpha T)$, SMEs will repay, banks will not face the moral hazard; ii) if $t>p_A/c_A(1+\alpha T)$, SMEs will not repay; iii) if $c_A'/c_A(1+\alpha T)<t<p_A/c_A(1+\alpha T)$, SMEs repay with a certain probability.

Remark 1: In the proof of Lemma 2 the process, this paper does not consider products' (B) earnings, whether SMEs repay or not has control over product B, while product A depends on whether SMEs repay or not, SMEs need to balance the profits between giving up product A and possessing product A. If giving up product A can large SMEs' profits, SMEs will choose not to repay.)

With SMEs repayment and first purchase product A, banks' expected profit and SMEs' expected profit are respectively:

$$\pi_b = tc_A q_{A0}(1+\alpha T) - tc_A q_{A0}(1+\alpha' T) \tag{6}$$

$$\begin{aligned} E\pi_e &= E\pi_A(q_A) + E\pi_B(q_B) = p_A q_{A0} + c_A{}'' q_A - tc_A q_{A0}(1+\alpha T) - c_A{}''\mu_A - (p_A + c_A{}'' - c_A{}')\int_0^{q_{A0}} F_A(x_A)dx_A \\ &+(p_B + c_B{}'' - c_B)\frac{m_0 + (t-1)c_A q_{A0}}{c_B} - c_B{}''\mu_B - (p_B + c_B{}'' - c_B{}')\int_0^{\frac{m_0+(t-1)c_A q_{A0}}{c_B}} F_B(x_B)dx_B \end{aligned} \tag{7}$$

Among them, SMEs' expects profit function is proved in Appendix B.

The analysis on multi-products is the same as the single product.

By equation (6), and then,

$$q_{A0}{}^* = \frac{p_A + c_A{}'' - tc_A(1+\alpha T) + (p_B + c_B{}'' - c_B)\dfrac{c_A(t-1)}{c_B} - (p_B + c_B{}'' - c_B{}')\dfrac{m_0 c_A(t-1)}{D_B c_B{}^2}}{\dfrac{p_A + c_A{}'' - c_A{}'}{D_A} + \dfrac{(p_B + c_B{}'' - c_B')c_A{}^2(t-1)^2}{D_B c_B{}^2}} \tag{8}$$

Equation (8) is the reaction function of the loan-to-value t, and banks' problem becomes

$$\max \pi_b = tc_A q_{A0}(1+\alpha T) - tc_A q_{A0}(1+\alpha' T) \tag{9}$$

Put equation (8) into equation (9), and then

$$\max \pi_b = c_A(\alpha - \alpha')T\,\frac{t\left(p_A + c_A{}''\right) - t^2 c_A(1+\alpha T) + (p_B + c_B{}'' - c_B)\dfrac{c_A t(t-1)}{c_B} - \dfrac{m_0 c_A t(t-1)}{D_B c_B{}^2}}{\dfrac{p_A + c_A{}'' - c_A{}'}{D_A} + \dfrac{(p_B + c_B{}'' - c_B')c_A{}^2(t-1)^2}{D_B c_B{}^2}} \tag{10}$$

By equation (10), and then,

$t = t^*$, and $t^* \in [0, \dfrac{c_A{}'}{c_A(1+\alpha T)}]$.

(Note: equation t^* is too complex for expression to write out here, but it is proved to exist.)

So Stackelberg equilibrium is,

$$\left(t^*, q_{A0}{}^*\right) = [t^*, \frac{p_A + c_A{}'' - t^* c_A(1+\alpha T) + (p_B + c_B{}'' - c_B)\dfrac{c_A(t^*-1)}{c_B} - (p_B + c_B{}'' - c_B{}')\dfrac{m_0 c_A(t^*-1)}{D_B c_B{}^2}}{\dfrac{p_A + c_A{}'' - c_A{}'}{D_A} + \dfrac{(p_B + c_B{}'' - c_B')c_A{}^2(t^*-1)^2}{D_B c_B{}^2}}]$$

Proposition 2 With SMEs repayment, first purchase product A and initial capital surplus, banks' optimal expected profit and SMEs' optimal order quantities are respectively:

$$\pi_b^{\,*} = c_A(\alpha-\alpha')T\frac{t^*\left(p_A+c_A''\right)-\left(t^*\right)^2 c_A(1+\alpha T)+(p_B+c_B''-c_B)\dfrac{c_A t^*(t^*-1)}{c_B}-\dfrac{m_0 c_A t(t-1)}{D_B c_B^{\,2}}}{\dfrac{p_A+c_A''-c_A'}{D_A}+\dfrac{(p_B+c_B''-c_B')c_A^{\,2}(t^*-1)^2}{D_B c_B^{\,2}}}$$

$$q_{A0}^{\,*} = \frac{p_A+c_A''-t^*c_A(1+\alpha T)+(p_B+c_B''-c_B)\dfrac{c_A(t^*-1)}{c_B}-(p_B+c_B''-c_B')\dfrac{m_0 c_A(t^*-1)}{D_B c_B^{\,2}}}{\dfrac{p_A+c_A''-c_A'}{D_A}+\dfrac{(p_B+c_B''-c_B')c_A^{\,2}(t^*-1)^2}{D_B c_B^{\,2}}}$$

$$q_B^{\,*} = q_{B0}+q_{B1} = \frac{m_0-\left(1-t^*\right)c_A q_{A0}^{\,*}}{c_B}$$

2) Product A First and Initial Capital no Surplus

Assume SMEs first purchase product A and use up initial capital, namely, $c_A q_{A0} \ge m_0$.

Under the situation, when $t \le c_A' / c_A(1+\alpha T)$, SMEs will repay. The analysis on this is the same in 3.2.1. So banks' expected profits and SMEs' expected profits are respectively:

$$\pi_b = tc_A q_{A0}(1+\alpha T) - tc_A q_{A0}(1+\alpha' T) \tag{11}$$

$$\begin{aligned} E\pi_e = {} & p_A q_{A0} + c_A'' q_{A0} - tc_A q_{A0}(1+\alpha T) - c_A''\mu_A - (p_A+c_A''-c_A')\int_0^{q_{A0}} F_A(x_A)dx_A + \\ & (p_B+c_B''-c_B)\frac{tc_A q_{A0}}{c_B} - c_B''\mu_B - (p_B+c_B''-c_B')\int_0^{\frac{tc_A q_{A0}}{c_B}} F_B(x_B)dx_B \end{aligned} \tag{12}$$

By equation (12), and then,

$$q_{A0}^{\,*} = \frac{[p_A+c_A''-tc_A(1+\alpha T)]D_A D_B c_B^{\,2}+(p_B+c_B''-c_B')D_A D_B tc_A c_B}{(p_A+c_A''-c_A')D_B c_B^{\,2}+(p_B+c_B''-c_B')D_A t^2 c_A^{\,2}}$$

Because $c_A q_{A0}^{\,*} \ge m_0$ and $\dfrac{\partial^2 E\pi}{\partial q_{A0}^{\,2}} < 0$, $E\pi_e$ is a monotone increasing function when $q_{A0} \in [0, \dfrac{m_0}{c_A}]$. It is easy to understand that the optimal order quantity is $q_{A0}^{\,*} = \dfrac{m_0}{c_A}$.

Put $q_{A0}^{\,*} = \dfrac{m_0}{c_A}$ into equation (11), and then,

$$\pi_b = c_A T(\alpha-\alpha')\frac{m_0}{c_A}t$$

Because $t \le \dfrac{c_A'}{c_A(1+\alpha T)}$, ,banks obtain the optimal expected profits when $t^* = \dfrac{c_A'}{c_A(1+\alpha T)}$.

So Stackelberg equilibrium is,

$$\left(t^*, q_{A0}^{\,*}\right) = [\frac{c_A'}{c_A(1+\alpha T)}, \frac{m_0}{c_A}]$$

Proposition 3. With SMEs repayment, first purchase product A and initial capital no surplus, banks' optimal expected profit and SMEs' optimal order quantities are respectively:

$$\pi_b^* = \frac{c_A' m_0 T(\alpha - \alpha')}{c_A(1+\alpha T)}$$

$$q_{A0}^* = \frac{m_0}{c_A}$$

$$q_{B1}^* = \frac{c_A' m_0}{c_A c_B (1+\alpha T)}$$

3) Product B First and Initial Capital Surplus

The analysis on the case is the same as product A first in 3.2.1, so we easily get the Stackelberg equilibrium:

$$\left(t^*, q_{B0}^*\right) = [t^*, \frac{p_B + c_B'' - t^* c_B(1+\alpha T) + (p_A + c_A'' - c_A)\frac{c_B(t^*-1)}{c_A} - (p_A + c_A'' - c_A')\frac{m_0 c_B (t^*-1)}{D_A c_A^2}}{\frac{p_B + c_B'' - c_B'}{D_B} + \frac{(p_A + c_A'' - c_A')c_B^2 (t^*-1)^2}{D_A c_A^2}}]$$

Proposition 4 With SMEs repayment, first purchase product B and initial capital surplus, banks' optimal expected profit and SMEs' optimal order quantities are respectively:

$$\pi_b^* = c_B(\alpha - \alpha')T \frac{t^*\left(p_B + c_B''\right) - \left(t^*\right)^2 c_B(1+\alpha T) + (p_A + c_A'' - c_A)\frac{c_B t^*(t^*-1)}{c_A} - (p_A + c_A'' - c_A')\frac{m_0 c_B t^*(t-1)}{D_A c_A^2}}{\frac{p_B + c_B'' - c_B'}{D_B} + \frac{(p_A + c_A'' - c_A')c_B^2 (t^*-1)^2}{D_A c_A^2}}$$

$$q_A^* = q_{A0} + q_{A1} = \frac{m_0 - \left(1 - t^*\right) c_B q_{B0}^*}{c_A}$$

$$q_{B0}^* = \frac{p_B + c_B'' - t^* c_B(1+\alpha T) + (p_A + c_A'' - c_A)\frac{c_B(t^*-1)}{c_A} - (p_A + c_A'' - c_A')\frac{m_0 c_B (t^*-1)}{D_A c_A^2}}{\frac{p_B + c_B'' - c_B'}{D_B} + \frac{(p_A + c_A'' - c_A')c_B^2 (t^*-1)^2}{D_A c_A^2}}$$

4) Product B First and Initial Capital no Surplus

The analysis on the case is the same as product A first in 3.2.2, so we easily get the Stackelberg equilibrium:

$$\left(t^*, q_{B0}^*\right) = [\frac{c_B'}{c_B(1+\alpha T)}, \frac{m_0}{c_B}]$$

Proposition 5 With SMEs repayment, first purchase product B and initial capital no surplus, banks' optimal expected profit and SMEs' optimal order quantities are respectively:

$$\pi_b^* = \frac{c_B' m_0 T(\alpha - \alpha')}{c_B(1+\alpha T)}$$

$$q_{A1}^* = \frac{c_B' m_0}{c_A c_B (1+\alpha T)}$$

$$q_{B0}{}^{*} = \frac{m_0}{c_B}$$

From above analysis, if $E\pi_{eA} \geq E\pi_{eB}$, SMEs should first purchase product A, on the contrary, SMEs should first purchase product B.

IV. CONCLUSIONS

In this paper, regarding newsboy model as the prototype and applying Stackelberg game theory, we consider inventory management with capital constraint, and establish the model for single product and multi-product with based-inventory financing.

Although our research obtain the optimal solution for banks and SMEs when they make decisions in inventory financing, there are still many open issues: (1) This paper only analyzes the cases under SMEs repayment. In fact there are three situations: SMEs will repay, SMEs will not repay, and SMEs repay with a certain probability. Therefore, two other cases need further study. (2) We construct the model for multi-products, only concerning two products, how is the inventory model with more than two products?

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