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Research Article

An EOQ Model with Stock-Dependent Demand under Two Levels of Trade Credit and Time Value of Money

[1]H.A.O. Jia-Qin and [2]M.O. Jiangtao
[1]School of Mathematics and Statistics, Suzhou University, Suzhou, Anhui 234000, China
[2]College of Mathematics and Information Science, Guangxi University, Nanning, Guangxi 530004, China

Abstract: Since the value of money changes with time, it is necessary to take account of the influence of time factor in making the replenishment policy. In this study, to investigate the influence of the time value of money to the inventory strategy, an inventory system for deteriorating items with stock-dependent demand is investigated under two levels of trade credit. The method to efficiently determine the optimal cycle time is presented. Numerical examples are provided to demonstrate the model and the method.

Keywords: Deteriorating items, EOQ model, stock-dependent demand, time value of money, two levels of trade credit

INTRODUCTION

In real market to stimulate retailer's ordering qualities the supplier allows a certain fixed permissible delay in payment, which is trade credit, to settle the amount. Similarly, a retailer may offer his/her customs a permissible delay period to settle the outstanding balance when they received a trade credit by the supplier, which is a two-level trade credit. Goyal (1985) developed an EOQ model for permissible delays in payment. Huang (2003) extended Goyal' model (Goyal, 1985) to an inventory model with two levels of trade credit. Chang *et al*. (2010a) discussed an optimal manufacturer's replenishment policies for deteriorating items. Min *et al*. (2010) established an EOQ model for deterioration items with a current-stock-dependent demand. Kreng and Tan (2010) proposed to determine the optimal replenishment decisions if the purchasers order quantity is greater than or equal to a predetermined quantity.

In the above inventory models did not consider the effects of the time value of money. All cashes have different values at different points of time. Therefore, it is necessary to take the effect of the time value of money on the inventory policy into consideration. Chang *et al*. (2010b) investigated the DCF approach to establish an inventory model for deteriorating items with trade credit based on the order quantity. Chung and Lin (2011) used the DCF approach for the analysis of the inventory model for trade credit in economic ordering policies of deteriorating items. Chung and Liao (2006, 2009) adopted the DCF approach to discuss the effect of trade credit depending on the ordering quantity. Liao and Huang (2010) extended the inventory model to consider the factors of two levels of trade credit, deterioration and time discounting.

In this study, we develop an inventory system for deteriorating items and stock-dependent demand is investigated under two-level trade credit and time value of money. The theorem is developed to efficiently determine the optimal cycle time and the present value of total cost for the retailer. Finally, numerical examples and sensitive analysis of major parameters are given to illustrate the theoretical result obtain some managerial insight.

NOTATIONS AND ASSUMPTIONS

Notations: The following notations are used throughout this study.

- A = The ordering cost one order
- c = Unit purchasing cost per item
- p = Unit selling price per item $p>c$
- h = Holding cost per unit time excluding interest charges
- r = The continuous rate of discount
- $I(t)$ = The inventory level at the time of t
- T = The cycle time
- Q = The retailer' order quantity per cycle

Assumptions: The assumptions in this study are as follows:

- Time horizon is infinite and the lead time is negligible

Corresponding Author: M.O. Jiangtao, College of Mathematics and Information Science, Guangxi University, Nanning 530004, China
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- Replenishments are instantaneous and shortage is not allowed
- A constant θ(θ<θ<1) fraction of the on-hand inventory deteriorates per unit of time and there is no repair or replacement of the deteriorated inventory
- The demand rate D(t) is a known function of retailer's instantaneous stock level I(t), which is given by D(t) = D + αI(t), where D and α are positive constants
- When T≥M, the account is settled at T = Mand the retailer would pay for the interest charges on items in stock with rate I_p (per $ per year) over the interval [M, T]; when T≤M, the account is also settled at T = M and the retailer does not need to pay any interest charge of items in stock during the whole cycle
- The retailer can accumulate revenue and earn interest after his/her customer pays for the amount of purchasing cost to the retailer until the end of the trade credit period offered by the supplier. That is, the retailer can accumulate revenue and earn interest during the period N to M with rate I_e (per $ per year) under the condition of trade credit
- The fixed credit period offered by the supplier to the retailer is no less to his/her customers, i.e., 0<N ≤M.

MATHEMATICAL MODEL

Based on above assumptions, depletion due to demand and deterioration will occur simultaneously. The inventory level of the system can be described by the following differential equation:

$$I'(t)+\theta I(t)=-D-\alpha I(t),\ 0\le t\le T,\ I(T)=0$$

The solution to above equation is:

$$I(t)=D\left[e^{(\alpha+\theta)(T-t)}-1\right]\Big/(\alpha+\theta),\ 0\le t\le T$$

So the retailer's order size per cycle is:

$$Q=I(0)=D\left[e^{(\alpha+\theta)T}-1\right]\Big/(\alpha+\theta)$$

The present value of all future cash-flow cost PV_∞ (T) consists of the following elements:

- The present value of order cost: Vo = A/(1-e^{-rT})
- The present value of holding cost excluding interest charges:

$$V_H=\frac{h}{1-e^{-rT}}\int_0^T I(t)e^{-rt}dt=\frac{hD}{\alpha+\theta}\left[\frac{e^{(\alpha+\theta)T}-e^{-rT}}{(\alpha+\theta+r)\left(1-e^{-rT}\right)}-\frac{1}{r}\right];$$

- The present value of purchasing cost:

$$V_C=\frac{cQe^{-rM}}{1-e^{-rT}}=\frac{cDe^{-rM}}{(\alpha+\theta)\left(1-e^{-rT}\right)}\left(e^{(\alpha+\theta)T}-1\right)$$

Additionally, the present values of interest charged and earned are addressed as follows:

Case 1: 0<T≤N.

There is no interest charged, that is V_{IPI} = 0. In this case, the present value of interest earned is:

$$V_{IE1}=\frac{pI_e}{1-e^{-rT}}\int_N^M e^{-rt}\int_0^T D(\mu)\,d\mu dt$$
$$=\frac{pI_eD\left(e^{-rN}-e^{-rM}\right)}{r(\alpha+\theta)^2\left(1-e^{-rT}\right)}\left[\theta(\alpha+\theta)T+\alpha\left(e^{(\alpha+\theta)T}-1\right)\right].$$

Case 2: N<T≤M.

This case is similar case 1, there is no interest charged, that is V_{IP2} = 0 and the present value of interest earned is:

$$V_{IE2}=\frac{pI_e}{1-e^{-rT}}\left[\int_N^T e^{-rt}\int_0^t D(\mu)\,d\mu dt+\int_T^M e^{-rt}\int_0^T D(\mu)\,d\mu dt\right]$$
$$=\frac{pI_eD}{r(\alpha+\theta)\left(1-e^{-rT}\right)}\left\{\frac{\theta}{r}\left[(1+rN)e^{-rN}-rTe^{-rM}-e^{-rT}\right]\right.$$
$$+\frac{\alpha e^{(\alpha+\theta)T}}{\alpha+\theta}\left[e^{-rN}-e^{-rM}-\frac{re^{-(\alpha+\theta+r)N}}{\alpha+\theta+r}\right]$$
$$\left.+\frac{\alpha e^{-rM}}{\alpha+\theta}-\frac{\alpha e^{-rT}}{\alpha+\theta+r}\right\}.$$

Case 3: M < T.

In this case, the present value of interest charged is given by:

$$V_{IP3}=\frac{cI_p}{1-e^{-rT}}\int_M^T I(t)e^{-rt}\,dt$$
$$=\frac{cI_pD}{(\alpha+\theta)\left(1-e^{-rT}\right)}\left[\frac{e^{(\alpha+\theta)(T-M)-rM}-e^{-rT}}{\alpha+\theta+r}+\frac{e^{-rT}-e^{-rM}}{r}\right].$$

The present value of interest earned is:

$$V_{IE3}=\frac{pI_e}{1-e^{-rT}}\int_N^M e^{-rt}\int_0^t D(\mu)\,d\mu dt$$
$$=\frac{pI_eD}{(\alpha+\theta)\left(1-e^{-rT}\right)}\left\{\frac{\theta}{r^2}\left[(rN+1)e^{-rN}-(rM+1)e^{-rM}\right]\right.$$
$$\left.+\frac{\alpha e^{(\alpha+\theta)T}}{\alpha+\theta}\left[\frac{e^{-rN}-e^{-rM}}{r}+\frac{e^{-(\alpha+\theta+r)M}-e^{-(\alpha+\theta+r)N}}{\alpha+\theta+r}\right]\right\}.$$

From the above arguments, PV_∞ (T) can be expressed as:

$$PV_\infty(T)=\begin{cases}PV_1(T) & 0<T\le N;\\ PV_2(T) & N<T\le M;\\ PV_3(T) & M<T.\end{cases}$$

where, $PVj(T) = V_O + V_H + V_C + V_{IPj} - V_{IEj}$ $j = 1, 2, 3$

Since $PV_1(N) = PV_2(N)$ and $PV_2(M) = PV_3(M)$, $PV_\infty(T)$ is continuous and well-defined.

THEORETICAL RESULTS

The objective in this study is to find the replenishment time T^* to minimize the present value of all future cash-flow cost of the retailer.

Case 1: $0<T\le N$.

Taking derivative of $PV_1(T)$ with respect to T, we obtain:

$$PV_1'(T)=f_1(T)e^{-rT}\Big/\left(1-e^{-rT}\right)^2. \tag{1}$$

where,

$$f_1(T)=-r(1-e^{-rT})PV_1(T)+\frac{e^{rT}-1}{\alpha+\theta+r}D\Big\{e^{(\alpha+\theta)T}E-he^{-rT} -\frac{pI_e\theta}{r(\alpha+\theta)}(\alpha+\theta+r)\left(e^{-rN}-e^{-rM}\right)\Big\}, \tag{2}$$

$$E=(\alpha+\theta+r)ce^{-rM}+h-\frac{\alpha pI_e(\alpha+\theta+r)}{r(\alpha+\theta)}\left(e^{-rN}-e^{-rM}\right)$$

And $f_1(0) = - rA$.

From (2) we know that

$$f_1'(T)=\left(e^{rT}-1\right)e^{(\alpha+\theta)T}Dg(T). \tag{3}$$

where,

$$g(T)=E-\theta pI_e e^{-(\alpha+\theta)T}\left(e^{-rN}-e^{-rM}\right)\Big/(\alpha+\theta). \tag{4}$$

Lemma 1: Let T^*_1 is the minimum point of $PV_1(T)$ on (0, N].

- When $g(N)\ge0$, if $f_1(N)<0$, $T^*_1 = N$; else, $T^*_1 = T^0_1$, where T^0_1 is the unique solution of $f^1(T) = 0$on (0, N]
- When $g(N) < 0$, $T^*_1 = N$

Proof: since $g'(T)=pI_e\theta\left(e^{-rN}-e^{-rM}\right)e^{-(\alpha+\theta)T}\ge0$, we know g(T) is increasing on (0, N].

- If $g(N)\ge0$, (i) when $g(0)\ge0$, we have $g(T)\ge0$, that is, $f_1'1(T)<0$. If $f_1(N)<0$, then we have $f_1(T)<0$ and from (1) we obtain $T^*_1 = N$; else, there is the unique $T^0_1\in(0, N]$ which satisfies $f_1(T) = 0$. Furthermore, we have $f_1(T)\le0$ for $T\in(0, T^0_1]$ and $f_1(T)>0$ for $T\in(T^0_1, N]$ and from (1) we obtain $T^*_1 = T^0_1$; (ii) when $g(0)<0$, $g(T) = 0$ has a unique root (say $T^\#_1$) on (0, N] and $g(T)\le0$ for $T\in(0, T^\#_1]$, $g(T)>0$for $T\in(T^\#_1, N]$. Similar (i), we obtain if $f_1(N)<0$, then $f_1(N)<0$ for $T\in(T^\#_1, N]$; else, $f_1(T)\le0$ for $T\in(T^\#_1, T^0_1]$ and $f_1(T)>0$ for $T\in(T^0_1, N]$, Additionally, $f_1(T)$ is decreasing on $(0, T^\#_1]$, so we get the same result as (i).
- When $g(N)<0$, we have $g(T)<0$, that is $f_1'(T)<0$. Since $f_1(0)<0$, we have $f_1(T)<0$ for $T\in(0,N]$ and from (1) we obtain $T^*_1 = N$.

Case 2: $N\le T\le M$.

Taking derivation of $PV_2(T)$ with respect to T, we have

$$PV_2'(T)=f_2(T)e^{-rT}\Big/\left(1-e^{-rT}\right)^2. \tag{5}$$

where,

$$f_2(T)=\frac{e^{rT}-1}{\alpha+\theta+r}D\left[\frac{\alpha pI_e}{\alpha+\theta}\left(e^{(\alpha+\theta)(T-N)-rN}-e^{-rT}\right)+e^{(\alpha+\theta)T}E -he^{-rT}+\frac{\theta pI_e}{r(\alpha+\theta)}(\alpha+\theta+r)\left(e^{-rM}-e^{-rT}\right)\right] -r(1-e^{-rT})PV_2(T). \tag{6}$$

From (6) we have

$$f_2'(T)=\left(e^{rT}-1\right)De^{(\alpha+\theta)T}h(T). \tag{7}$$

where,

$$h(T)=E+pI_e\left[\theta e^{-(\alpha+\theta)T-rM}+\alpha e^{-(\alpha+\theta+r)N}\right]\Big/(\alpha+\theta). \tag{8}$$

Lemma 2: Let $T^*_2$is the minimum point of $PV_2(T)$ on [N, M].

- If $h(M)\ge0$, (i) when $f_2(N)\ge0$, $T^*_2 = N$; (ii) when $f_2(N)<0$, $T^*_2 = T^0_2$ if $f_2(M)\ge0$; else, $T^*_2 = M$, where T^0_2 is the unique solution of $f_2(T) = 0$on [N, M];
- If $h(N)\ge0>(M)$, (i) when $f_2(T^\#_2)<0$, $T^*_2 = M$; (ii)when $f_2(T^\#_2)\ge0$ $PV_2(T^*_2) = \min\{PV_2(N), PV_2(M)\}$, if $f_2(N)\ge0$; else, when $f_2(M)\ge0$, then $T^*_2 = T^0_2$, where T^0_2 is the unique solution of $f_2(T)\ge = 0$ on [N, M]; when $f_2(M)<0$, $PV_2(T^*_2) = \min\{PV_2(T^0_2), PV_2(M)\}$, where T^0_2 is the smallest solution of $f_2(T) = 0$ on [N, M].

- If h (N)<0, then $PV_2(T^*_2)$ = min {$PV_2(N)$, $PV_2(M)$}, where $T^\#_2$ is unique solution of h(T) = 0on [N, M].

Proof: Since $h^{'}(T) = -\theta p I_e e^{-(\alpha+\theta)T-rM} < 0$, we know h(T) is decreasing on [N, M] .

- If h(M)≥0, then we have h(T)≥0, that is, $f'_2(T) \le 0$, (i) When $f_2(N)\ge 0$, we know $f_2(T)\ge 0$ for T∈(N,M],. From (5) we obtain T^*_2= N; (ii) when $f_2(N)<0$ $f_2(M)$, there exists a unique root T^0_2∈(N,M], to $f_2(T) = 0$ and $f_2(T)\le 0$ 0for T∈(N, T^0_2], $f_2(T)>0$, for T∈(T^3_2, M]. From (5) we obtain $T^*_2 = T^0_2$; (iii) when $f_2(T)<0$, we have $f_2(T)<0$ for T∈(N, M], and from (5) we obtain T^*_2 = M.
- When h(N)≥0>h (M), h(T) = 0has a unique root(say $T^\#_2$) and h(T)≥0 for [N, $T^\#_2$], h(T)<0 for T∈($T^\#_2$, M], and from (7) we obtain $f_2(T)$ is increasing on [N, $T^\#_2$] and decreasing on ($T^\#_2$, M. (i) If $f_2(T^\#_2)<0$, then we have $f_2(T)<0$ for T∈(N, M]. From (5) we obtain T^*_2 = M; (ii) If., when $f_2(N)\ge 0$, if $f_2(M)\ge 0$, then we have $f_2(T)\ge 0$ for T∈(N,M], and from (5) we obtain T^*_1 = N; else, the equation $f_2(T) = 0$ has a unique root (say T^1_2) on [$T^\#_2$, M] and $f_2(T)\ge 0$ for T∈($T^\#_2$, T^1_2], $f_2(T)<0$ for T∈(T^1_2, M]. Additionally, $f_2(T)$ is increasing on T∈[N, $T^\#_2$], so $f_2(T)\ge 0$ when T∈[N, T^1_2], $f_2(T)<0$ when T∈(T^1_2, M] and from (5) we obtain $PV_2(T^*_2)$ = min{PV_2 (N), $PV_2(M)$}; Consequently, when $f_2(N)\ge 0$, $PV_2(T^*_2)$ = min {$PV_2(N)$, $PV_2(M)$} .
  When $f_2(N)<0$, the equation $f_2(T)$ = 0has a unique root (say T^0_2) on [N, $T^\#_2$]. If $f_2(M)\ge 0$, then we have $f_2(T)\ge 0$ for T∈($T^\#_2$, M], . Similarly, we obtain $T^*_2 = T^0_2$; If $f_2(M)<0$, then there exists a unique solution T^2_2 ∈($T^\#_2$, M] and $f_2(T)\ge 0$ for T∈($T^\#_2$, T^2_2], $f_2(T)<0$ for. T∈(T^2_2, M], From (5) we obtain $PV_2(T^*_2)$ min {$PV_2(T^\#_2)$, $PV_2(M)$, when T∈($T^\#_2$, M], since $PV_2(T^0_2)\le PV_2(T^\#_2)$, so $PV_2(T^0_2)$ min {$PV_2(T^0_2)$, $PV_2(M)$} where T^0_2 is the smallest solution of $f_2(T) = 0$ on [N, M]
- When h(N)<0, we have h(T)<0. From (7) we know $f'_2(T)<0$ for T∈[N, M]. (i) If $f_2(T)\ge 0$, then $f_2(T)\ge 0$ for T∈[N, M] and from (5) we obtain T^*_2 = N; (ii) If $f_2(M)<0\le f_2(N)$, then $f_2(T) = 0$ has a unique root T^3_2 on[N, M] and $f_2(T)\ge 0$ when T∈(N, T^3_2], $f_2(T)$ <0 when T∈(T^3_2, M] and from (5) we have $PV_2(T^*_2)$ = min {PV_2 (N), $PV_2(M)$}; (iii) If $f_2(N)<$ 0, then we have $f_2(T)\le 0$ for T∈[N,M] and from (5) we have T^*2 = M.

Case 3: M≤T.

Taking derivative of $PV_3(T)$ with respect to T, we obtain:

$$PV_3^{'}(T) = f_3(T) e^{-rT} \Big/ \left(1-e^{-rT}\right)^2. \qquad (9)$$

where,

$$\begin{aligned} f_3(T) = &-r(1-e^{-rT})PV_3(T)\frac{\left(e^{rT}-1\right)D}{\alpha+\theta+r}\Big[e^{(\alpha+\theta)T}E \\ &+cI_p e^{(\alpha+\theta)(T-M)-rM} - e^{-rT}\left(h+cI_p\right) \\ &+\frac{\alpha p I_e}{\alpha+\theta}e^{(\alpha+\theta)T}\left(e^{-(\alpha+\theta+r)N}-e^{-(\alpha+\theta+r)M}\right)\Big]. \end{aligned} \qquad (10)$$

From (10) we know that:

$$f_3^{'}(T) = \left(e^{rT}-1\right)De^{(\alpha+\theta)T}K. \qquad (11)$$

where,

$$K = E + cI_p e^{-(\alpha+\theta+r)M} + \frac{\alpha p I_e}{\alpha+\theta}\left(e^{-(\alpha+\theta+r)N}-e^{-(\alpha+\theta+r)M}\right). \qquad (12)$$

Lemma 3: Let T^*_3 is the minimum point of $PV_3(T)$ on [M, + ∞)

- When K≥0, T^*_3 = M if $f_2(M)\ge 0$; else, $T^*_3 = T^0_3$, where T^0_3 is the unique solution of $f_3(T) = 0$ on [M, +∞)
- (b)When K<0, $PV_3\left(T_3^*\right) = \min\left\{PV_3(M), \lim_{T\to+\infty} PV_3(T)\right\}$

Proof:

- When K≥0, we have $\lim_{T\to+\infty} f_3(T) = +\infty$ and $f'_3(T)\ge 0$ for T∈(M, +∞); (i) If $f_3(M)\ge 0$, then for T∈(M, + ∞], and from (9) we obtain T^*_3 = M; (ii) If $f_3(M)<0$, then $f_3(T) = 0$ has a unique root T^0_3on [M, + ∞) and $f_3(T)\le 0$ for T∈[M, T^0_3], $f_3(T)>0$ for T∈(T^0_3, ∞) and from (9) we obtain $T^*_3 = T^0_3$.
- When K<0, we have $\lim_{T\to+\infty} f_3(T) = -\infty$ and $f'_3 1(T)<0$, (i) If $f_3(M)\ge 0$, then there is a unique root T^1_3 on [M, + ∞) and $f_3(T)\ge 0$ for T∈(M, T^1_3], $f_3(T)<0$ for T∈(T^1_3 + ∞) and from (9) we obtain $PV_3\left(T_3^*\right) = \min\left\{PV_3(M), \lim_{T\to+\infty} PV_3(T)\right\}$; (ii) If $f_3(M)<0$, then $f_3(T)<0$ for T∈[M, + ∞] and from (9) we obtain $PV_3\left(T_3^*\right) = \lim_{T\to+\infty} PV_3(T)$.

From lemmas 1-3, we have the following result.

Theorem 1: The optimal cycle time T^* and the present value of all future cash-flow cost $PV_\infty(T^*)$ will be determined by the following:

$$PV_\infty\left(T^*\right) = \min\left\{PV_1\left(T_1^*\right), PV_2\left(T_2^*\right), PV_3\left(T_3^*\right)\right\}$$

Table 1: r = 0.08, the impact of change of M and N on T*and $PV_\infty(T^*)$

M	N	$PV_1(T^*_1)$	$PV_2(T^*_2)$	$PV_3(T^*_3)$	T^*
0.30	0.10	18696	15398	15327	$T^*_3 = 0.3657$
	0.20	16060	15445	15366	$T^*_3 = 0.3691$
	0.30	15521	15521	15429	$T^*_3 = 0.3747$
0.40	0.10	18509	15130	15142	$T^*_2 = 0.3680$
	0.20	15870	15168	15178	$T^*_2 = 0.3715$
	0.30	15327	15231	15237	$T^*_2 = 0.3771$
0.5	0.10	18325	14934	15102	$T^*_2 = 0.3696$
	0.20	15681	14973	15132	$T^*_2 = 0.3730$
	0.30	15135	15036	15181	$T^*_2 = 0.3787$

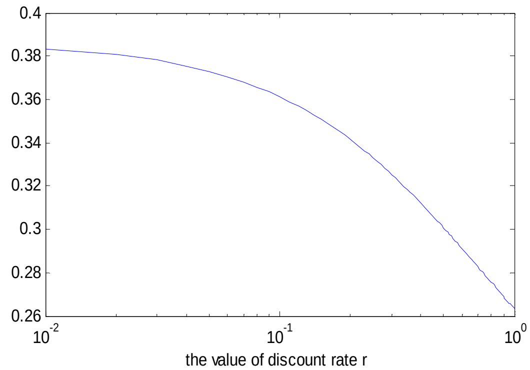

Fig. 1: The impact of change of r on T^*

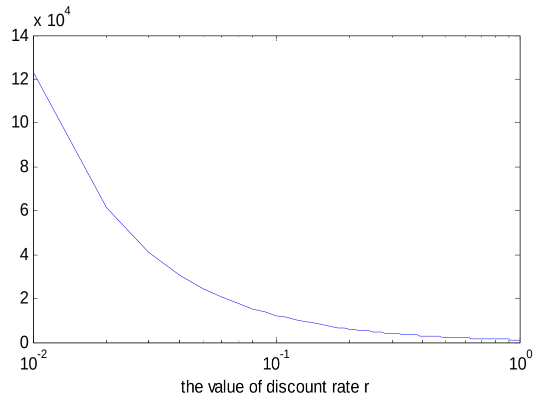

Fig. 2: The impact of change of ron $PV_\infty(T^*)$

NUMERICAL EXAMPLLES

To illustrate the results obtained in this study, we provide the following numerical examples.

Let A = \$50/order, D = 200 unit/year, c = \$5/unit, $\alpha = 0.3$, $\theta = 0.05$, Ip = 0.08/\$/year, p = \$7/unit, $I_e =$ 0.05/ \$/year

In Table 1, we study the effects of change of parameters M and N on T^* and $PV_\infty(T^*)$.

The following inferences can be made based on Table 1:

- For fixed other parameters, the larger the value of M, the smaller the value of $PV_\infty(T^*)$ and larger the value of T^*.

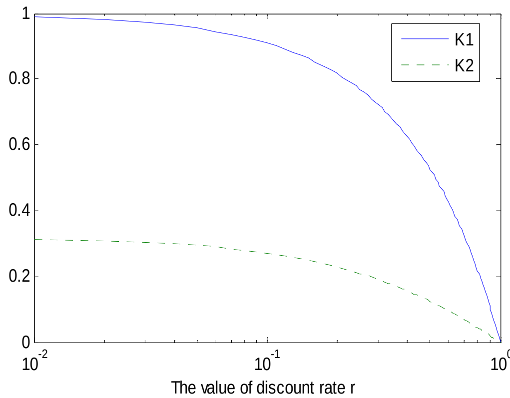

Fig. 3: The impact of change of r on K_1 and K_2

- For fixed other parameters, the larger the value of N, the larger the values of $PV_\infty(T^*)$ and T^*.

Figure 1 to 2 show when M = 0.3 year and N = 0.1 year, the relative change of T^*, $PV_\infty(T^*)$, relative ratios K_1 and K_2 (where PV_* and T^* are the value of optimal present value of all future cash-flow cost and the value of the optimal cycle time when r = 1, $K1 = [PV_\infty(T^*)-PV_*]/PV_\infty(T^*)$ and $K_2 = (T^* - T_*)/T^*)$. when the parameter of the discount rate r is changed from (0, 1].

The following inferences can be made based on Fig. 1 to 3:

- For fixed other parameters, the larger the value of r, the smaller the values of T* and $PV_\infty(T^*)$.
- For fixed other parameters, the larger the value of r, the smaller the relative ratios K_1 and K_2.

CONCLUSION

In this study, an inventory model for deteriorating items with two-level trade credit is established by DCF approach. We assumed that the demand is stock-dependent and the retailer pays for the purchasing cost to the supplier until the end of the trade credit period. By analyzing the present value of all future cash-flow cost, we developed theoretical results to obtain optimal solutions. Finally, we provided numerical examples to illustrate the proposed model and conducted a sensitive analysis of key parameters.

In regards to future research, one could consider incorporating more realistic assumptions into the model, such as the demand dependents the selling price, trade credit links to order quantity, etc.

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