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Effect of Inflation on a Deteriorating Inventory Model with Non-linear Holding Cost and Non-linear Demand

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Abstract

Deterioration becomes a major problem in any inventory modeling. Inflation is a concept closely related to time. Inflation is that state of disequilibrium, in which an expansion of purchasing power tends to cause, or is the effect of an increase in the price level. So, in this paper, we study the effect of inflation on an inventory model with nonlinear holding cost and nonlinear demand under the effect of inflation with partial backlogging shortages and trade credit. Some numerical examples and sensitivity analysis are conducted to illustrate the findings of the inventory models and some observations are also discussed. A numerical illustration is carried out by using the software MATHEMATICA 12.0.

Keywords: Nonlinear holding cost, nonlinear demand, inflation, Deterioration, Trade credit

1. Introduction

The term degradation refers to damage, spoilage, decay, etc., which decreases the usefulness of a commodity. Due to its massive impact on the overall profitability of an inventory system, degradation has been widely studied in recent years. According to Ghare and Scharder (1963), deterioration is a process that occurs over time.

Inflation has become a realistic situation in today's business scenario. Inflation refers to an increase in the general level of prices of commodities and services in an economy over a period that results from a decrease in the purchasing power of money. Due to a high inflation rate, many companies suffer a significant decline in their purchasing power. So, the effect of inflation cannot be overlooked in the development of any inventory model. Firstly, Buzacott, (1975) introduced the inflation rate in inventory modeling with different pricing policies. An optimal replenishment policy is given by Jaggi, et al. (2007) under an inflationary environment for deteriorating products by applying discounted cash flow (DCF) approach. For deteriorating items, Jaggi, and Verma (2010) studied a two-warehouse system with linear demand trends under an inflationary environment. In this model, shortages are allowable with complete backlogging. Jain and Singh (2011) gave inflationary implications with uncertain lead time and expiration date on an inventory in a multi-echelon supply chain. Also in the same year, an optimal replenishment policy is introduced by Singh et al. for ameliorating items with shortages under inflation and the time value of money. Tayal et al. (2014) developed a deteriorating model under the inflationary environment with effective investment in preservation technology. Rao and Rao (2015) explored an EOQ model considering the permissible delay in payments for deteriorating items under an inflationary environment but shortages are not permitted in this model. An inventory model for deteriorating items is studied by Pando et al. (2013) having stock-dependent demand. In their inventory model, they have taken holding cost as a function of time. Yang (2014) developed an inventory model under a stock-dependent demand rate and stock-dependent holding cost rate with relaxed terminal conditions. an EPQ model is proposed by Agrawal et al. (2015) for deteriorating items assuming linear demand under the effect of inflation and the time value of money. Also, backlogging rate is taken as an exponential function of time.

Recently Dobson et al. (2017) proposed an EOQ inventory model for perishable items, where the demand for the items/products depends on their age. An EOQ inventory model for a single development is also proposed by San-José et al. (2018) where the demand for the product depends on both the time and price. They considered the case of shortages in their inventory model. Also, in the same year, Rastogi and Singh presented a production inventory model for deteriorating products with selling price-dependent demand and shortages under an inflationary environment. Li and Teng (2018) formulated an inventory model for perishable goods whose demand depends on selling and reference price, the freshness of the product, and the displayed stock.

Saha and sen (2019) presented an inventory model with selling price and time-dependent demand, constant holding cost, and time-dependent deterioration. In this model, shortages are assumed to be partially backlogged. It is designed keeping in mind to optimize total inventory cost under the effect of inflation. Cardenas et al. (2020) dealt with an economic order quantity (EOQ) inventory model under both nonlinear stock-dependent demand and nonlinear holding cost. This inventory model is developed from the retailer's point of view, where the supplier offers a trade credit period to the retailer.

Sharma et al. (2020) developed an inventory model for non-instantaneous, deteriorating products, taking into account of the acceptability of progressive payment delays. The two warehouses' inventory models for non-instantaneous deteriorating items are considered by Tripathy et al. (2021) in a financial environment with a trade credit policy. Also developed a cost function for various situations depending on the trade credit period in an economic environment. Padiyar et al. (2022) developed a multi-echelon inventory model for deteriorating multi-items with imperfect production in an environment of inflation. In the same year, sharma et al. considered an inventory model for a non-instantaneous deteriorating item in a financial environment where trade credit policy plays a major role.

The recent literature review for this study is in tabular form in table 1.

Table 1. Literature Review

Author's name	Demand	Holding cost	Deterioration	Inflation	Trade credit	Shortages
(Ghare, P.M. and Schrader, 1963)	Constant	Constant	✓	×	×	×
(Yang, C.T., 2014)	Stock dependent demand	Stock dependent	✓	×	×	×
(Agarwal, Rani and Singh, 2015)	Time dependent	Linear	✓	✓	×	Partially backlogged
(Rastogi. Mohit and ; Singh.S.R , 2018)	Selling price dependent	constant	✓	✓	×	Partially backlogged
(Cárdenas -barrón *et al.*, 2018)	Non - linear stock dependent	Nonlinear stock dependent	×	×	✓	Partially backlogged

Table 1 (continued). Literature Review

Present study	Non-linear Stock dependent	Nonlinear stock dependent	Constant	✓	✓	Partially backlogged

The paper examines the EOQ model when stocks and holding costs are nonlinear with constant deterioration. A trade credit period is offered by the supplier to the retailer in this inventory model. Instead of assuming a zero ending inventory level, we assume a non-zero ending inventory level (the ending inventory level may be positive, zero, or negative). As the ending inventory level becomes negative, shortages are permitted and partially backlogged with a constant backlog rate. In this paper, we study the inventory model with deteriorating items. The primary objective of both inventory models is to determine the optimal ordering cost.

2. Assumptions and Notations:

To formulate the model, the following assumptions and notations are used:

2.1 Assumptions:

1. The planning horizon of the inventory system is infinite.
2. Replenishment rate is instantaneous, and lead-time is negligible.
3. Shortages are permitted, and these are partially backlogged with a backlogging rate ‘δ’; δ> 0.
4. Single level trade credit policy is considered. Here, the supplier/manufacturer/retailer gives a credit facility to his/her customer up to a specified period under terms and conditions well defined.
5. The holding cost is a nonlinear function which is dependent on stock level, and it is given by $H(t) = h[I(t)]^{\gamma}$; $\gamma > 0$.

6.The demand function is considered as a nonlinear stock dependent demand given by

$$D(t) = \begin{Bmatrix} a[I(t)]^{\beta} & I(t) \geq 0 \\ a & I(t) \leq 0 \end{Bmatrix}$$

7. Inflation is considered in this model with rate of inflation ‘r’; r > 0.
8. Rate of deterioration is to be considered as constant with parameter ‘θ’; θ > 0.

2.2 Notations:

C_o Ordering cost per order.
c Purchasing cost per unit.
p Selling price per unit.
h Holding cost per unit per unit time.
c_s Shortage cost per unit per unit time.
c_l Lost sale cost per unit.
γ The elasticity of holding cost; $0 < \gamma < 1$.
β Demand elasticity; $0 < \beta < 1$.
δ Partial backlogging parameter;
a Scale parameter of the demand rate.
$q(t)$ Units inventory level at any time t where $0 \leq t \leq T$.
M Unit time the retailer's trade credit period provided by the supplier.
r Rate of inflation; $0 < r < 1$.
θ Constant rate of deterioration; $0 < \theta < 1$.
I_e Unit time Interest earned by the retailer.
I_p Unit time Interest paid by the retailer.
Q Order quantity per cycle.
B The end inventory level at time 'T'.
λ Time at which inventory level is zero.
τ The length of replenishment cycle.
TP The total profit per unit time.

3. Mathematical Model formulation:

The study is designed for any retailing company. A cycle starts with Q units of inventory in stock. To replenish inventory, the order quantity must be Q-B, which raises the inventory level to Q units at the beginning of the next cycle. The supplier also offers the retailer a trade credit period (M). To derive the total profit per unit time for inventory models with shortage ($B \leq 0$). The governing differential equations describing the inventory level is given as below.

$$\frac{dI_1(t)}{dt} = -D(t) - \theta I_1(t)$$

$$\frac{dI_1(t)}{dt} = -a[I_1(t)]^{\beta} - \theta I_1(t) \qquad (0 \leq t \leq \lambda) \qquad (1)$$

$$\frac{dI_2(t)}{dt} = -D\delta$$

$$\frac{dI_2(t)}{dt} = -a\delta \qquad (\lambda \leq t \leq \tau) \qquad (2)$$

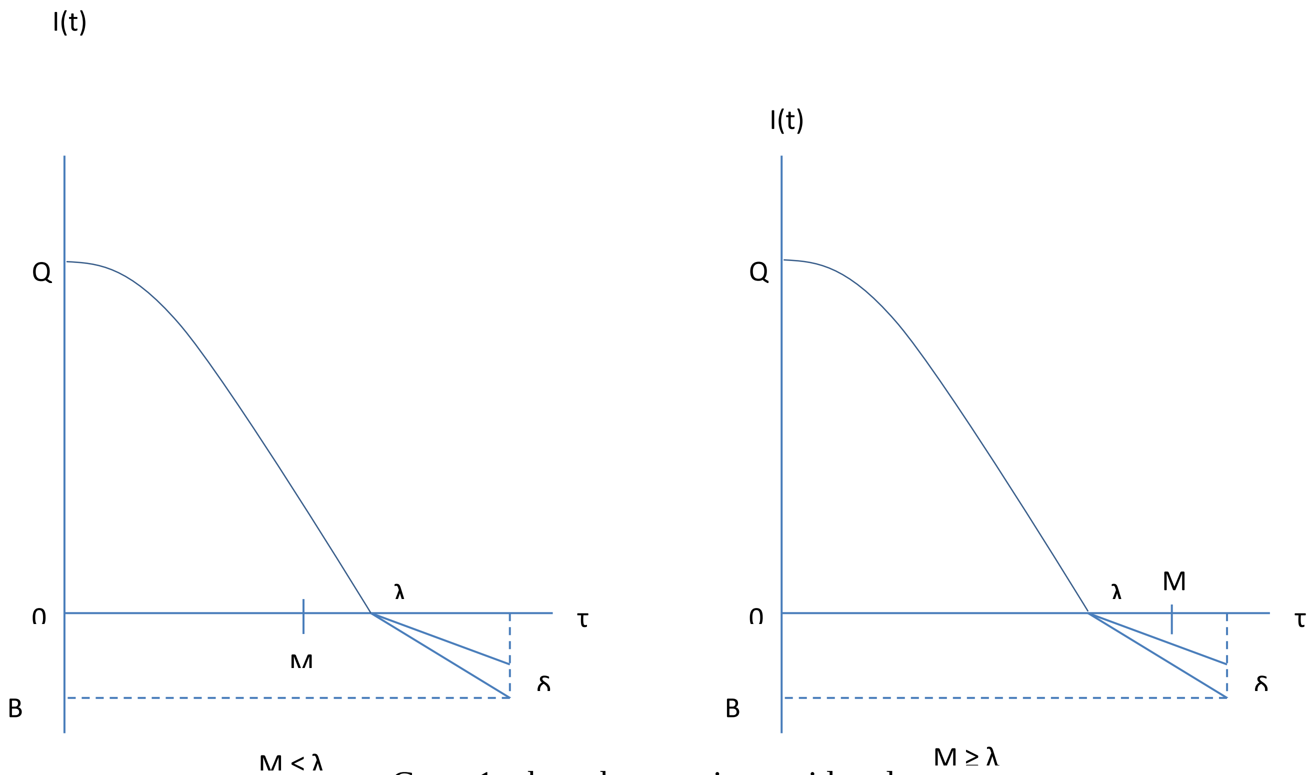
with,

$I_1(0) = Q$

$I_2(\lambda) = 0 = I_1(\lambda)$

On solving equations (1), (2). We get,

$$I_1(t) = [\frac{a}{\theta}(e^{\theta(1-\beta)(\lambda-t)} - 1)]^{\frac{1}{(1-\beta)}}$$
$$I_2(t) = B + a\,\delta\,(\tau - t)$$
$$Q = [\frac{a}{\theta}(e^{\theta(1-\beta)\lambda} - 1)]^{\frac{1}{(1-\beta)}}$$
B = $a\delta(\lambda - \tau)$



Case: 1 when shortage is considered.

Inventory Cost Components:

Holding Cost:

$$= h\int_0^{\lambda} [I_1\,(t)]^{\gamma} e^{-rt} dt$$
$$= hQ^{1-\beta}[\frac{(1-e^{-r\lambda})}{r} + \gamma(\theta + \frac{a}{Q^{1-\beta}})(\frac{r\lambda\, e^{-r\lambda} + e^{-r\lambda} - 1}{r^2})]$$

Ordering cost: C_0

Purchasing cost:

= c(Q-B)

$$= c[(\frac{a}{\theta}(e^{\theta(1-\beta)\lambda} - 1)^{\frac{1}{(1-\beta)}} - B]$$

Sales Revenue cost:

= p(Q-B)

$$= p[(\frac{a}{\theta}(e^{\theta(1-\beta)\lambda} - 1)^{\frac{1}{(1-\beta)}} - B]$$

Deteriorating cost:

$$= d\int_0^{\lambda} \theta I_1(t)e^{-rt}dt$$

$$= d\theta[a(1-\beta)\lambda]^{\frac{1}{(1-\beta)}}\left[\frac{1-e^{-r\lambda}}{r} + \frac{[e^{-r\lambda} + r\lambda e^{-r\lambda} - 1]}{r^2\lambda(1-\beta)}\right]$$

Shortage cost:

$$= -c_s\int_{\lambda}^{\tau} I_2(t)e^{-rt}dt$$

$$= -c_s\left[\frac{B}{r}\left(e^{-r\lambda} - e^{-r\tau}\right) + \frac{\delta a}{r^2}\left(e^{-r\tau} + r(\tau-\lambda)e^{-r\lambda} - e^{-r\lambda}\right)\right]$$

Opportunity cost:

$$= c_l\int_{\lambda}^{\tau} a(1-\delta)\, e^{-rt}dt$$

$$= \frac{c_l a(1-\delta)(e^{-r\lambda} - e^{-r\tau})}{r}$$

Trade credit policy: For permissible delay in payment there arises two cases. In first case the trade credit period is less than the time at which inventory goes finished. In the second case the trade credit period is greater than the time at which inventory goes finished.

3.1 For case: 1(M < λ)

3.1.(a) Interest pay:

$$= ci_p\int_M^{\lambda} I_1(t)e^{-rt}\,dt$$

$$= ci_p(a(1-\beta)\lambda)^{\frac{1}{1-\beta}}[\left(\frac{(e^{-rM} - e^{-r\lambda})}{r}\right) + \frac{(1+r\lambda)e^{-r\lambda} - (1+rM)e^{-rM}}{r^2\lambda(1-\beta)}]$$

3.1 (b) Interest earn:

$$= pi_e\int_0^{M} D(t)te^{-rt}\,dt$$

$$= \frac{p i_e a^{1+\frac{\beta}{1-\beta}} (1-\beta)^{\frac{\beta}{1-\beta}}}{\frac{\beta}{1-\beta}+1} [(\lambda - M)^{\frac{\beta}{1-\beta}+1} (rM^2 - M) + \frac{1}{\frac{\beta}{1-\beta}+2} (\lambda^{\frac{\beta}{1-\beta}+2} + (\lambda - M)^{\frac{\beta}{1-\beta}+2} (2rM - 1)) + \frac{2}{\left(\frac{\beta}{1-\beta}+2\right)\left(\frac{\beta}{1-\beta}+3\right)} (\lambda^{\frac{\beta}{1-\beta}+3} - (\lambda - M)^{\frac{\beta}{1-\beta}+3})]$$

3.2 For case: 2 (M ≥ λ)

3.2 (a) Interest pay = 0

3.2 (b) Interest earn:

$$= p i_e \left(\int_0^{\lambda} D(t) t e^{-rt} dt + (M - \lambda) \int_0^{\lambda} D(t) e^{-rt} dt \right.$$

$$= \frac{p i_e\, a^{1+\frac{\beta}{1-\beta}} (1-\beta)^{\frac{\beta}{1-\beta}}}{(\frac{\beta}{1-\beta}+1)} [\frac{\lambda^{\frac{\beta}{1-\beta}+2}}{\left(\frac{\beta}{1-\beta}+2\right)} (1 - \frac{2r\lambda}{\left(\frac{\beta}{1-\beta}+3\right)}) + (M - \lambda) \lambda^{\frac{\beta}{1-\beta}+1} (1 - \frac{r\lambda}{\left(\frac{\beta}{1-\beta}+2\right)})]$$

3.3 Total profit for case: 1

$T.P_1$ = Sales revenue cost + interest earn – ordering cost – purchasing cost – holding cost – deteriorating cost – shortage cost – opportunity cost – interest pay.

$$= p[(\frac{a}{\theta} (e^{\theta(1-\beta)\lambda} - 1)^{\frac{1}{(1-\beta)}} - B] + \frac{p i_e a^{1+\frac{\beta}{1-\beta}} (1-\beta)^{\frac{\beta}{1-\beta}}}{\frac{\beta}{1-\beta}+1} [(\lambda - M)^{\frac{\beta}{1-\beta}+1} (rM^2 - M) + \frac{1}{\frac{\beta}{1-\beta}+2} (\lambda^{\frac{\beta}{1-\beta}+2} + (\lambda - M)^{\frac{\beta}{1-\beta}+2} (2rM - 1)) + \frac{2}{\left(\frac{\beta}{1-\beta}+2\right)\left(\frac{\beta}{1-\beta}+3\right)} (\lambda^{\frac{\beta}{1-\beta}+3} - (\lambda - M)^{\frac{\beta}{1-\beta}+3})] - C_0 - c[(\frac{a}{\theta} (e^{\theta(1-\beta)\lambda} - 1)^{\frac{1}{(1-\beta)}} - B] - hQ^{1-\beta} \left[\frac{(1-e^{-r\lambda})}{r} + \gamma \left(\theta + \frac{a}{Q^{1-\beta}} \right) \left(\frac{r\lambda e^{-r\lambda} + e^{-r\lambda} - 1}{r^2} \right) \right] - d\theta [a(1-\beta)\lambda]^{\frac{1}{(1-\beta)}} \left[\frac{1-e^{-r\lambda}}{r} + \frac{[e^{-r\lambda} + r\lambda e^{-r\lambda} - 1]}{r^2 \lambda (1-\beta)} \right] + c_s \left[\frac{B}{r} \left(e^{-r\lambda} - e^{-r\tau} \right) + \frac{\delta a}{r^2} \left(e^{-r\tau} + r(\tau - \lambda) e^{-r\lambda} - e^{-r\lambda} \right) \right] - \frac{c_l a (1-\delta)(e^{-r\lambda} - e^{-r\tau})}{r} - c i_p (a(1-\beta)\lambda)^{\frac{1}{1-\beta}} \left[\left(\frac{(e^{-rM} - e^{-r\lambda})}{r} \right) + \frac{(1+r\lambda)e^{-r\lambda} - (1+rM)e^{-rM}}{r^2 \lambda (1-\beta)} \right]$$

3.4 Total cost for case: 2

$T.P_2$ = Sales revenue cost + interest earn – ordering cost – purchasing cost – holding cost – deteriorating cost – shortage cost – opportunity cost.

$$=p[(\frac{a}{\theta}(e^{\theta(1-\beta)\lambda}-1)^{\frac{1}{(1-\beta)}}-B]+\frac{pi_e\, a^{1+\frac{\beta}{1-\beta}}(1-\beta)^{\frac{\beta}{1-\beta}}}{(\frac{\beta}{1-\beta}+1)}\left[\frac{\lambda^{\frac{\beta}{1-\beta}+2}}{\left(\frac{\beta}{1-\beta}+2\right)}\left(1-\frac{2r\lambda}{\left(\frac{\beta}{1-\beta}+3\right)}\right)+(M-\lambda)\lambda^{\frac{\beta}{1-\beta}+1}\left(1-\frac{r\lambda}{\left(\frac{\beta}{1-\beta}+2\right)}\right)\right]-C_0 - c[(\frac{a}{\theta}(e^{\theta(1-\beta)\lambda}-1)^{\frac{1}{(1-\beta)}}-B] - hQ^{1-\beta}\left[\frac{(1-e^{-r\lambda})}{r}+\gamma\left(\theta+\frac{a}{Q^{1-\beta}}\right)\left(\frac{r\lambda\, e^{-r\lambda}+e^{-r\lambda}-1}{r^2}\right)\right] - d\theta[[a(1-\beta)\lambda]^{\frac{1}{(1-\beta)}}\left[\frac{1-e^{-r\lambda}}{r}+\frac{[e^{-r\lambda}+r\lambda e^{-r\lambda}-1]}{r^2\lambda(1-\beta)}\right]+c_s\left[\frac{B}{r}\left(e^{-r\lambda}-e^{-r\tau}\right)+\frac{\delta a}{r^2}\left(e^{-r\tau}+r(\tau-\lambda)e^{-r\lambda}-e^{-r\lambda}\right)\right] - \frac{c_l a(1-\delta)(e^{-r\lambda}-e^{-r\tau})}{r}]$$

3.5 Total average cost: Total average cost for both cases are given as follows:

$$A.P_1=\frac{T.P_1}{\tau}$$

$$A.P_2=\frac{T.P_2}{\tau}$$

Numerical Illustration

Example 1**.** Let us consider a situation in which shortages is considers and input parameters are in appropriate units as a=100, h=15, d=12, r=0.06, c=40, p=70, $\gamma=0.1$, $\beta=0.04$, $C_0=50$, $\delta=0.2$, $C_s=0.4$, $i_p=0.3$, $\theta=0.05$, $i_e=0.35$, $C_l=0.05$, $\tau=5$

For case 1 when Trade credit period $M\le\lambda$

We get TP_1= 1144.1$, $\lambda=2.47465$ Months, M =0.959771 Months

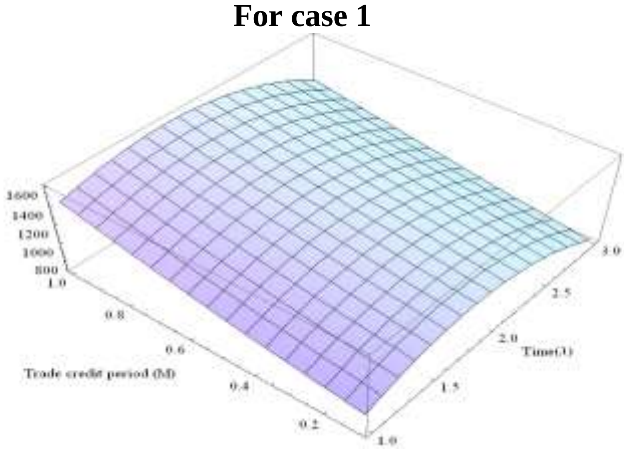
For case 2 when trade credit period $M\ge\lambda$

We get TP_2= 3343$, $\lambda=2.19607$ $Months$, M =2.19608 Months

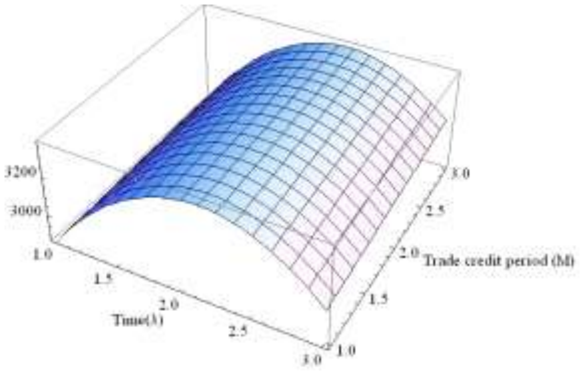
From numerical illustration we conclude that we get maximum profit in case 2.

Concavity

For case 1



For Case 2



Sensitivity Analysis

Table 2: Sensitivity of different parameters are as shown below.

Parameters	%Value	M	λ	TP_2
a	+20%	2.19049	2.19048	4009.22
	+10%	2.19322	2.19321	3676.28
	0%	2.19608	2.19607	3343.36
	-10%	2.19958	2.19957	3010.44
	-20%	2.20428	2.20427	2677.52
h	+20%	1.76115	1.76115	3030.43
	+10%	1.9551	1.95509	3169.79
	0%	2.19608	2.19607	3343.36
	-10%	2.50356	2.50355	3565.26
	-20%	2.90986	2.90986	3858.72
β	+20%	2.18793	2.18793	3337.29
	+10%	2.19202	2.19201	3340.32
	0%	2.19608	2.19607	3343.36
	-10%	2.20015	2.20014	3346.4
	-20%	2.20421	2.20420	3349.46
δ	+20%	2.08103	2.08103	3563.43
	+10%	2.13844	2.13844	3452.31
	0%	2.19608	2.19607	3343.36
	-10%	2.25377	2.25376	3236.57
	-20%	2.31161	2.31160	3131.96
r	+20%	2.23645	2.23644	3388.01
	+10%	2.21541	2.21540	3366.46
	0%	2.19608	2.19607	3343.36
	-10%	2.17843	2.17843	3318.09
	-20%	2.16288	2.16287	3289.75

Table 2 (continued): Sensitivity of different parameters are as shown below.

θ	+20%	2.24245	2.24244	3398.9
	+10%	2.21959	2.21958	3371.52
	0%	2.19608	2.19607	3343.36
	-10%	2.17164	2.17163	3314.16
	-20%	2.14598	2.14598	3283.62

Observations

1. On increases in the demand parameter 'a' the total profit increases and cycle length and trade credit period decreases**.**
2. On increases in the holding cost parameter 'h' the total profit decreases and cycle length and trade credit period also decreases.
3. On increases in the demand elasticity $'\beta'$ the total profit decreases and also cycle length and trade credit period decreases.
4. On increases in the backlogging rate $'\delta'$ the total profit increases and cycle length and trade credit period decreases.
5. On increases in the inflation rate 'r' the total profit is increases and cycle length and trade credit period are also increases.
6. On increase in the deterioration rate $'\theta'$ the total profit increases and cycle length and trade credit period is also increases.

Conclusion

This study examines the retailer's optimal strategy based on non-linear holding and stock dependent demand of his product when he is receiving a trade credit period from his/her supplier. Basically, this research work considered deteriorating items under the effect of inflation where shortages are permitted and partially backlogged. The primary objective of this study is to determine the optimal ordering quantity and the ending inventory level which maximizes the retailer's total profit per unit time. From the numerical illustration we conclude that we get maximum profit when the trade credit period is greater than the cycle length. From sensitivity analysis we observed that lessor the deterioration rate of inventory, the total profit is greater. For further research this study can be extended in stochastic situations.

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