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(Dedicated to Professor G. C. Sharma on His 85^{th} Birth Anniversary Celebrations)

AN EOQ MODEL WITH TRADE CREDIT BASED DEMAND UNDER INFLATION

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Abstract

In this work, an EOQ model is presented with trade credit period and time dependent demand under inflation and delay in payments for deteriorating items. Shortages are permitted and partially backlogged that depends on the waiting time of next replenishment cycle. The holding cost and deterioration rate is considered constant. The aim of this study is to maximize the total profit. An algorithm is presented to get the optimal values of total profit, total inventory and stock-out period. To illustrate theoretical model numerical assessments, graphical representation and sensitivity analysis is also discussed.

2020 Mathematical Sciences Classification: 90B05, 90B10, 90B50.
Keywords and Phrases: Trade credit period and time dependent demand, inflation, delay in payments, deteriorating items, partially backlogged shortages.

1 Introduction

There are so many factors such as demand, deterioration, inflation, holding cost, shortages etc. that effects a business directly. Deterioration of products during storage time is a common problem that industries face. Deterioration is described as decay or spoilage of products that affects the value of products. Similarly, demand of a product is defined as how much consumers want a companys product in a given duration. Price of product itself and related complementary goods, income of consumers, fashion trends are some factors that decides the demand of a product. Storehouses costs such as rents, salaries of these storehouses employees are termed as carrying cost and costs of financing, damage, handling inventory are some aspects that determine holding cost of an inventory system. Increase in prices and fall in the purchasing value of money is termed as inflation and it plays a major role in todays business world. There are a number of researchers that developed inventory models with including these aspects. With constant demand and decay rate, [5] presented A two-storage inventory model for perishable products under trade credit policy and shortages. Similarly, [33] introduced ordering policies with constant demand, deterioration and carrying cost under shortages. [18] and [4] investigated the effect of inflation on an inventory model with constant demand rate. Considering constant type of demand, [7], [1] and [35] also established ordering policies under trade credit policy. Researchers such as [8] and [42] developed inventory models with price linked demand for Weibull deteriorate commodities whereas for such products [28] analysed inventory control model with linear demand and carrying cost. [17], [15] and [30] developed inventory models for perishable products with price sensitive demand, linearly time linked deterioration rate and holding cost under fully backlogged shortages. [10] studied the effects of inflation and time value of money on an inventory model with linearly time linked demand under shortages, later [13] redevelop [10]s model by modifying the hypothesis of uniform inventory in each replenishment cycle. Considering linear carrying cost and time sensitive demand rate under without shortages, [9] represented inventory model which is applicable for food grains, fashion clothes and electronic products and with same assumptions [22] derived inventory model for those industries that use preservation techniques to control the deterioration. [2] and [12] derived inventory models for perishable commodities with stock sensitive demand under without shortages with storage time linked and constant carrying cost respectively and similarly, [43] also presented inventory model with stock induced demand and carrying cost and discussed it with and without shortages. For retail business [14] presented inventory model for perishable products with shortages and stock dependent demand under inflation and time discounting. With inventory induced demand and linearly time sensitive carrying cost, [41] developed inventory model for deteriorating commodities under inflation. [6] and [36] presented two-storehouse inventory model for single perishable product with time, selling price and recurrence of advertisement linked demand rate under partially backlogged shortages and in addition [36] also take account of alternative trade credit policy. Considering uniform demand and production rate, [32] presented inventory model with two-level trade credit strategy where supplier provide retailer a full trade-credit policy whereas retailer give their customers a partial trade credit policy for exponentially deteriorating products. [39] discussed two cases with time sensitive and uniform demand and time dependent and uniform carrying cost for case 1 and case 2 respectively under without shortages. For the products that deteriorate with time, [20] developed inventory model with stock sensitive demand and [3] studied the effect of price induced demand and default risk on optimal customer credit duration and cycle length under shortages. [19] discussed a production inventory model which comprise an unfilled-order backlog for an inventory system for exponential deteriorating products and later [29] presented an optional method to get the optimal aspects of [19]s model. [16] and [34] discussed inventory models under inflation with ramp-type demand and advertisement sensitive demand respectively. Under partially backlogged shortages, [23] discussed inventory model with exponentially decreasing time sensitive demand and [37] presented inventory model where demand depends on inventory level and time during storage duration and shortage duration respectively. For company possessed storehouses where deteriorating products stored for extended time with extra caution, [40] developed an EOQ model with linearly time induced demand and discussed it with both exponentially and linearly time sensitive carrying cost. For perishable products, [31] presented inventory model with time linked increasing demand and fixed production rate under without shortages and on the other hand, considering shortages, [11] discussed a cost minimization framework with promotional work and selling price induced demand. For non-spontaneous perishable products under inflation and shortages, [38] studied the effect of linearly time linked carrying cost on life time inventory model with price and stock sensitive Demand whereas [24] presented inventory model with price and advertisement sensitive demand under trade credit policy. Sometimes, to promote market competitiveness supplier and retailer both accept trade credit policy and provides price discount, considering these facts, for perishable products under shortages, [25] derived inventory model with stock linked demand and linearly time induced carrying cost and [27] presented two-level inventory model with price and stock sensitive demand. [26] analysed the retailers replenishment policies for perishable products with delay in payments where the demand rate decreases with time without shortages. [21] developed inventory model with time and selling price dependent demand and shortages under inflation and trade credit policy for constantly deteriorate commodities.

Demand is not always constant this varies with time. Just like the demand for coolers and fans goes high in summer, the demand for heater-geyser is more in winter. Apart from the season, celebrations also affect the demand, for example, the demand for clothes and jewelry is high during weddings and festivals. Nowadays fashion has also become a factor in generating demand. The increase in demand for masks, sanitizers, and other medical items in covid-19 is another example of time-dependent demand. When the credit period is offered by the supplier to the wholesaler, then a demand can be increased indirectly like the wholesaler can generate sales (like Diwali sale). Apart from this he/she can reduce inventory costs by ordering more goods in quantity and he/she can generate demand by selling goods to the customer at a lower price.

Considering the above facts in the present study, an inventory model is developed for spontaneous perishable products with trade credit period and time induced demand, constant carrying cost and deterioration rate under inflation. Delay in payments and shortages are tolerated and shortages are partially backlogged. The optimal ordering policies are established by optimizing the total profit and stock-out duration. The theoretical model is discussed with examples and sensitivity analysis of various parameters.

This work is arranges in the following manner: in section 2, the postulates and symbols of this study are mentioned. Mathematical representation with solution and solution procedure of this model is presented in section 3 and 4. Numerical examples, sensitivity analysis and results with observations are discussed in section 5, 6 and 7 respectively. Conclusion and future work in this direction is discussed in section 8.

2 Assumptions and Notations

The following notations and assumptions are applied to develop our model.

2.1 Assumptions

We have considered the upcoming hypothesis to construct the mathematical model of present inventory model

- Lead time is minimal.
- Replenishment rate is infinite.
- The infinite planning horizon is considered.
- The demand rate D_p depends on time and credit period π that is, $D_p(\pi, t) = \alpha\pi^{\lambda}e^{\sigma t}$, where α is the selling parameter and $\lambda > 0, 0 < \sigma < 1$.
- In present work inventory model is derived for single spontaneous perishing products.
- Supplier didnt offered the replacement or return or repair policy.
- Shortages are permitted and the fraction of shortages backordered depends on the awaiting time for the upcoming replenishment and $S(t) = e^{-\delta_p(T-t)}$ where $0 \leq \delta_p \leq 1$.
- During the trade credit period, the retailer need not to clear the account with the supplier. This policy is provided by the supplier to the retailer under terms and conditions for a fixed duration.

2.2 Notations

Symbols	P_0	ordering cost per order
	H_p	holding cost per item per order
	C_p	purchasing cost per item
	S_p	unit selling cost ($S_p > C_p$)
	C_2	shortage cost per unit per order
	C_0	lost sales cost per order
	R_0	inflation rate
	π	trade credit period
	P_c	interest charged per \$ /year
	P_e	interest earned per \$ /year
	θ_p	deterioration rate, $0 \leq \theta_p < 1$
	S	maximum inventory level
	P	maximum demand backlogged/cycle
	Q	total order quantity
	T	cycle length
Decision variables	t_P	stock out time period
Functions	$D_p(\pi, t)$	The demand rate D_p depends on time and credit period π that is, $D_p(\pi, t) = \alpha\pi^{\lambda}e^{\sigma t}$, where α is the selling parameter and $\lambda > 0, 0 < \sigma < 1$
	$S(t)$	$S(t) = e^{-\delta_p(T-t)}$ where $0 \leq \delta_p \leq 1$
	$I_p(t)$	inventory level, $0 \leq t \leq t_p$
	$I_s(t)$	inventory level, $t_p \leq t \leq T$
	$TP(t_p)$	total profit

3 Model Formulation

The inventory level for this paper is drafted in Figure 3.1. During the period $(0, t_p)$ the inventory level I_p depends on both demand and deterioration. It is governed by the equation:

$$\frac{dI_p(t)}{dt} = -D_p - \theta_p I_p(t) \qquad ; 0 \leq t \leq t_p. \tag{3.1}$$

The solution of the equation (3.1) with boundary condition $I_p(t_p) = 0$ is

$$I_p(t) = x_3 e^{-\theta_p t}(e^{x_2 t_p} - e^{x_2 t}), \tag{3.2}$$

where $x_1 = \alpha\pi^{\lambda}$, $x_2 = \sigma + \theta_p$ and $x_3 = \dfrac{x_1}{x_2}$.

The maximum inventory level is S, where

$$S = I_p(0) = x_3(e^{x_2 t_p} - 1). \tag{3.3}$$

During the period (t_p, T), the inventory level $I_s(t)$ is given by the differential equation

$$\frac{dI_s(t)}{dt} = -D_p e^{-\delta_p(T-t)} \qquad ; t_p \leq t \leq T. \tag{3.4}$$

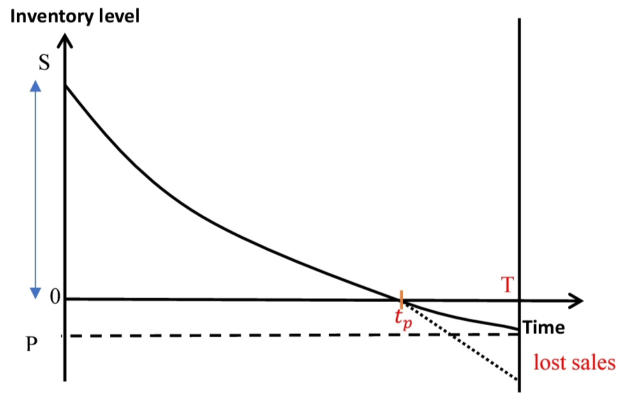

***Figure* 3.1:** Graphical representation of the inventory model

Using boundary condition $I_s(t_p) = 0$, the solution of the above Equation 3.4 is given by

$$I_s(t) = x_5 e^{-\delta_p T}(e^{x_4 t_p} - e^{x_4 t}), \tag{3.5}$$

where $x_4 = \sigma + \delta_p$ and $x_5 = \dfrac{x_1}{x_4}$.

The negative inventory is P, where

$$P = -I_s(T) = x_5 e^{-\delta_p T}(e^{x_4 T} - e^{x_4 t_p}). \tag{3.6}$$

Total order quantity $Q = S + P$.

$$Q = x_3(e^{x_2 t_p} - 1) + x_5 e^{-\delta_p T}(e^{x_4 T} - e^{x_4 t_p}). \tag{3.7}$$

The total cost per cycle depends on the following:

Ordering cost

$$f_1 = P_0,$$

Purchase cost

$$f_2 = C_p[S + P],$$

Holding cost

$$\begin{aligned} f_3 &= H_p \int_0^{t_p} I_p\,(t)\, e^{-R_0 t} dt \\ &= H_p x_3 \left[\frac{e^{x_2 t_p}(1 - e^{-x_6 t_p})}{x_6} + \frac{(1 - e^{-x_7 t_p})}{x_7} \right], \end{aligned}$$

where $x_6 = R_0 + \theta_p$ and $x_7 = R_0 - \sigma$.

Sales revenue

$$\begin{aligned} f_4 &= S_p \left[\int_0^{t_p} D_p e^{-R_0 t} dt + \int_{t_p}^{T} e^{-R_0 T} D_p e^{-\delta_p (T-t)} dt \right] \\ &= S_p x_1 \left[\frac{e^{-x_7 T} - e^{(x_8 t_p - x_9 T)}}{x_6} + \frac{(1 - e^{-x_7 t_p})}{x_7} \right], \end{aligned}$$

where $x_8 = \sigma + \delta_p$ and $x_9 = R_0 + \delta_p$.

Shortage cost

$$f_5 = \ -C_2 \int_{t_p}^{T} I_s\,(t)\, e^{-R_0 t} dt$$

$$= C_2 x_5 e^{-\delta_p T}\left[\frac{e^{-x_{10}t_p} - e^{x_{10}T}}{x_{10}} + \frac{e^{-t_p x_4}(e^{-R_0 T} - e^{-R_0 t_p})}{R_0}\right],$$

where $x_{10} = x_4 + R_0$.

Lost sales cost

$$f_6 = C_0\left[\int_{t_p}^{T} e^{-R_0 t} D_p (1 - e^{-\delta_p (T-t)})dt\right]$$
$$= C_0 x_1\left[\frac{(e^{x_7 T} - e^{x_7 t_p})}{x_7} + \frac{e^{-\delta_p T}(e^{x_{11}T} - e^{-x_{11}t_p})}{x_{11}}\right],$$

where $x_{11} = \sigma + \delta_p - R_0$.

Interest payable

***Case* 1.** $0 \le \pi \le t_p$

$$SP_1 = C_p P_c \int_{\pi}^{t_p} I_p(t) e^{-R_0 t} dt$$
$$= C_p P_c x_3\left[\frac{(e^{-x_{12}t_p} - e^{-x_{12}\pi})}{x_{12}} + \frac{e^{t_p x_2}(e^{-x_6 \pi} - e^{-x_6 t_p})}{x_6}\right],$$

where $x_{12} = x_2 + \theta_p - R_0$.

***Case* 2.** $t_p \le \pi \le T$

$$SP_2 = 0.$$

Interest earned

***Case* 1.** $0 \le \pi \le t_p$

$$SE_1 = S_p P_e \int_0^{\pi} D_p t e^{-R_0 t} dt$$
$$= S_p P_e x_{13}[1 + e^{-x_7 \pi}(x_7 \pi - 1)],$$

where

$$x_{13} = \frac{x_1}{x_7^2}$$

***Case* 2.** $t_p \le \pi \le T$

$$SE_2 = S_p P_e\left[\int_0^{t_p} D_p t e^{-R_0 t} dt + (\pi - t_p)\int_0^{t_p} D_p e^{-R_0 t} dt\right]$$
$$= S_p P_e x_{13}[(1 + e^{-x_7 t_p}(x_7 t_p - 1)) + x_7(\pi - t_p)(1 - e^{-x_7 t_p})].$$

The total profit per unit time, is described as

$$TP(t_p) = \begin{cases} TP_1(t_p); 0 \le \pi \le t_p \\ TP_2(t_p); t_p \le \pi \le T, \end{cases}$$

where

$$TP_1(t_p) = \frac{(f_4 + SE_1 - f_1 - f_2 - f_3 - f_5 - f_6 - SP_1)}{T}, \tag{3.8}$$

$$TP_1(t_p) = \frac{1}{T}\left\langle\left\{S_p x_1\left[\frac{e^{-x_7 T} - e^{(x_8 t_p - x_9 T)}}{x_6} + \frac{(1 - e^{-x_7 t_p})}{x_7}\right]\right\} + S_p P_e x_{13}\big[1 + e^{-x_7 \pi}(x_7 \pi - 1)\big]\right. \tag{3.9}$$

$$
\begin{aligned}
&- P_0 - C_p\big[x_3(e^{x_2 t_p}-1) + x_5 e^{-\delta_p T}(e^{x_4 T} - e^{x_4 t_p})\big] - H_p x_3\left[\frac{e^{x_2 t_p}(1-e^{-x_6 t_p})}{x_6} + \frac{(1-e^{-x_7 t_p})}{x_7}\right]\\
&- C_2 x_5 e^{-\delta_p T}\left[\frac{(e^{-x_{10} t_p} - e^{x_{10} T})}{x_{10}} + \frac{e^{-t_p x_4}(e^{-R_0 T} - e^{-R_0 t_p})}{R_0}\right]\\
&- C_0 x_1\left[\frac{(e^{x_7 T} - e^{x_7 t_p})}{x_7} + \frac{e^{-\delta_p T}(e^{x_{11} T} - e^{-x_{11} t_p})}{x_{11}}\right]\\
&- C_p P_c x_3\left[\frac{(e^{-x_{12} t_p} - e^{-x_{12}\pi})}{x_{12}} + \frac{e^{t_p x_2}(e^{-x_6 \pi} - e^{-x_6 t_p})}{x_6}\right]\Bigg\rangle,
\end{aligned}
$$

$$
TP_2(t_p) = \frac{(f_4 + SE_2 - f_1 - f_2 - f_3 - f_5 - f_6 - SP_2)}{T}, \tag{3.10}
$$

$$
\begin{aligned}
TP_2(t_p) = &\frac{1}{T}\Bigg\langle\left\{S_p x_1\left[\frac{e^{-x_7 T} - e^{(x_8 t_p - x_9 T)}}{x_6} + \frac{(1-e^{-x_7 t_p})}{x_7}\right]\right\} \qquad (3.11)\\
&+ S_p P_e x_{13}\big[(1 + e^{-x_7 t_p}(x_7 t_p - 1)) + x_7(\pi - t_p)(1 - e^{-x_7 t_p})\big]\\
&- P_0 - C_p\big[x_3(e^{x_2 t_p}-1) + x_5 e^{-\delta_p T}(e^{x_4 T} - e^{x_4 t_p})\big]\\
&- H_p x_3\left[\frac{e^{x_2 t_p}(1-e^{-x_6 t_p})}{x_6} + \frac{(1-e^{-x_7 t_p})}{x_7}\right]\\
&- C_2 x_5 e^{-\delta_p T}\left[\frac{(e^{-x_{10} t_p} - e^{x_{10} T})}{x_{10}} + \frac{e^{-t_p x_4}(e^{-R_0 T} - e^{-R_0 t_p})}{R_0}\right]\\
&- C_0 x_1\left[\frac{(e^{x_7 T} - e^{x_7 t_p})}{x_7} + \frac{e^{-\delta_p T}(e^{x_{11} T} - e^{-x_{11} t_p})}{x_{11}}\right] - 0\Bigg\rangle.
\end{aligned}
$$

4 Solution Procedure

***Step* 1.** In the beginning differentiate TP_i with respect to t_p ,i.e. $\dfrac{d(TP_i)}{dt_p}$ $i = 1, 2$ respectively.

***Step* 2.** Putting the above derivative equal to zero, i.e. $\dfrac{d(TP_i)}{dt_p} = 0$.

***Step* 3.** Find the value of t_p.

***Step* 4.** Find $\dfrac{d^2(TP_i)}{dt_p^2}$.

***Step* 5.** If $\dfrac{d^2(TP_i)}{dt_p^2} < 0$ at t_p then TP_i will be maximum.

With the help of MATLAB software, the optimal value of t_p which is denoted by t_p^* can be obtained. Then from Equations (3.7),(3.9) and (3.11), the values of TP^* and Q^* can be found. Here we assume suitable values for $P_0, H_p, C_P, S_p, C_0, C_2, R_0, \pi, P_c, P_e, \theta_p, T, \alpha, \lambda, \sigma$ and δ_p with appropriate units.

5 Numerical Examples

The trial and error method has been used for the numerical data of this paper. Tried increasing and decreasing all fixed values and finally the set of fixed values which gives maximum total profit is as follows

P_0	10000	R_0	0.7	H_p	5
θ_p	.5	C_p	5	S_p	40
σ	0.3	λ	4	α	5000
δ_p	0.3	C_2	3	C_0	3
P_c	2	P_e	4	T	1

.

***Example* 5.1.** When $0 \le \pi \le t_p$.

Using the above data with $\pi = 0.02$, we find the optimal values as $t_p^* = 0.6733, TP_1{}^* = 8607.6$ *and* $Q^* = 29.3899$. For the data taken in this, we get $\dfrac{d(TP_1)}{dt_p} = 0.00$. and $\dfrac{d^2(TP_1)}{dt_p^2} = -0.02$. i.e. $\dfrac{d^2(TP_1)}{dt_p^2} < 0$.

***Example* 5.2.** When $t_p \le \pi \le T$.

In this case we consider $\pi = 0.46$. Using the above data we obtain the optimal values $t_p^* = 0.4541, {TP_2}^* = 359.8152$ *and* $Q^* = 63.7898$. For the data taken in this, we get $\dfrac{d(TP_2)}{dt_p} = 0$ and $\dfrac{d^2(TP_2)}{dt_p^2} < 0$.

The examples are solved by MATLAB software.

6 Sensitivity Analysis

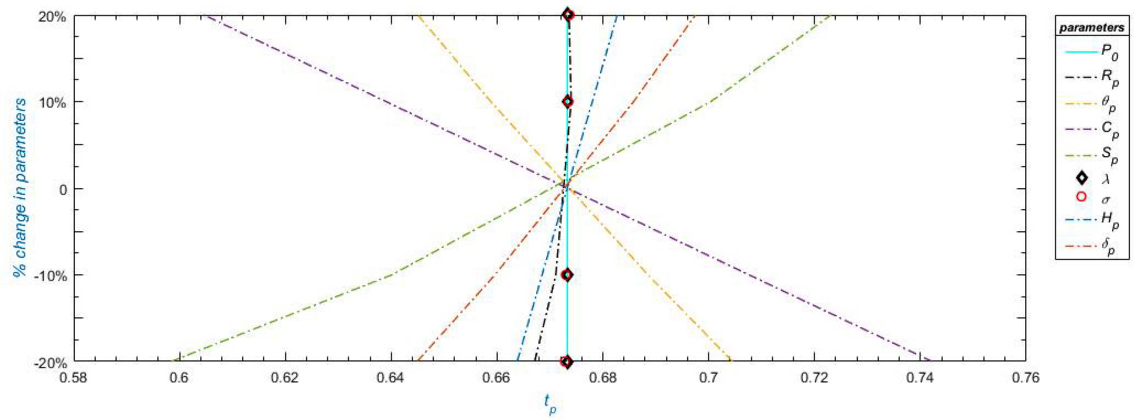

***Figure* 6.1:** Analysis of t_p with respect to the parameters

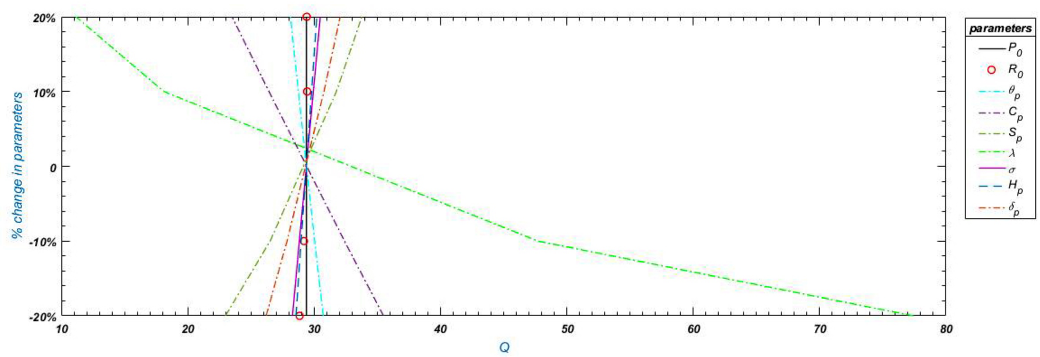

***Figure* 6.2:** Analysis of Q with respect to the parameters

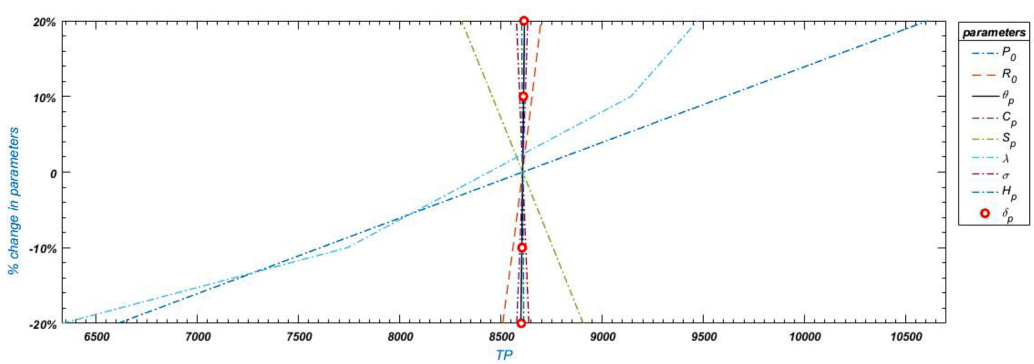

***Figure* 6.3:** Analysis of TP with respect to the parameters

Now, using ***Example* 5.1** a sensitivity analysis is examined to analyze the effects of changes in parameters on optimal values of t_p^*, $Q^* and\, TP_1{}^*$. The results are described in Table 6.1.

***Table* 6.1:** Sensitivity analysis of key parameters

parameters	% change	t_p	TP_1	Q
P_0	-20	0.6733	6607.6 0	29.3899
	-10	0.6733	7607.60	29.3899
	+10	0.6733	9607.60	29.3899
	+20	0.6733	10608.0	29.3899
R_0	-20	0.6671	8508.60	28.8508
	-10	0.6711	8559.30	29.1984
	+10	0.6740	8653.60	29.4509
	+20	0.6736	8697.50	29.4160
θ_p	-20	0.7045	8598.20	30.7251
	-10	0.6885	8603.00	30.0463
	+10	0.6588	8612.00	28.7514
	+20	0.6450	8616.20	28.1343
C_p	-20	0.7422	8577.70	35.4926
	-10	0.7076	8593.30	32.4018
	+10	0.6390	8620.50	26.4278
	+20	0.6046	8632.20	23.5051
S_p	-20	0.5984	8905.80	22.9833
	-10	0.6401	8757.40	26.5221
	+10	0.7004	8456.80	31.7653
	+20	0.7231	8305.20	33.7798
λ	-20	0.6733	6332.30	77.4150
	-10	0.6733	7740.20	47.6993
	+10	0.6733	9142.10	18.1086
	+20	0.6733	9471.40	11.1576
σ	-20	0.6728	8637.40	28.2880
	-10	0.6730	8622.70	28.8336
	+10	0.6735	8592.20	29.9397
	+20	0.6737	8576.50	30.4920
H_p	-20	0.6638	8612.50	28.5646
	-10	0.6685	8610.10	28.9724
	+10	0.6780	8605.10	29.7996
	+20	0.6827	8602.60	30.2103
δ_p	-20	0.6449	8600.40	26.2033
	-10	0.6596	8604.20	27.8604
	+10	0.6858	8610.80	30.7790
	+20	0.6975	8613.60	32.0666

7 Results and observation

Effect of % change in parameters on t_p, Q and TP is described as:

- As we raise the parameter P_0, total inventory Q and stock-out period t_p remains unchanged and total profit TP increases rapidly.
- Hike in the parameter R_0 remains t_p and Q almost unchanged and there is a slight increase in total profit TP.
- Total profit TP and total inventory Q behaves proportional to the parameter θ_p whereas t_p behaves inversely proportional.
- As we increase the parameter S_p, Q and t_p boosts and TP declines, on the other hand, total inventory Q, total profit TP and t_p behaves exactly opposite for the parameter C_p.
- When the parameter λ grows, t_p remains unchanged, TP and Q rapidly raises and drops respectively.

- Raising the parameter σ results t_p remains unchanged whereas TP and Q slightly hikes and declines respectively.
- As the parameters H_p and δ_p grows, t_p and Q rises whereas TP remains almost unchanged.

8. Conclusion and Future Research Direction

In this article, we presented an inventory model for spontaneous perishable products with trade credit period and time dependent demand rate under the effect of inflation. The carrying cost and deterioration of products are considered constant over the ordering cycle time. Partially backlogged shortages and delay in payments is allowed. The objective of this model is to maximizing the total profit by optimizing total inventory and stock-out period. Numerical example is discussed to demonstrate this model. The major findings of this study are

- If we increase the trade credit duration, it results more profit.
- To get maximum total profit, retailer should raise ordering cost.
- Hike in selling price of commodities, reduces total profit.

The further study in this direction can be done by considering variable holding cost and deterioration rate and selling price dependent demand rate. Also, this study can be performed for non-instantaneous deteriorating items.

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