

Perishable Inventory Models for Stock Dependent Quadratic Demand under Inflation

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Abstract: *Inventory models are developed with stock dependent quadratic demand under inflation for perishable items. It is assumed that the deterioration rate is constant. The solution of the model is obtained using the procedure of standard Reccati differential equation. The effect of inflation on the system total profit is studied for items having inventory level dependent quadratic demand. The model is tested through a hypothetical example. At last, the sensitivity of the model is presented and analyzed.*

Keywords: *Quadratic demand, inflation, stock dependent, perishable, inventory*

I. Introduction

In inventory system, different types of demand generally considered are constant demand, time dependent demand, price dependent demand, probabilistic demand and stock dependent demand. It is a common belief that large piles of goods displayed in super markets will lead the customer to buy more (Levin et. al [1]). Silver and Peterson [2] have also noted that the sales at retail level tend to be proportional to the inventory displayed. Since then researchers have made attempts to investigate inventory models assuming a functional form between the demand rate and on-hand inventory. Gupta and Vrat [3] suggested inventory models with variable rates of demand, Baker and Uber [4] formulated a deterministic inventory system with stock dependent demand rate, Mandal and Phaujdar [5] discussed an Inventory Model for Deteriorating Items and Stock Dependent Consumption Rate. Datta and Pal [6] presented a note on an inventory level dependent demand rate, Goh [7] developed an EOQ models with general demand and holding cost function, Ray and Chaudhuri [8] presented an EOQ model under inflation and time discounting allowing shortages, Beltran and Krass [9] discussed about dynamic lot sizing with returning items and disposals. Raman Patel and Reena [10] discussed an inventory model for Weibull deteriorating items with stock dependent demand, time varying holding cost and variable selling price. Rekha Rani et al [11] studied an optimal inventory model for time dependent decaying items with stock dependent demand rate and shortages. Raman Patel and Reena [12] developed a deteriorating items inventory model with stock dependent demand under shortages and variable selling price. Pal and Chandra [13] studied a periodic review inventory model with stock dependent demand, permissible delay in payment and price discount on backorders. Yashveer Singh et al [14] studied an inflation induced stock-dependent demand inventory model with permissible delay in payment. Tripathi and Mishra [15] developed an inventory model with inventory-dependent demand for deteriorating items in a single warehouse system. Maisuriya et al [16] discussed an EOQ model with stock dependent demand rate and variable time. Singh and Malik [17] studied an inventory model with stock-dependent demand with two storages capacity for non-instantaneous deteriorating items. Kuo-Lung Hou et al [18] discussed an inventory model for deteriorating items with stock-dependent selling rate and partial backlogging under inflation. Valliathal and Uthayakumar [19] developed an EOQ model for perishable items under stock and time-dependent selling rate with shortages. Padmanabhan and Vrat [20] developed EOQ models for perishable items under stock dependent selling rate. Valliathal and Uthayakumar [21] presented a new study of an EOQ model for deteriorating items with shortages under inflation and time discounting. Yen-Wen Wang et al [22] studied inventory models for deteriorating items with variable selling price under stock-dependent demand. Nita Shah et al [23] presented optimal integrated inventory policy for stock-dependent demand when trade credit is linked to order quantity. Patra and Ratha [24] discussed an inventory replenishment policy for deteriorating items under inflation in a stock dependent consumption market with shortage. These studies were based on the assumption that the stock dependent demand rate is either linear or exponential.

Thus it is proposed to study the optimal inventory policies for deteriorating items when the demand rate is a quadratic function of stock level. Now, in this paper, section-2 gives some usual assumptions and notations to develop the mathematical model. Section-3 contains the formulation and solution of the model. A numerical example and the sensitive analysis are given in this section. Section-4 gives some concluding remarks.

II. Assumptions And Notations

The mathematical model is developed on the following assumptions and notations:

- (i) The Demand rate $D(t)$ at time t is assumed to be $D(t) = a + bI(t) + c(I(t))^2$, $a \geq 0, b \neq 0, c \neq 0$. Here 'a' is the initial rate of demand, 'b' is the initial rate of change of the demand and 'c' is the acceleration of demand rate.
- (ii) Replenishment rate is infinite and lead time is zero.
- (iii) p is the selling price per unit.
- (iv) The rate of inflation is constant
- (v) The unit cost and other inventory related cost are subjected to the same rate of inflation, say k . This implies that the ordering quantity can be determined by minimizing the total system cost over the planning period.
- (vi) $A(t)$ is the ordering cost at time t .
- (vii) $\theta(0 < \theta < 1)$ is the constant rate of deterioration.
- (viii) $C(t)$ denotes unit cost at time t .
- (ix) $I(t)$ is the inventory level at time t .
- (x) $Q(t)$ is the ordering quantity at time $t=0$
- (xi) 'h' is per unit holding cost excluding interest charges per unit per year.

III. Formulation And Solution Of The Model

The objective of the model is to determine the optimum profit for items having stock dependent quadratic demand and the rate of deterioration is assumed to be a constant with no shortages.

The inventory level depletes as the time passes due to demand and deterioration during $(0, t_1)$ and due to demand only during the period (t_1, T) .

If $I(t)$ be the inventory level at time t , the differential equations which describes the inventory level at time t are given by

$$\frac{dI(t)}{dt} + \theta I(t) = -(a + bI(t) + c(I(t))^2) \quad 0 \leq t \leq t_1 \quad (1)$$

$$\frac{dI(t)}{dt} = -(a + bI(t) + c(I(t))^2) \quad t_1 \leq t \leq T \quad (2)$$

together with $I(t)=I(0)$ at time $t=0$ and $I(T)=0$. (3)

Now equation (1) can be expressed as

$$\frac{dI(t)}{dt} = -(a + (b + \theta)I(t) + c(I(t))^2) \quad (4)$$

which is a non-linear first order Reccati equation. The solution of equation (4) is obtained as follows:
Let 'f' is any solution of equation (4) and also we use the following transformation

$$I(t) = f + \frac{1}{v} \quad (5)$$

where v is a function of time 't'.

Then the above equation (5) reduces to linear equation in 'v' as

$$\frac{dv}{dt} - (b + \theta + 2cf)v = c \quad (6)$$

To get an explicit solution of equation (6), we now assume $f(t)$ as

$$f(t) = t \quad (7)$$

and using the initial conditions, then the solution of equation (6) is given by

$$v = \frac{ctt_1 - \frac{c(b + \theta)t_1^2}{2} + (b + \theta)t_1 + \frac{c(b + \theta)t_1^3}{2} - 1}{t_1(1 - (b + \theta)t - ct^2)} \quad (8)$$

Thus from equations (5), (7) and (8), the solution of equation (4) can be expressed as

$$I(t) = t + \frac{t_1(1 - (b + \theta)t - ct^2)}{\left(ctt_1 - \frac{c(b + \theta)t_1 t^2}{2} + (b + \theta)t_1 + \frac{c(b + \theta)t_1^3}{2} - 1 \right)} \text{ for } 0 \leq t \leq t_1 \quad (9)$$

In a similar manner, we obtained the solution of equation (2) which is given by

$$I(t) = t + \frac{t_1(1 - bt - ct^2)}{\left(ctt_1 - \frac{bct_1 t^2}{2} + bt_1 + \frac{bct_1^3}{2} - 1 \right)} \text{ for } t_1 \leq t \leq T \quad (10)$$

Since $I(0) = Q$ at $t = T$, the Ordering Quantity 'Q' is calculated as

$$Q = \frac{2T}{2(b + \theta)T + c(b + \theta)T^3 - 2} \quad (11)$$

Let $C(t)$ denotes the unit cost at time t .

i.e., $C(t) = C_0 e^{kt}$ where C_0 is the unit cost at time zero.

Let $A(t)$ denotes the Ordering cost at time t .

i.e., $A(t) = A_0 e^{kt}$ where A_0 is the ordering cost at time zero.

Total system cost during the planning period ' τ ' is the sum of the Material cost, ordering cost and Carrying cost. Assume that $\tau = m \cdot T$, Where ' m ' is an integer for the number of replenishments to make during the period ' τ ', and ' T ' is time between replenishments.

The Ordering cost during the period $(0, \tau)$ is

$$\begin{aligned} & [A(0) + A(T) + A(2T) + A(3T) + \dots + A(m-1)T] \\ & = [A_0 e^{(0)kT} + A_0 e^{(1)kT} + A_0 e^{(2)kT} + A_0 e^{(3)kT} + \dots + A_0 e^{(m-1)kT}] \\ & = A_0 (1 + e^{kT} + e^{2kT} + e^{3kT} + \dots + e^{(m-1)kT}) \end{aligned}$$

The Ordering Cost is $A_0 \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right)$ where $\tau = mT$ (12)

The Material cost during the period $(0, \tau)$ is

$$\begin{aligned} & Q[C(0) + C(T) + C(2T) + C(3T) + \dots + C(m-1)T] \\ & = Q[C_0 e^{(0)kT} + C_0 e^{(1)kT} + C_0 e^{(2)kT} + C_0 e^{(3)kT} + \dots + C_0 e^{(m-1)kT}] \\ & = QC_0 (1 + e^{kT} + e^{2kT} + e^{3kT} + \dots + e^{(m-1)kT}) \\ & = QC_0 \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) \end{aligned} \quad (13)$$

Similarly, The Carrying Cost/holding cost during the period $(0, \tau)$ is $C(t)h \int_0^T I(t)dt$

But we have $C(t) = C_0 \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right)$ in the period $(0, \tau)$

The Carrying Cost/holding cost is

$$\begin{aligned}
 &= C_0 \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) h \int_0^T I(t) dt = C_0 h \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) \left(\int_0^{t_1} I(t) dt + \int_{t_1}^T I(t) dt \right) \\
 &= C_0 h \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) \left[(a + bp + cp^2) \left(\frac{t_1^2}{2} + \frac{\theta t_1^4}{12} \right) - \left[\frac{(a + bp + cp^2)(T - t_1)^2}{2} \right] \right] \quad (14)
 \end{aligned}$$

The total cost over the period $(0, \tau)$ is

TC = Ordering cost + Material cost + Carrying cost

$$\begin{aligned}
 &= A_0 \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) + QC_0 \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) + C_0 h \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) \left(\int_0^{t_1} I(t) dt + \int_{t_1}^T I(t) dt \right) \\
 &= \left(A_0 + QC_0 + C_0 h \left(\int_0^{t_1} I(t) dt + \int_{t_1}^T I(t) dt \right) \right) \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right)
 \end{aligned}$$

Thus we have

$$TC = \left(A_0 + C_0 (a + bp + cp^2) \left(T + \frac{\theta T^3}{6} \right) + C_0 h \left((a + bp + cp^2) \left(\frac{t_1^2}{2} + \frac{\theta t_1^4}{12} \right) - \frac{(a + bp + cp^2)(T - t_1)^2}{2} \right) \right) \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) \quad (15)$$

If shortages are not allowed then the Sales revenue per cycle is given by

$$\begin{aligned}
 p \int_0^T D(t) dt &= p \int_0^T (a + bI(t) + c(I(t))^2) dt \\
 p \int_0^T D(t) dt &= p \left(\int_0^{t_1} (a + bI(t) + c(I(t))^2) dt + \int_{t_1}^T (a + bI(t) + c(I(t))^2) dt \right) \quad (16)
 \end{aligned}$$

Thus the total profit $P(T, \tau)$ per unit time is given by

$P(T, \tau) = (1/T)(\text{Sales revenue} - \text{Total cost})$

$$\begin{aligned}
 &= \left(\frac{1}{T} \right) \left(p \left(\int_0^{t_1} (a + bI(t) + c(I(t))^2) dt + \int_{t_1}^T (a + bI(t) + c(I(t))^2) dt \right) - \left(A_0 + QC_0 + C_0 h \left(\int_0^{t_1} I(t) dt + \int_{t_1}^T I(t) dt \right) \right) \left(\frac{e^{k\tau} - 1}{e^{kT} - 1} \right) \right) \quad (17)
 \end{aligned}$$

The optimum value of T and τ are obtained by solving

$$\frac{\partial}{\partial T} P(T, \tau) = 0, \quad \frac{\partial}{\partial \tau} P(T, \tau) = 0$$

The necessary and sufficient conditions to maximize the Profit are

$$\frac{\partial^2}{\partial T^2} P(T, \tau) < 0, \quad \frac{\partial^2}{\partial \tau^2} P(T, \tau) < 0 \quad (18)$$

and

$$\left(\frac{\partial^2}{\partial T^2} P(T, \tau) \right) \left(\frac{\partial^2}{\partial \tau^2} P(T, \tau) \right) - \left(\frac{\partial^2}{\partial T \partial \tau} P(T, \tau) \right)^2 > 0 \quad (19)$$

It is found that the optimal conditions are satisfied only for $b > 0$ and $c > 0$ which shows that the model has accelerated growth in demand rate.

IV. Numerical Example

The following hypothetical data is taken to validate the effectiveness of the models developed:

$$\begin{array}{ccccc} a = 200, & b = 0.01, & c = 0.003, & A_0 = 500, & C_0 = 25, \\ \theta = 0.05, & h = 0.03, & k = 0.04 & p = 50 & \end{array}$$

The optimality conditions given by (18) and (19) are satisfied with the choice of the parameter given above. For these values the optimum values of replenishment time (τ), cycle time (T), ordering quantity (Q) and the total profit $P(T, \tau)$ of the system are 0.953, 8.149, 160.994 and 9449.00 respectively when stock dependent quadratic demand rate is considered. These optimum values of the system are tabulated in Table-1 and Table-2 for various values of inflation parameter (k) and deterioration parameter (θ) by keeping the other parameter as a constant. The following are noted from Table-1 and Table-2:

- (i) For a fixed value of $\theta = 0.05$ and the inflation rate k increases from 0.04 to 0.044, the cycle time and the ordering quantity remain unchanged but the total profit $P(T, \tau)$ and replenishment cycle time are marginally effected.
- (ii) For some particular value of $k = 0.04$ and θ increases from 0.046 to 0.054, the cycle time, replenishment cycle time and the total profit $P(T, \tau)$ are effected moderately while the ordering quantity is effected significantly.

V. Sensitive Analysis

To study the sensitivity of optimal values of cycle time, ordering quantity and total profit of the system, the above values of parameters are again considered and the values are given in Table-3. The following observations are made from these two tables:

- (i) The profit function $P(T, \tau)$ is highly sensitive to the changes in the parameter 'p' and also for all the parameters taken together. The profit function is moderately sensitive to the changes in the parameter ' θ ' while it is less sensitive to all other parameter namely ' b ', ' c ', ' k ', ' A_0 ' and ' C_0 '.
- (ii) It is observed that the ordering quantity ' Q ' is highly sensitive w.r.t the changes in the parameters ' b ', ' c ' and ' θ '. It is also highly sensitive for the changes in all the parameters taken together. However the values of ' Q ' increases (decreases) when the parameter values ' b ', ' c ' and ' θ ' decreases (increases).
- (iii) The replenishment time ' τ ' of the inventory system is highly sensitive to the changes in the values of the parameter ' c ', ' τ ' and ' A_0 ', and moderately sensitive to the changes in the parameter value of ' C_0 ' and ' p ', and insignificant to the changes in the parameter values ' b ' and ' k '. However, the replenishment time ' τ ' is highly sensitive to the changes made in all the parameters taken together. It is also observed that the replenishment time ' τ ' increases (decreases) when all the parameter values increases (decreases).
- (iv) The inflation rate ' k ' plays insignificant role in this stock dependent quadratic demand models. Fig-1 also shows the variations of the system total profit for the change made in some parameters.

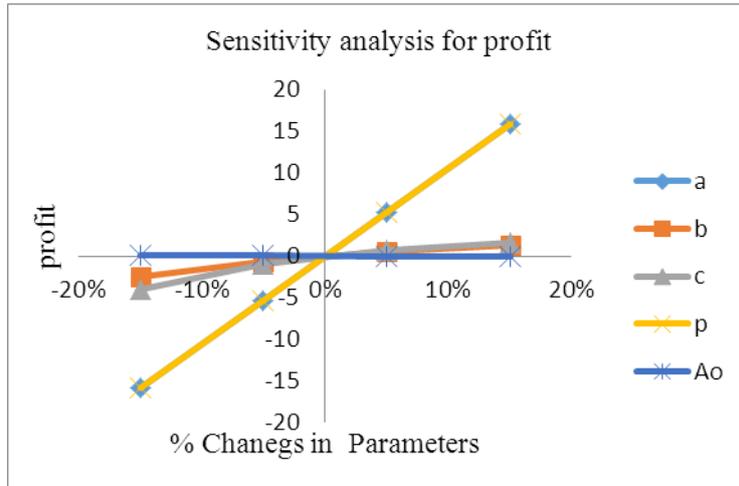


Fig-1: Variations of total profit w.r.t the values of some important parameters

VI. Conclusions

Here stock dependent quadratic demand rate with constant deterioration is considered in developing the inventory models. The solution of the models is obtained using the standard Reccati differential equation method. The system profit is calculated with a numerical example. It is observed that the effect of inflation rate is insignificant in the calculation of the system’s total profit for stock dependent demand models. The sensitivity is performed and discussed.

Table -1:

S.No	θ	K	T	τ	$P(T, \tau)$	Q
1	0.05	0.040	8.149	0.953	9449	160.994
2		0.041	8.149	0.956	9446	160.994
3		0.042	8.149	0.96	9444	160.994
4		0.043	8.149	0.964	9441	160.994
5		0.044	8.149	0.967	9439	160.994

Table -2:

S.No	k	θ	T	τ	$P(T, \tau)$	Q
1	0.04	0.046	8.464	0.814	6927	965.784
2		0.048	8.304	0.881	9088	275.982
3		0.050	8.149	0.953	9449	160.994
4		0.052	7.988	1.032	9598	113.644
5		0.054	7.851	1.119	9680	87.816

Table-3:

Parameters	% change	Change in T (%)	Change in τ (%)	Change in $P(T, \tau)$ (%)	Change in Q (%)
a	15%	0.0000	0.0000	15.8853	0.0000
	5%	0.0000	0.0000	5.2916	0.0000
	-5%	0.0000	0.0000	-5.2916	0.0000
	-15%	0.0000	0.0000	-15.8747	0.0000
b	15%	-1.3989	0.5247	1.2700	-23.8090
	5%	-0.4663	0.1049	0.4974	-9.4339
	-5%	0.4786	-0.1049	-0.6244	11.6271
	-15%	1.4235	0.0000	-2.4341	45.4520
c	15%	-0.9081	29.0661	1.6298	-29.8732
	5%	-0.3068	9.3389	0.6667	-12.4340
	-5%	0.3068	-9.0241	-0.8996	16.5491
	-15%	0.9204	-26.0231	-3.9898	74.2121
θ	15%	-6.7370	36.6212	3.3019	-60.9749
	5%	-2.3070	10.4932	1.8415	-34.2460
	-5%	2.3929	-9.3389	-5.8207	108.6867
	-15%	163.8115	-	-	-
k	15%	152.3623	-	-0.1587	0.0000
	5%	0.0000	0.7345	-0.0529	0.0000
	-5%	0.0000	-0.7345	0.0423	0.0000
	-15%	-	-	0.1482	0.0000

A_o	15%	6.4916	-20.6716	-0.1058	0.0000
	5%	2.3070	-7.4502	-0.0317	0.0000
	-5%	-2.4788	7.9748	0.0317	0.0000
	-15%	-8.0133	25.7083	0.0952	0.0000
C_o	15%	-6.8720	6.4008	-0.7937	0.0000
	5%	-2.3561	2.5184	-0.2646	0.0000
	-5%	2.4297	-3.0430	0.2646	0.0000
	-15%	7.4979	-10.5981	0.7937	0.0000
p	15%	0.0000	14.6905	15.8853	0.0000
	5%	0.0000	4.9318	5.2916	0.0000
	-5%	0.0000	-4.9318	-5.3021	0.0000
	-15%	0.0000	-14.7954	-15.8959	0.0000
All	15%	-8.9459	88.6674	37.6865	-70.2809
	5%	-3.0679	22.2455	13.0278	-43.6327
	-5%	3.1906	-17.9433	-25.9075	316.4460
	-15%	10.0626	-45.9601	-20.4254	-

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