A Deterministic Inventory Model for Perishable Items with Price Sensitive Quadratic Time Dependent Demand Under Trade Credit Policy

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ABSTRACT: *An inventory system is considered with trended demand which is assumed to be a function of price and time dependent quadratic demand. For minimizing the total cost of the inventory system, it is assumed that the deterioration rate is constant and the supplier offers the retailer a credit period to settle the account of the procurement units. To solve the model it is further assumed that shortages are not allowed. Salvage value is also considered and observed its effect on the total cost. A numerical example is given to test the strength of the model. Critical parameters are identified by studying the sensitivity of the system.*

Keywords: *Price sensitive, Quadratic demand, Weibull, holding cost, inventory model, credit policy.*

I.   INTRODUCTION

In modern business, it is well known that 'trade credit policy' is the most effective way of a supplier to encourage retailer to buy more goods and to attract more retailers. Trade credit can also be used as a multi-faceted marketing management (or relationship management) tool which gives some information to the market or to a buyer about the firm or its products or its future plans. The EOQ model developed by Wilson was based on the assumption that the retailer will pay for the items as soon as it is received by the system. In reality the supplier may offer some credit period to the retailer to settle the accounts in a reasonable time period. Thus the delay in payment can be treated as a kind of price discount to the retailer.

Haley and Higgins (1973) studied the relationship between inventory policy and credit policy in the context of the classical lot size model. Chapman et al. (1984) developed an economic order quantity model which considers possible credit periods allowable by suppliers. This model is shown to be very sensitive to the length of the permissible credit period and to the relationship between the credit period and inventory level. Davis and Gaither (1985) developed optimal order quantities for firms that are offered a onetime opportunity to delay payment for an order of a commodity. A mathematical model is developed by Goyal (1985) when supplier announces credit period in settling the account, so that no interest charges are payable from the outstanding amount if the account is settled with in the allowable delay period. Aggarwal and Jaggi (1995) developed mathematical model for deteriorating inventories for which supplier allowed certain fixed period to settle the account. Shah et al. (1988) extended the above model by allowing shortages. Mandal and Phaujdar (1989a, b) have studied Goyal (1985) model by including interest earned from the sales revenue on the stock remaining beyond the settlement period. Carlson and Rousseau (1989) examined EOQ under date terms supplier credit by partitioning carrying cost into financial cost and variable holding costs. Chung and Huang (2003) extended Goyal (1985) model when replenishment rate is finite.

Dallenbach (1986, 1988), Ward and Chapman (1987), Chapman and Ward (1988) argued that the usual assumptions as to the incidence and the value of the inventory investment opportunity cost made by the traditional inventory theory are correct and also established that if trade credit surplus is taken into account, the optimal ordering quantities decreases rather than increase. Chung (1998) established the convexity of the total annual variable cost function for optimal economic order quantity under conditions of permissible delay in payments. Jamal et al. (2000) discussed the problem in which the retailer can pay the supplier either at the end of credit period or later incurring interest charges on the unpaid balance for the overdue period. Sarker et al. (2001) obtained optimal payment time under permissible delay in payments when units in an inventory are subject to deterioration. Abadand Jaggi (2003) considered the seller-buyer channel in which the end demand is price sensitive and the suppler offers trade credit to the buyer. Shinn and Hwang (2003) dealt with the problem of determining the retailer's optimal price and order size simultaneously under the condition of order size dependent delay in payments. It is assumed that the length of the credit period is a function of the retailer's

order size and also the demand rate is a function of the selling price. Chung et al. (2005) determined the economic order quantity under conditions of permissible delay in payments where the delay in payments depends on the quantity ordered when the order quantity is less than the quantity at which the delay in payments is permitted, the payment for the item must be made immediately. Otherwise, the fixed credit period is allowed. Huang (2007) examined optimal retailer's replenishment decisions in the EOQ model under two levels of trade credit policy by assuming that the supplier would offer the retailer partially permissible delay in payments when the order quantity is smaller than a predetermined quantity. Tenget. al. (2007) derived retailer's optimal ordering policies with trade credit financing.

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. Section- 3.1 contains the offered credit period is less than or equal to the cycle time i.e., case-1. A numerical example is given in section-3.1.1 for case-1. Section-3.2 contains the offered credit period is greater than to the cycle time i.e., case-2. A numerical example is given in section-3.2.1 for case-2. Section-4 contains the sensitive analysis. And finally the conclusions are discussed in section-5.

II. ASSUMPTIONS AND NOTATIONS

The following assumptions are used to develop the model:

* The system deal with a single item
* The demand rate $R(p,t)$ is a function of price and time dependent quadratic demand
* $\theta (0 < \theta < 1)$ is the constant rate of deterioration.
* The replenishment rate is infinite.
* The lead time is zero and shortages are not allowed.
* The salvage value, γp_c $(0 \le \gamma < 1)$ is associated to deteriorated units during the cycle time. Here p_c is the purchase cost of an item.

The following notations are used to develop the model:

* The Demand rate $R(t)$ at time t is assumed to be $R(p,t) = a(1 + bt + ct^2)p^{-\eta}$ $a > 0, 0 < b < 1$, c < b and $\eta > 1$. Here 'a' is a constant demand rate, 'b' is the rate of change of the demand and 'c' is the acceleration of demand rate. 'p' is the retail price and 'η' is price mark up.
* A is the ordering cost per order.
* p is the selling price per unit
* $Q(t)$ is the ordering quantity at time $t=0$
* h is per unit holding cost excluding interest charges per unit per year.
* I_e is the interest earned per year.
* I_c is the interest charged per stocks per year.
* M is the permissible delay in settling the accounts, $0<M<1$.
* T is the interval between two successive orders
* $TC (T, p)$ is the total cost per unit time.

III. FORMULATION AND SOLUTION OF THE MODEL

Let $I(t)$ be the inventory level at time t ($0 \le t \le T$). The inventory depletes due to deterioration and the demand, and then the differential equation which describes the inventory level at time t is given by

$$\frac{dI(t)}{dt} + \theta I(t) = -R(p,t), \qquad 0 \le t \le T \tag{1}$$

where $R(p,t) = a(1 + bt + ct^2)p^{-\eta}$

with the following boundary conditions

    (i) $I(T) = 0$ when $t = T$, and   (ii) $I(0) = Q$.   (2)

The solution of equation (6.1) using the boundary condition $I(T) = 0$ is given by

$$I(t) = (ap^{-\eta}) \left(\begin{array}{l} (T-t) + \dfrac{(\theta + b)(T^2 - t^2)}{2} + \dfrac{(b\theta + c)(T^3 - t^3)}{3} + \dfrac{(c\theta)(T^4 - t^4)}{4} \\ - (\theta t)\left((T-t) + \dfrac{b(T^2 - t^2)}{2} + \dfrac{c(T^3 - t^3)}{3} \right) \end{array} \right) \tag{3}$$

where we take series expansion and ignored the second and higher powers of θ as θ is small.
Since $I(0) = Q$, we obtain

$$Q = (ap^{-\eta})\left(T + \frac{(\theta+b)(T^2)}{2} + \frac{(b\theta+c)(T^3)}{3} + \frac{(c\theta)(T^4)}{4}\right)$$ (4)

The Ordering cost is given by

$$OC = A$$ (5)

The number of units that deteriorate during one cycle is given by

$$D(T) = Q - R(p,T)T = (ap^{-\eta})\left(\frac{\theta T^2}{2} + \frac{b\theta T^3}{3} + \frac{c\theta T^4}{4} - \frac{bT^2}{2} - \frac{2cT^3}{3}\right)$$ (6)

The cost due to deterioration is given by

$$CD = P_c.D(T) = P_c(ap^{-\eta})\left(\frac{\theta T^2}{2} + \frac{b\theta T^3}{3} + \frac{c\theta T^4}{4} - \frac{bT^2}{2} - \frac{2cT^3}{3}\right)$$ (7)

where P_c is the cost per unit time.
The salvage value is given by

$$SV = \gamma.CD = \gamma P_c(ap^{-\eta})\left(\frac{\theta T^2}{2} + \frac{b\theta T^3}{3} + \frac{c\theta T^4}{4} - \frac{bT^2}{2} - \frac{2cT^3}{3}\right)$$ (8)

The inventory holding cost during the cycle is given by

$$IHC = h\int_0^T I(t)dt = h\left(\frac{60T^2 + 40bT^3 + 30cT^4 + 40\theta T^3 + 15b\theta T^4 + 12c\theta T^5}{120}\right)$$ (9)

We now calculate the total cost of the inventory system in the following two cases:

3.1 Case 1: $M \leq T$ *i.e.,* the offered credit period is less than or equal to the cycle time.

The retailer can sell units during *[0, M]* at a sale price '*p*' per unit which he can put an interest rate '*I_e*' per unit per annum in an interest bearing account. So the total interest earned during *[0, M]* is:

$$IE_1 = pI_e\int_0^M R(p,t)tdt = (ap^{-\eta+1})I_e\left(\frac{M^2}{2} + \frac{bM^3}{3} + \frac{cM^4}{4}\right)$$ (10)

Now, in the period *[M, T]*, the supplier will charge the interest to the retailer on the remaining stock at the rate '*I_c*' per unit per annum. Hence, total interest charges payable by the retailer during *[M, T]* is:

$$IC_1 = pI_c\int_M^T I(t)dt = \frac{ap^{-\eta+1}I_c(M-T)^2}{120}\begin{pmatrix} 60 + 10M^2c + 30T^2c + 20Mb + 40Tb \\ + 20T\theta - 5M^2\theta b - 2M^3\theta c + 15T^2\theta b \\ + 12T^3\theta c + 20MTc - 20M\theta - 10MT\theta b \\ - 6MT^2\theta c - 4M^2T\theta c \end{pmatrix}$$ (11)

Now, the total cost *(TC₁(T, p))* per time unit is

$$TC_1(T, p) = \frac{1}{T}\left(OC + IHC + CD + IC_1 - IE_1 - SV\right)$$

$$= \frac{A}{T} + \frac{ap^{-\eta}}{T} \left(\begin{array}{l} h\left(\dfrac{60T^2 + 40bT^3 + 30cT^4 + 40\theta T^3 + 15b\theta T^4 + 12c\theta T^5}{120} \right) \\[2ex] + (1-\gamma)P_c\left(\dfrac{\theta T^2}{2} + \dfrac{b\theta T^3}{3} + \dfrac{c\theta T^4}{4} - \dfrac{bT^2}{2} - \dfrac{2cT^3}{3} \right) \\[2ex] + \dfrac{pI_c(M-T)^2}{120}\left(\begin{array}{l} 60 + 10M^2c + 30T^2c + 20Mb + 40Tb \\ + 20T\theta - 5M^2\theta b - 2M^3\theta c + 15T^2\theta b \\ + 12T^3\theta c + 20MTc - 20M\theta - 10MT\theta b \\ - 6MT^2\theta c - 4M^2T\theta c \end{array} \right) \\[2ex] - pI_e\left(\dfrac{M^2}{2} + \dfrac{bM^3}{3} + \dfrac{cM^4}{4} \right) \end{array} \right) \qquad (12)$$

Using MATHCAD, the optimum value of *T* and *p* are obtained by solving

$$\frac{\partial}{\partial T}TC_1(T,p) = 0, \quad \frac{\partial}{\partial p}TC_1(T,p) = 0$$

The following conditions are necessary and sufficient to minimize the Total Cost $TC_1(T,p)$ per unit time

$$\frac{\partial^2}{\partial T^2}TC_1(T,p) < 0, \quad \frac{\partial^2}{\partial p^2}TC_1(T,p) < 0$$

(6.13)

and

$$\left(\frac{\partial^2}{\partial T^2}TC_1(T,p) \right)\left(\frac{\partial^2}{\partial p^2}TC_1(T,p) \right) - \left(\frac{\partial^2}{\partial T\partial p}TC_1(T,p) \right)^2 < 0$$

(6.14)

3.1.1 Numerical Example

To demonstrate the effectiveness of the model developed, a numerical example is taken with the following values for the parameters:

a =1000	b=0.25	c=0.001 h=1.5	p=15	$\gamma = 0.1$
I_c=0.16	I_e=0.12	$\theta = 0.05$	P_c=8	A=200
T=4	M=0.6	$\eta = 1.1$		

For the above example, it is found that the optimality conditions are satisfied in all the following Two cases for all *T & p* viz.,

(i)   *a* >0, *b*> 0 and *c*> 0 (i.e., accelerated growth model)
(ii)   *a* >0, *b*> 0 and *c*< 0 (i.e., retarded decline model)

The optimal values of cycle time (T), sale price (p), order quantity (Q) and the total cost of the system are calculated as 0.597, 22.369, 331.254 and 4806.20 respectively for accelerated growth model and the values of the same parameters are 0.598, 23.383, 331.782 and 4818.784 respectively for retarded decline model when the credit period is less than or equal to the cycle time.

3.1.2 Sensitivity Analysis

We now study sensitivity of the models developed to examine the implications of underestimating and overestimating the parameters individually and all together on optimal value of total profit. The Sensitive analysis is performed by varying individual parameters and all parameters by -30%, -15%, +15% and +30%. Since both the models show similar results, we will present only the sensitivity for accelerated growth model. The results are shown in *Table*-1. The following observations are made from this table:

(i) The total cost *TC (T,p)* of the system increases (decreases) with an increase (decrease) in the values of the parameters *a, θ, γ*and *I_c* while it decreases (increases) with increase (decrease) in the values of the parameters *b, c, I_e*and *η*.

(ii) However, the total cost *TC (T,p)* is highly sensitive to the changes in the values of the parameters *a* , η and I_c, moderately sensitive to the changes in θ and slightly sensitive to the changes in the values of the parameters *b, c, I_e,* and *γ*.

(iii) As expected, the increase (decrease) in the variable holding cost decreases (increases) in the value of the total cost *TC (T,p)* of the system.

(iv) Similarly the increase (decrease) in the salvage value increases (decrease) the profit of the system.

The variations of *TC (T,p)* with respect to the values of some important parameters is shown in Fig-1. The variations of *TC (T,p)* with respect to t_1 and t_2 are shown in Fig.-2 and Fig.-3 respectively.

3.2 Case-2: *M>T i.e.,* the offered credit period is greater than the cycle time.
In this case, the interest earned is

$$IE_2 = pI_e\left[\int_0^T R(p,t)t\,dt + R(p,T)T(M-T)\right]$$

$$= (ap^{-\eta+1})I_e\left[MT + bMT^2 + cMT^3 - \frac{T^2}{2} - \frac{2bT^3}{3} - \frac{3cT^4}{4}\right] \tag{15}$$

and the interest charges is zero,
$$\text{i.e., } IC_2 = 0 \tag{16}$$

Therefore the total cost *(TC₂ (T, p))* per time unit is

$$TC_2(T,p) = \frac{1}{T}\left(OC + IHC + CD + IC_2 - IE_2 - SV\right) = \frac{1}{T}\left(OC + IHC + (1-\gamma)CD - IE_2\right)$$

$$= \frac{A}{T} + \frac{ap^{-\eta}}{T}\left(\begin{array}{l} h\left(\dfrac{60T^2 + 40bT^3 + 30cT^4 + 40\theta T^3 + 15b\theta T^4 + 12c\theta T^5}{120}\right) \\[2mm] + (1-\gamma)P_c\left(\dfrac{\theta T^2}{2} + \dfrac{b\theta T^3}{3} + \dfrac{c\theta T^4}{4} - \dfrac{bT^2}{2} - \dfrac{2cT^3}{3}\right) \\[2mm] - pI_e\left[MT + bMT^2 + cMT^3 - \dfrac{T^2}{2} - \dfrac{2bT^3}{3} - \dfrac{3cT^4}{4}\right] \end{array}\right) \tag{17}$$

The optimum value of *T* and *p* are obtained by solving

$$\frac{\partial}{\partial T}TC_2(T,p) = 0, \quad \frac{\partial}{\partial p}TC_2(T,p) = 0$$

The following conditions are necessary and sufficient to minimize the Total Cost *TC₂(T,p)* per unit time

$$\frac{\partial^2}{\partial T^2}TC_2(T,p) < 0, \quad \frac{\partial^2}{\partial p^2}TC_2(T,p) < 0 \tag{18}$$

and

$$\left(\frac{\partial^2}{\partial T^2}TC_2(T,p)\right)\left(\frac{\partial^2}{\partial p^2}TC_2(T,p)\right) - \left(\frac{\partial^2}{\partial T\partial p}TC_2(T,p)\right)^2 < 0 \tag{19}$$

Using MATHCAD, the above equations are solved for optimality.

3.2.1 Numerical Example
To test the robustness of the model developed above, once again we consider the values of the parameters given in 6.3.1. The optimal values of cycle time (T), sale price (p), order quantity (Q) and the total cost of the system are calculated as 0.596, 22.304, 330.652 and 4837.114 respectively for accelerated growth model and the values of the same parameters are 0.598, 23.338, 331.782 and 4812.706 respectively for retarded decline model when the credit period is greater than the cycle time.

3.2.2. Sensitivity Analysis

We now study sensitivity of the models developed to examine the implications of underestimating and overestimating the parameters individually and all together on optimal value of total profit. The Sensitive analysis is performed by changing each of the parameter by -30%, -15%, +15% and +30% taking one parameter at a time and keeping the remaining parameters are unchanged and finally all parameters are considered. Since both the models show similar results, we will present only the sensitivity for accelerated growth model. The results are shown in *Table*-2. The following observations are made from this table:

(i) The total cost $TC(T,p)$ of the system increases (decreases) with an increase (decrease) in the values of the parameters $a,\ \theta,\ \gamma$ and I_c while it decreases (increases) with increase (decrease) in the values of the parameters $b,\ c,\ I_e$ and η.

(ii) However, the total cost $TC(T,p)$ is highly sensitive to the changes in the values of the parameters a, η and I_c, moderately sensitive to the changes in θ and slightly sensitive to the changes in the values of the parameters $b,\ c,\ I_e,$ and γ.

(iii) As expected, the increase (decrease) in the variable holding cost decreases (increases) in the value of the total cost $TC(T,p)$ of the system.

(iv) Similarly the increase (decrease) in the salvage value increases (decrease) the profit of the system.

The variations of $TC(T,p)$ with respect to the values of some important parameters and t_1 and t_2 are shown in Fig-4, Fig.-5 and Fig.-6 respectively.

IV. CONCLUSIONS

EOQ models are developed for perishable items with trended demand rate under trade credit policy. The optimal policies are discussed when the credit period is more than (or less than) the cycle time. When comparing the two credit periods, it is observed that the total cost of the system is more in case of $M \leq T$ as compared with $M > T$. It is further observed that in both cases the total cost is highly sensitive to the changes in the mark up price η.

Table-1: a >0, b> 0 and c> 0 (i.e., accelerated growth model)

S.NO.	Parameter	% Change	Change in T (%)	Change in p (%)	Change in $TC_1(T, p)$ (%)	Change in Q (%)
1	a	15%	-6.1977	-15.8478	14.8440	15.0000
		5%	-2.1776	-6.0262	4.9480	5.0001
		-5%	2.5126	7.0008	-4.9480	-5.0001
		-15%	8.0402	25.0972	-14.8440	-15.0000
2	b	15%	-	-	2.6378	1.0463
		5%	-3.3501	-37.2212	0.8793	0.3487
		-5%	2.1776	37.9051	-0.8792	-0.3487
		-15%	5.1926	117.0191	-2.6378	-1.0463
3	c	15%	0.0000	-0.3398	-0.0196	0.0015
		5%	0.0000	-0.1118	-0.0065	0.0006
		-5%	0.0000	0.1118	0.0066	-0.0006
		-15%	0.0000	0.3398	0.0196	-0.0018
4	θ	15%	1.3400	28.4099	3.3503	0.2255
		5%	0.5025	9.4238	1.1167	0.0752
		-5%	-0.6700	-9.3880	-1.1167	-0.0752
		-15%	-2.0101	-28.0522	-3.3502	-0.2255
5	Ic	15%	0.0000	0.2101	10.0578	0.0000
		5%	0.0000	0.0760	3.3526	0.0000
		-5%	0.0000	-0.0849	-3.3526	0.0000
		-15%	-0.1675	-0.2861	-10.0578	0.0000
6	Ie	15%	-8.2077	-30.6764	-0.1414	0.0000
		5%	-2.6801	-11.4712	-0.0471	0.0000
		-5%	2.5126	13.0404	0.0471	0.0000
		-15%	7.5377	45.3172	0.1414	0.0000
7	γ	15%	0.6700	10.5146	0.4357	0.0000
		5%	0.1675	3.5049	0.1452	0.0000
		-5%	-0.1675	-3.5004	-0.1452	0.0000
		-15%	-0.6700	-10.4967	-0.4357	0.0000
8	η	15%	10.0503	-42.4337	-35.6598	-36.0346
		5%	2.5126	-27.3638	-13.6942	-13.8383
		-5%	-2.3451	97.6441	15.8936	16.0605
		-15%	-29.4807	-	55.7485	56.3344

9	P_c	15%	-	-	-3.9216	0.0000
		5%	-2.5126	-31.4900	-1.3072	0.0000
		-5%	1.6750	31.6375	1.3072	0.0000
		-15%	3.8526	95.8693	3.9217	0.0000

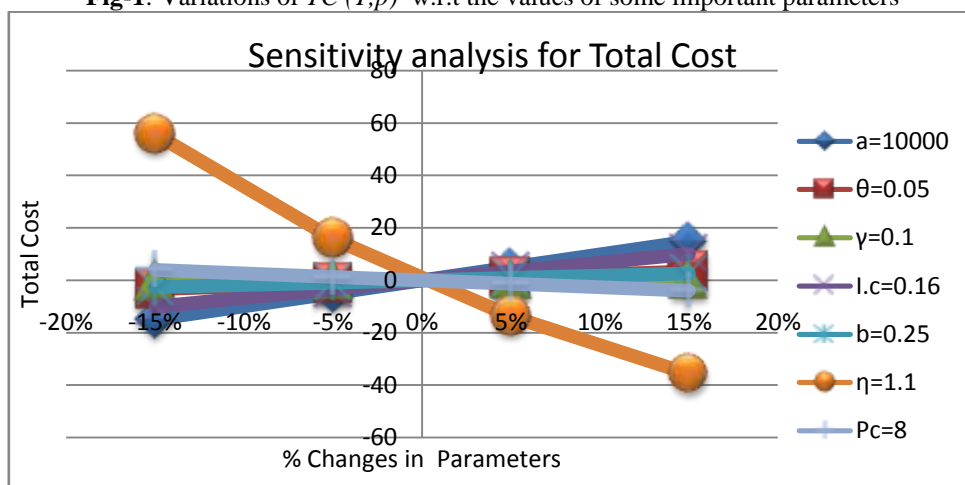**Fig-1**: Variations of *TC (T,p)* w.r.t the values of some important parameters

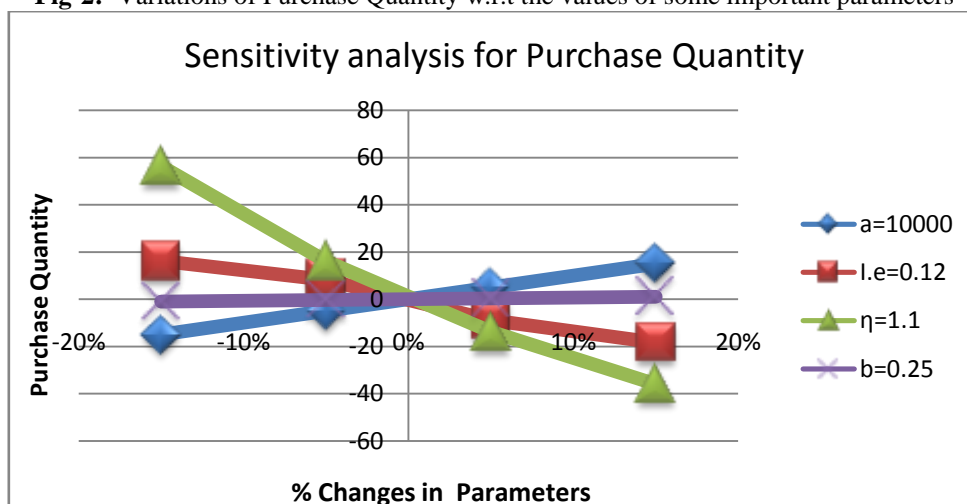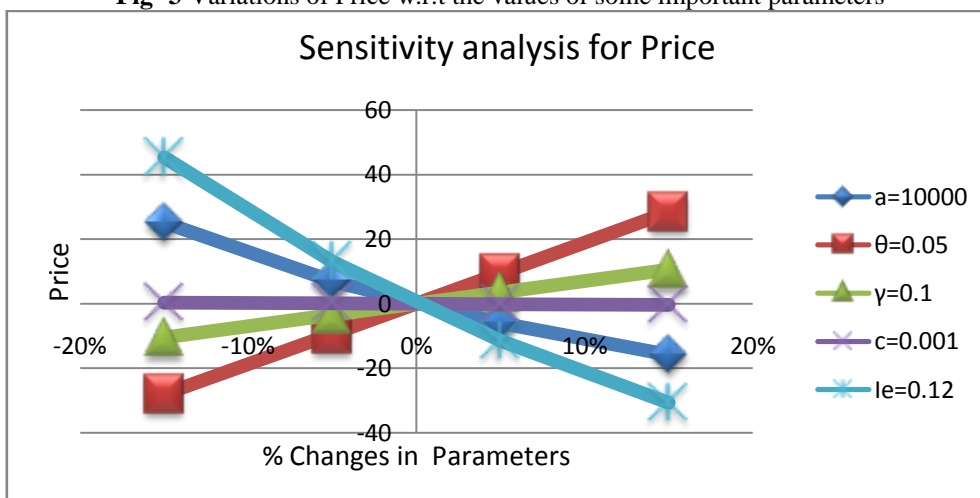**Fig-2:** Variations of Purchase Quantity w.r.t the values of some important parameters

Fig- 3 Variations of Price w.r.t the values of some important parameters

Table-2: a >0, b> 0 and c> 0 (i.e., accelerated growth model)

S.NO.	Parameter	% Change	Change in T (%)	Change in p (%)	Change in TC$_2$(T, p) (%)	Change in Q (%)
1	a	15%	-7.5503	-19.1849	14.8450	15.0001
		5%	-2.6846	-7.2902	4.9483	5.0001
		-5%	3.0201	8.4604	-4.9483	-5.0001
		-15%	9.5638	30.3264	-14.8449	-15.0001
2	b	15%	-	-	4.3365	1.0446
		5%	-4.0268	-38.7599	1.4455	0.3481
		-5%	2.6846	39.5310	-1.4455	-0.3481
		-15%	6.3758	122.6731	-4.3365	-1.0446
3	c	15%	0.0000	-0.3497	0.0379	0.0015
		5%	0.0000	-0.1166	0.0126	0.0006
		-5%	0.0000	0.1121	-0.0126	-0.0006
		-15%	0.0000	0.3452	-0.0378	-0.0018
4	θ	15%	1.8456	29.4118	2.7717	0.2253
		5%	0.6711	9.7471	0.9239	0.0750
		-5%	-0.6711	-9.7113	-0.9239	-0.0750
		-15%	-2.3490	-29.0127	-2.7717	-0.2253
5	Ie	15%	-8.3893	-31.1603	9.9489	0.0000
		5%	-3.0201	-12.3655	3.3163	0.0000
		-5%	3.3557	15.1228	-3.3163	0.0000
		-15%	10.5705	57.6220	-9.9488	0.0000
6	γ	15%	0.8389	10.9084	0.4330	0.0000
		5%	0.3356	3.6316	0.1443	0.0000
		-5%	-0.1678	-3.6361	-0.1443	0.0000
		-15%	-0.8389	-10.8949	-0.4329	0.0000
7	η	15%	13.0872	-37.8094	-35.6621	-36.0346
		5%	3.1879	-26.2554	-13.6951	-13.8381
		-5%	-2.8523	95.0771	15.8946	16.0607
		-15%	-38.0872	-	55.7523	56.3345
8	P$_c$	15%	-	-	-3.8966	0.0000
		5%	-3.0201	-32.6982	-1.2989	0.0000
		-5%	2.0134	32.8237	1.2989	0.0000
		-15%	4.6980	99.5606	3.8966	0.0000

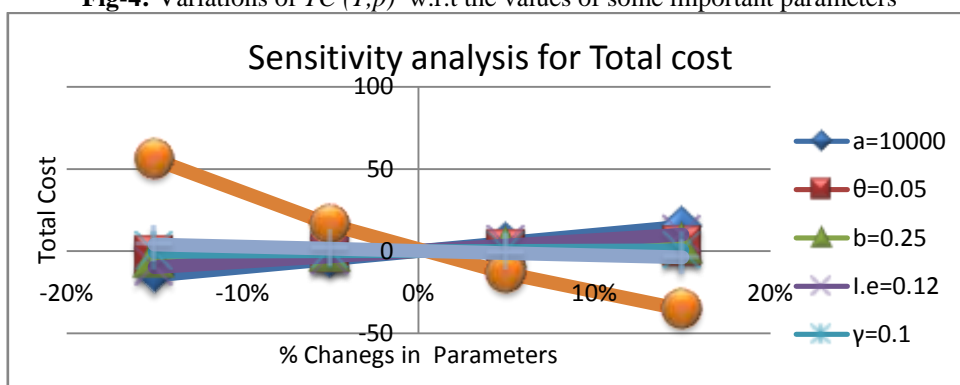**Fig-4:** Variations of *TC (T,p)* w.r.t the values of some important parameters

Fig-5: Variations of Purchase Quantity w.r.t the values of some important parameters
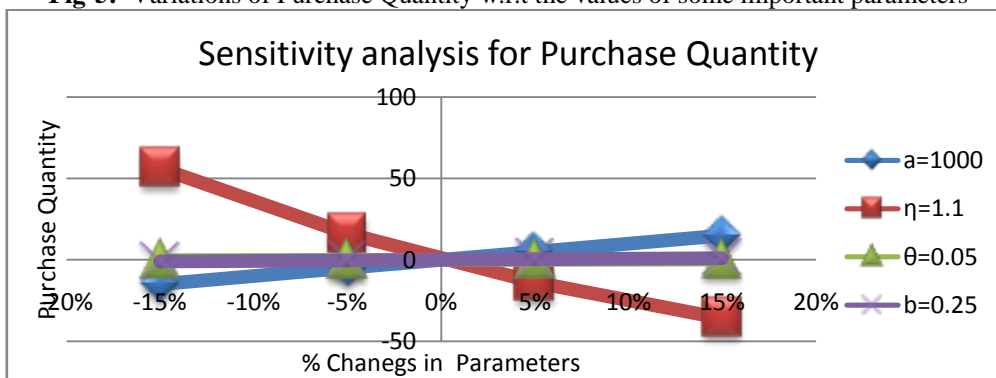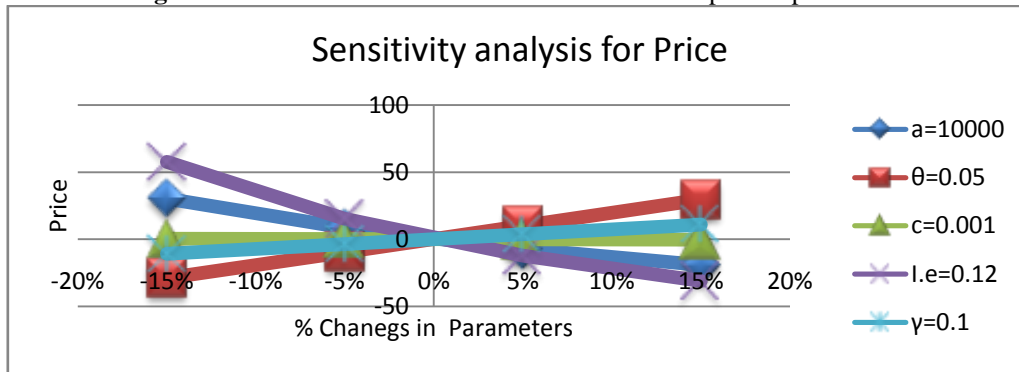
Fig- 6: Variations of Price w.r.t the values of some important parameters

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