Influence of Selling Price, Freshness, Inventory Levels, Advertising Frequency on Demand and Cost Structures for Perishable Products in India

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ABSTRACT

In this study we developed an integrated inventory model to analyse how Indian perishable product influence Selling Price, Freshness, Inventory Levels, Advertising Frequency on Demand and Cost Structures of Perishable Products in India. We take a price dependent demand function that is influenced by selling price, freshness, inventory levels, and advertising frequency. The main objective of this study is to check how these key parameters affect the demand and cost structure of perishable products in Indian markets. We perform a numerical and sensitive analysis based on Indian conditions to understand how these key variables affect the demand and cost of perishable products in India. A numerical example is performed with the help of MATLAB.

Keywords: Price dependent demand, Freshness, Advertising frequence, EQO Model, Perishable Inventory.

INTRODUCTION

Perishable fresh products in India have a limited shelf life, quality deterioration, and high spoilage costs; therefore, management of these requires considerable attention. Traditional Inventory models are primarily focused on constant and time-dependent deterioration demand, but demand for perishable products in India is influenced by multiple interacting variables like selling price, product freshness, advertising frequency, inventory level, etc. that are recognized in recent studies. Early contributions were established by [1, 2]. They study the inventory model, multivariate demand, which is price sensitive, and jointly optimize the price and maximize the profit. After that, other inventory models show that product quality decay directly affects consumer purchasing willingness over time, and these models include freshness-dependent demand [3,4]. Stock-dependent demand inventory also developed, which shows a higher display inventory level influences the demand of perishable products. They highlight the effect of inventory by improving the stock availability and display through the holding costs [5,6]. They build an inventory for perishable products in which a shortage is allowed to find the optimal solution of ordering quantity and total cost [7]. An EOQ model is developed to maximize the profit and optimize the cycle time and green effort and combine the freshness, stock, and price-dependent demand of perishable products [8]. Further study extends these inventory models where demand jointly depends on freshness, price, and stock and adds the nonlinear holding cost to better understand the real-world scenario [10].

Many recent inventory models include market-related variables such as advertising and promotional effects because these variables directly affect the customer demand of perishable products. In the above paper, they study an inventory model with price- and promotion-dependent demand to optimize the cost and maximize the profit of perishable products. The highlight is the importance of advertising and marketing effects [11]. In this study, an EOQ inventory model is developed to determine the optimal solution for an existing inventory level, unit price, and cycle time where demand is directly dependent on selling price, display stock, and freshness with non-zero inventory sold at market markdown price[12].Model integrate promotional policies ,trade credit and

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privational technology to show the realistic behaviour of supply chain by analyse the inventory by optimizing the ordering policies for reduce the costs [15,14]. Markovian EOQ model to capture how demand in the next period depends on market effect. It optimizes the advertising and marketing effect to improve the inventory decision [13]. Recent work developed stochastic inventory models for price-sensitive demand that jointly optimize promotional replenishment, preservation technology investment, pricing, and shortage for maximizing the profit under quantity discounts and partial backlogging [16]. The EOQ model for fresh agricultural perishable products focuses on carbon emissions and freshness-dependent demand. It focuses on optimizing the inventory control strategy [17]. This work develops an inventory model for perishable products under carbon tax policy and inspection, and demand depends on advertising and stock [18].

Previous research studies mainly focus on perishable products in international countries, but there's limited research on Indian perishable products. The Indian perishable product market has some unique challenges like high prices, freshness, advertising, and inventory management. Prior research shows how all key parameters affect the demand and cost structure of perishable products.

The main aim of this research is to analyze how key variables like selling price, freshness, inventory, and advertising frequency affect the demand and cost structure of perishable products in India. This research mainly focuses on Indian perishable products; we can use secondary research data to analyze the combined effect of key variables on Indian perishable products.

Assumptions:

This inventory model focuses on one perishable item from India, which has a fixed shelf life.

There are two different types of degradation of the product in inventory with time: one is constant degradation that is manifested physically, and the second is gradual loss of freshness that is observed.

The shelf-life of the item is determined and finite, and once the item reaches that shelf-life, it will not be able to be sold in the market.

The demand is function of selling price, the amount of on-hand stock, the freshness of the product, and also advertising frequency. The demand factor that is price-dependent is assumed to take a linear function.

It is assumed that in each cycle end, the inventory level becomes zero.

Holding costs are time-dependent and nonlinear and have the quadratic nature of time.

The deterioration cost and the salvage value are considered for units that deteriorate during the inventory time.

It assumed that horizon planning is infinite. The lead time is still of concern, and it is assumed to be insignificant; therefore, replenishment is set to occur at the very beginning of every cycle.

In the beginning of the cycle (t=0), item are absolutely fresh; therefore, no depreciation of demand on freshness takes place. With time, the items become stale, and thus, it reduces the demand rate.

The cycle length T cannot exceed the shelf life of item N because the item cannot be sold if it is expired.

Table 1: Notation

Category	Symbol / Function	Description
Parameter	p	Selling price in INR
Parameter	A	Advertising frequency
Parameter	C_a	Expenditure per advertising in INR
Parameter	T	Replenishment cycle length
Parameter	θ	Rate at which inventory deteriorates

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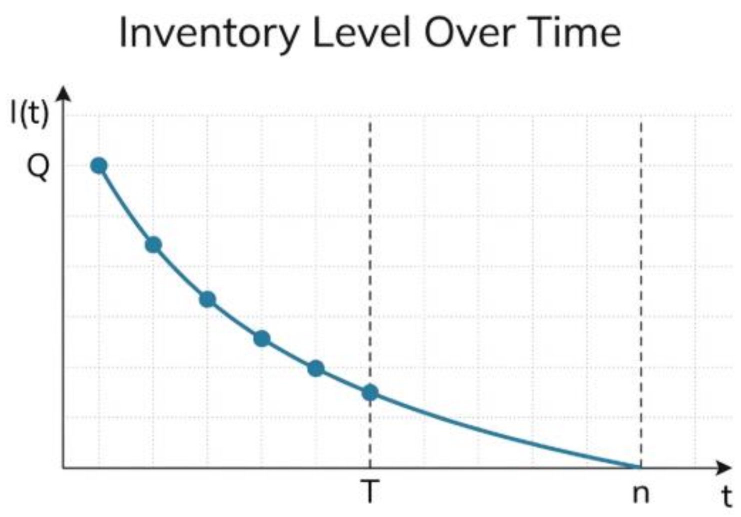
Parameter	*ƨ*	Product shelf life
Parameter	*x, y*	Price-demand parameters
Parameter	ω	Inventory-dependent demand coefficient
Parameter	W	Maximum shelf space
Parameter	s	Salvage cost of deteriorated items
Parameter	c	Purchase cost in INR
Parameter	*c_d*	Deterioration cost in INR
Parameter	h	Holding cost in time
Parameter	h_1	Holding cost in time2
Parameter	h_2	Holding cost in time3
Parameter	Q	Size of order
Parameter	O	Ordering cost per order in INR
Parameter	γ	Advertising elasticity
Parameter	μ	Salvage coefficient ($0 \le \mu \le 1$)
Function	$d(p)$	Linear form price-dependent demand
Function	$I(t)$	At time t, quantity of inventory available
Function	$D(p, I(t), A, t)$	Demand at time t depending on price, inventory, advertisement, and age (freshness)
Function	$H(t)$	Holding cost function
Function	$\Pi(p, T, A)$	Total profit
Decision Variable	p, T, A	Selling price, replenishment cycle length, advertising frequency
Dependent Decision Variable	Q	Size of order

Mathematical Model formulation:

The demand function is an extension of [1] with advertising dependent demand where the product has a set shelf life, and each replenishment cycle should be limited within a specific period, which shelf life not more that a specific period. The demand function is depend on selling price, Inventory level, freshness and advertising frequence of the product. The inventory model is formulated in a way that the level of the stock becomes zero at the end of the inventory. In cycle, some part of the inventory is wearing out and deterioration costs, as well as the value of the salvage, are part of the analysis.



Demand Function:

At Time t the demand rate is defined as:

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$$D\,(p, I(t), A, t) = A^{\gamma}(x - yp)\left(1 + \frac{t}{Ƨ}\right)^{1} + \omega I(t),$$

$$Ƨ > 0, \quad t \le Ƨ \;, \omega \ge 0\,, \gamma \in [0, 1)$$

where d(p) represents the price dependent demand, is taken as

$$d(p) = x - yp, \qquad 0 \le p \le \frac{x}{y}$$

linear demand where p is the selling price, At time t the inventory level is I(t), A represents advertising frequency, Ƨ is product shelf life. By considering assumptions, Differential equations is:

$$\frac{dI(t)}{dt} = -D\,(p, I(t), A, t) - \theta I(t), T \ge t \ge 0$$

With $I(T) = 0$ boundary conditions

By solving differential equation I(t) is expressed as

$$I(t) = \frac{A^{\gamma}(x - yp)}{\omega + \theta}\left(1 + \frac{1}{Ƨ(\omega + \theta)}\right)\left(e^{(\omega+\theta)(T-t)} - 1\right) - \frac{A^{\gamma}(x - yp)}{Ƨ(\omega + \theta)}\left(Te^{(\omega+\theta)(T-t)} - t\right), \quad T \ge t \ge 0$$

The ordering quantity occurs when I(0) and ordering quantity represented Q

$$Q = A^{\gamma}\,\frac{(x - yp)}{\omega + \theta}\left(-1 - \frac{1}{Ƨ(\omega + \theta)}\right) + A^{\gamma}\,\frac{(x - yp)e^{(\omega+\theta)T}}{\omega + \theta}\left(1 + \frac{1}{Ƨ(\omega + \theta)} - \frac{T}{Ƨ}\right) \le W.$$

The profit is calculated by difference between total revenue and total costs during a replenishment cycle divided by the cycle length T. All the cost components of the profit function are calculated in detail and are mathematically shown as below:

Sales revenue generated per cycle

$$S\,R = p\int_{0}^{T} D(p, I(t), t, A)\;dt$$

$$= p\int_{0}^{T}[A^{\gamma}(x - yp)\left(1 + \frac{t}{Ƨ}\right)^{1} + \omega I(t)]dt$$

$$= [A^{\gamma}(x - yp)T(1 - \frac{T}{2Ƨ}) - \frac{\omega A^{\gamma}(x - yp)T}{\omega + \theta}(1 - \frac{T}{2Ƨ} + \frac{1}{Ƨ(\omega + \theta)}) + \frac{\omega A^{\gamma}(x - yp)}{\omega + \theta}(\frac{e^{(\omega+\theta)T} - 1}{\omega + \theta})(1 + \frac{1}{Ƨ(\omega + \theta)} - \frac{T}{Ƨ}]$$

Deteriorated items per cycle Salvage value is

$$S\,V = s\mu\text{ (Deteriorated units per cycle)}$$

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$$S\,V = s\mu\,(Q - \int_0^T [A^\gamma(x - yp)\left(1 + \frac{t}{Ƨ}\right)^1 + \omega I(t)]dt)]$$

$$S\,V = s\mu\,\{\frac{A^\gamma(x-yp)}{\omega+\theta}(-1 - \frac{1}{Ƨ(\omega+\theta)}) + A^\gamma\,\frac{(x-yp)e^{(\omega+\theta)T}}{\omega+\theta}(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ}) - [A^\gamma(x-yp)T(1 - \frac{T}{2Ƨ}) - \frac{\omega A^\gamma(x - yp)T}{\omega+\theta}(1 - \frac{T}{2Ƨ} + \frac{1}{Ƨ(\omega+\theta)}) + \frac{\omega A^\gamma(x - yp)}{\omega+\theta}(\frac{e^{(\omega+\theta)T}-1}{\omega+\theta})(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ})]\}$$

Ordering cost generated per cycle

$$O\,C = O$$

The Holding cost generated per cycle

$$H\,C = \int_0^T H(t)I(t)\,dt = \int_0^T (h + h\,1t + h2t^2)T(t)dt$$

$$= h\{\frac{A^\gamma(x-yp)}{\omega+\theta}[-1 + \frac{T}{2Ƨ} - \frac{1}{Ƨ(\omega+\theta)}] + \frac{e^{(\omega+\theta)T}-1}{\omega+\theta}[A^\gamma\,\frac{(x-yp)}{\omega+\theta}(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ})]\} + h1\{A^\gamma\,\frac{(x-yp)T^2}{\omega+\theta}[-\frac{1}{2} + \frac{T}{3Ƨ} - \frac{1}{2Ƨ(\omega+\theta)}] + \frac{e^{(\omega+\theta)T}-(\omega+\theta)-1}{(\omega+\theta)^2}[A^\gamma\,\frac{(x-yp)}{\omega+\theta}(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ})] + h2\,\{A^\gamma\,\frac{(x-yp)T^3}{\omega+\theta}[[-\frac{1}{3} + \frac{T}{4Ƨ} - \frac{1}{3Ƨ(\omega+\theta)}] + \frac{2e^{(\omega+\theta)T}-[T(\omega+\theta)(T(\omega+\theta)+2-2]}{(\omega+\theta)^2}[A^\gamma\,\frac{(x-yp)}{\omega+\theta}(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ})]$$

Purchase Cost generated per cycle

$$P\,C = CQ$$

$$= C[A^\gamma\,\frac{(x-yp)}{\omega+\theta}(-1 - \frac{1}{Ƨ(\omega+\theta)}) + A^\gamma\,\frac{(x-yp)e^{(\omega+\theta)T}}{\omega+\theta}(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ})]$$

The Deterioration cost generated per cycle

$$D\,C = cd\,(Q - \int_0^T [A^\gamma(x - yp)\left(1 + \frac{t}{Ƨ}\right)^1 + \omega I(t)]dt)$$

$$= cd\{\frac{A^\gamma(x-yp)}{\omega+\theta}(-1 - \frac{1}{Ƨ(\omega+\theta)}) + A^\gamma\,\frac{(x-yp)e^{(\omega+\theta)T}}{\omega+\theta}(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ}) - [A^\gamma(x-yp)T(1 - \frac{T}{2Ƨ}) - \frac{\omega A^\gamma(x - yp)T}{\omega+\theta}(1 - \frac{T}{2Ƨ} + \frac{1}{Ƨ(\omega+\theta)}) + \frac{\omega A^\gamma(x - yp)}{\omega+\theta}(\frac{e^{(\omega+\theta)T}-1}{\omega+\theta})(1 + \frac{1}{Ƨ(\omega+\theta)} - \frac{T}{Ƨ})]\}$$

The Advertising cost per cycle

$$A\,C = CaA$$

The total profit generated per cycle

$$\pi(p,T,A) = \frac{1}{T}(S\,R + S\,V - P\,C - O\,C - H\,C - A\,C)$$

Algorithm:

Step 1 Give values to all key parameters of inventory model

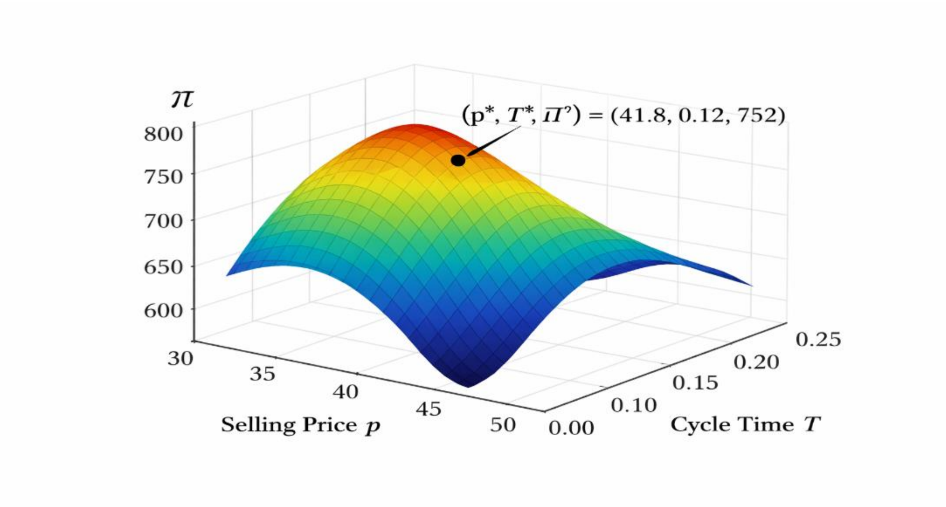
Step 2 For Optimal solution put $\frac{\partial \pi}{\partial p} = 0$,$\frac{\partial \pi}{\partial T} = 0$, $\frac{\partial \pi}{\partial A} = 0$ and solve together for p, T, A.

Step 3 Calculate optimal Solution.

Numerical Applications:

We consider a numerical example for a fresh perishable product, namely tomatoes, in an urban Indian retail market. The parameter values are obtained from secondary sources such as government retail price reports and post-harvest loss studies. The average retail price of tomatoes in India is approximately 52 per kg. Retail prices typically fluctuate between 20 and 85 per kg depending on season and supply conditions. Post-harvest losses for perishable crops in India can reach 30–40%, indicating a high deterioration rate in the supply chain. The following parameter values are used $x = 1200, y = 20, p = 52, c = 30, \theta = 0.25,\ h = 3, O = 300,\ A = 5$

By solving we find optimal solution p*=41.8/kg, T*=0.12week, Q*=61.4 units and total profit π*=752.0 for per cycle. Concavity of profit function shown figure below.



Sensitivity analysis:

We perform sensitivity analysis with the help of all key parameters and changing values of one parameter at a time. By using that method, we check the effect of all key parameters of inventory model. All parameters are varied ±20% while keeping others constant.

Sensitivity analysis Table

Parameter	% Change of parameter	p*	T*	Π*	%Change in profit
x	-20%	39.0	0.104	601.0	-20.1%
x	+20%	44.3	0.137	904.0	+20.2%
y	-20%	46.2	0.124	841.0	+11.8%
y	+20%	37.1	0.112	667.0	-11.3%
ϴ	-20%	42.6	0.131	826.0	+9.8%
ϴ	+20%	40.9	0.109	678.0	-9.8%
h	-20%_	42.1	0.125	783.0	+4.1%
h	+20%	41.5	0.113	720.0	-4.3%
O	-20%	41.9	0.116	779.0	+3.6%

O	+20%	41.7	0.122	721.0	-4.1%
A	-20%	40.2	0.111	659.0	-12.4%
A	+20%	43.4	0.130	866.O	+15.2%

The results indicate that the demand scale parameter has the most significant influence on profit may be presented in Diagrammatical representation. An increase in demand substantially improves profitability, while higher price sensitivity reduces profit margins not equity. Less deterioration rate has a strong negative impact, highlighting the importance of freshness preservation. Advertising frequency positively influences demand and profit, demonstrating the effectiveness of promotional strategies in perishable product markets. Impact solution must compare with exact optimal values.

CONCLUSIONS

This study develops inventory model shows influence of Selling Price, Freshness, Inventory Levels, Advertising Frequency on Demand and Cost Structures for Perishable Products in India. This shows when demand function is extended to advertising frequency it higher the marketing cost but it also increases the profit. Using Indian parameters, the base-case optimum, in terms of the parameters, is about 41.8/kg, a cycle time of about 0.12 week, and a profit of about 7,520/cycle. Sensitivity analysis shows that market demand and freshness have the strongest impact keeping freshness and price display the same in parallel with relatively low advertisement activity give the highest amount of profit increases. The research integrates pricing, freshness control, inventory, and advertising to achieve maximum profit with minimum waste. The inventory model mainly focuses on the Indian context. The result shows that by combine the advertising frequency increase with the demand of perishable product reduce the wastage of perishable product in India.

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