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Green Inventory Model with Price Sensitivity Investment in Preservation Technology and Permissible Delay in Payment

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Abstract

In contemporary inventory, integrating sustainability practices is paramount. This study proposes a Green Inventory Model that incorporates price sensitivity, investment in preservation technology, and permissible delay in payment. The model aims to optimize inventory decisions by considering the effects of deteriorating items, environmental impacts, and financial strategies. The inclusion of price sensitivity allows the model to adjust for variations in consumer demand based on pricing strategies. Investment in preservation technology is modeled to mitigate the deterioration rate of inventory, thereby reducing waste and enhancing sustainability. Additionally, the permissible delay in payment offers a financial incentive for retailers, potentially improving cash flow and reducing inventory holding costs. By integrating these components, the model provides a comprehensive approach to managing inventory in an eco-friendly and economically efficient manner. Numerical examples and sensitivity analysis are provided to illustrate the model's applicability and the impact of various parameters on the optimal solutions. The findings demonstrate that strategic investment in preservation technology, coupled with adaptive pricing and favorable payment terms, can significantly enhance both environmental sustainability and profitability in inventory operations.

Keywords: Green inventory model, preservation technology, permissible delay in payment

1. Introduction

In the contemporary business environment, sustainability has emerged as a critical component of corporate strategy, driven by increasing environmental concerns and regulatory pressures. The integration of green practices into inventory management has become essential for companies aiming to minimize their ecological footprint while maintaining economic viability. A green inventory model not only optimizes stock levels and reduces waste but also incorporates advanced preservation technologies that enhance the shelf life and quality of products. This study explores an innovative green inventory model that combines price sensitivity and investment in preservation technology with trade credit terms. The model is designed to address the dual objectives of environmental sustainability and economic efficiency. By incorporating price sensitivity, the model accounts for the dynamic relationship between product pricing, consumer demand, and inventory levels. Investment in preservation technology, on the other hand, is crucial for reducing spoilage and extending product life, thereby reducing waste and improving the overall sustainability of the supply chain. Trade credit, a common practice in business transactions, allows buyers to delay payment for goods, providing them with financial flexibility. This model examines how trade credit terms can be strategically used to encourage investment in preservation technologies and to balance the financial dynamics between suppliers and buyers. The integration of these elements into a cohesive inventory model aims to provide a comprehensive framework that supports green practices while maintaining competitive advantage and financial stability. This study contributes to the growing body of literature on sustainable supply chain management by offering insights into how businesses can effectively combine economic and environmental objectives through innovative inventory practices.

2. Literature Review

Preservation technology plays a pivotal role in modern inventory management, particularly in the context of sustainable and green supply chain practices. Its significance spans several key areas, including product longevity, waste reduction, cost efficiency, and overall environmental impact. Hsu, *et.* (2010) first introduced preservation technology in the inventory model for declining inventory. Dye *et. al (2012)* formulated the efficient preservation technology investment is combined with an ideal replenishment strategy for failing products. Hsieh *et.al (2013)* developed the production-inventory model that takes into account the impact of preservation technology investment in situations where demand varies over time. Dye *et.al (2013)* says that Investment in preservation technologies and optimal dynamic pricing for degrading items with reference price impacts. Singh and Sharma's (2013) provide a comprehensive analysis of global optimizing policies for managing decaying items within the context of trade credit financing and preservation technology. Daryanto*et. al*(2015) says that the Model of non-instantaneous depreciating inventory is under the combined influence of trade credit, preservation technology, and marketing strategy. Jaggi*et.al* (2015) told the Price-dependent demand, preservation technology, and volume agility about sustainable production practices. Tayal et al (2014) explore the complexities of managing deteriorating items within a two-echelon supply chain model, emphasizing the role of effective investment in preservation technology. Zhang and Tang (2014) delve into the intricacies of pricing strategies for deteriorating items, emphasizing the role of preservation technology investments. Their research is situated within the broader discourse on inventory management and pricing optimization, specifically addressing the challenges posed by items that degrade over time. Yang (2015) present a comprehensive examination of optimal dynamic trade credit and preservation technology allocation within the context of deteriorating inventory models. Their work contributes to the ongoing discourse on inventory management by addressing the intricate balance between financial incentives and technological investments to mitigate the challenges posed by perishable goods. Singh et al (2016) presents an Economic Order Quantity (EOQ) model specifically designed for deteriorating products subject to stock-dependent demand, incorporating trade credit periods and preservation technology. Zhang *et al.* (2016) present a comprehensive study on the optimal strategies for pricing, service, and preservation technology investments in the context of deteriorating items under common resource constraints. The research addresses the complex decision-making processes that businesses face when dealing with perishable goods, which inherently lose value over time. Saha and Moon (2017) contribute significantly to this discourse with their research on optimal retailer investments in green operations and preservation technology for deteriorating items. Pal et al (2018) explores optimal replenishment policies for non-instantaneously perishable items, focusing on the integration of preservation technology and the impact of random deterioration start times. Shah et al (2019) investigate the optimal control analysis of service, inventory, and preservation technology investments within the context of perishable goods management. Shen et al (2019) present an insightful study on production inventory management for deteriorating items, with a specific focus on the integration of collaborative preservation technology investment under a carbon tax regime. Shaikh et al (2019) investigate the economic order quantity (EOQ) model for deteriorating items, incorporating preservation technology, time-dependent demand, partial backlogging, and trade credit. Jaggi et al (2020) focuses on sustainable production policies and examines how volume agility, preservation technology, and price-reliant demand impact production strategies. Shen et al (2021) delve into the intersection of economic growth targets and green technology innovation, providing insights into how policy-driven growth objectives impact the development and adoption of environmentally friendly technologies. Zhang *et.al (2021)* says the Evaluating green technology indicators in the context of developing nations for sustainable investments and cleaner production. Padiyar et al (2022) developed three echelon supply chain model for decaying items. They show the effect of inflation. Taskin*et.al* (2022) express that the intersection of environmental responsibility, green technology, clean energy and green finance represents a significant advancement in sustainability. Shen*et.al* (2022) explore that the impact of targets for economic growth on the invention of green technologies. Singh and Rana (2023) developed sustainable production inventory model for growing items with trade credit policy. Handa et al (2023) developed inventory model in which impact of Carbon emission and volume flexibility is considers on a reverse logistics inventory model. They also use two level trade credit. According to Sahoo*et.al* (2023), they found that what effects do green technology innovation and green knowledge management have on the environmental performance of businesses? Recognizing the importance of acquiring green knowledge. Sahu*et.al* (2023) told the Economic order quantity model with partial backlog and trade credit for decaying items using preservation technologies in time-dependent demand. Pravin (2024) formulates sustainable inventory model for deteriorating items. To reduce the carbon emission, they use green technology. The whole study is divided in to 9 sections. In the first section Introduction is given. In the next section literature review, next section notations and assumptions, next mathematical modelling, next numerical illustration, next convexity, next sensitivity analysis, next observations and in the last section conclusion is presented.

3. Notations and assumptions

3.1 Notations: - Following notations are used to develop the model.

Decision variables

s: selling price (/ unit), T: Cycle time

Dependent decision variable

y_0**:** Deterioration rate, a, b: Demand parameters

c: Purchasing cost (/unit), C_h: Inventory holding cost (/unit/unit time)

τ: Fraction of per unit profit, M: Trade credit period

I_c : Rate of interest charge I_e: Interest earn per unit

C_1: Order cost (per order), D(s): Price dependent demand rate

$q(t)$: Inventory level at any time t, TP(T,P, τ):Per unit total profit

$y(s,\tau)$: Deterioration rate when preservation technology is used.

3.2 Assumptions

The proposed model is developed based on the assumptions from Rini and Jaggi (2022), with the exception of trade credit and green technology.

i. The demand rate is price dependent, i.e.,

D(s) = a – bs, where a, b > 0.

ii. Planning horizon is infinite.

iii. An EOQ lot-sizing inventory replenishment policy is considered, where replenishment occurs instantaneously.

iv. Investment in preservation technology reduces the rate of deterioration through a specific function.

$$y(s,\tau) = y_0 e^{-(s-c)^2\tau}$$

Which is convex in nature with

$$0 < \tau < 1, s > 0 \; and \; y(s,0) = y_0$$

v. The selling price is greater than the unit purchase cost, s > c.

vi. Green technology is taken into consideration.

vii. Permissible delay in period is allowed in this paper.

4. Mathematical model

In the system under consideration, inventory depletes due to both demand and deterioration. A price-dependent investment in preservation technology significantly reduces the original deterioration rate, thereby decreasing the inventory loss attributed to deterioration. This behaviour of the inventory system is depicted in Figure 1.

The differential equation representing the inventory level is

$$\frac{dq(t)}{dt} + y(s,\tau)q(t) = -(a-bs)\,, \quad 0 \le t \le T \qquad (1)$$

$$q(t) = \frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)(T-t)} - 1\right], \quad 0 \le t \le T$$

At $t = 0, q(0) = Q$

$$Q = \frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] \qquad (2)$$

Total number of deteriorated inventory, $D_T = Q - D(s)T$

$$D_T = \frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] - D(s)T$$

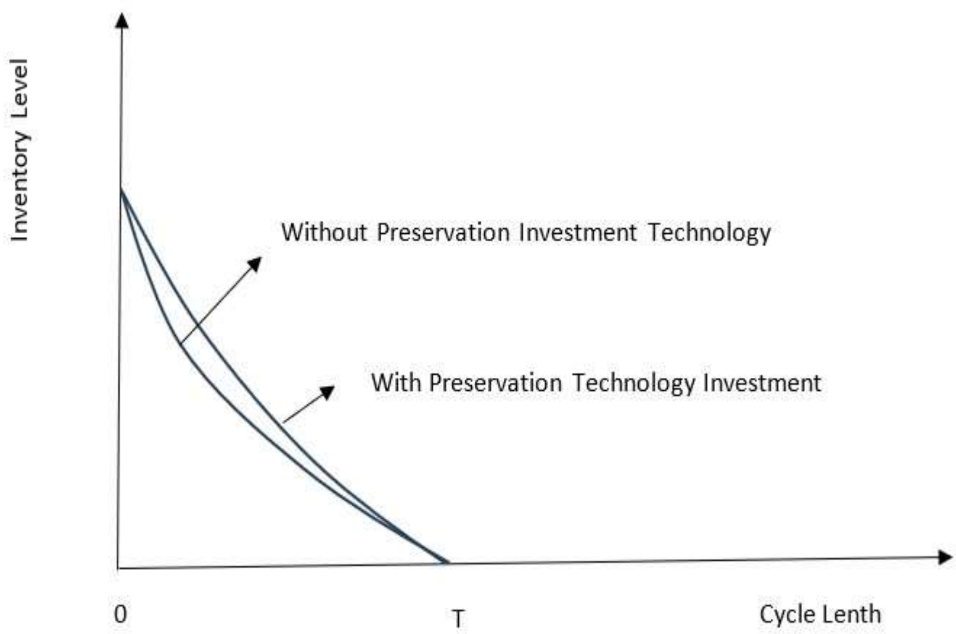

Figure 1. Represent the behaviour of inventory level

Inventory Costs

Holding Cost $= C_h \int_0^T q(t)dt = \frac{C_h(a-bs)}{(y(s,\tau))^2}\left[e^{y(s,\tau)T} - y(s,\tau)T - 1\right]$

Ordering Cost = C_1

Purchasing Cost = $\frac{c\,(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right]$

Preservation Technology = $(s-c)\alpha\,\frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right]$

Investment in Green Technology = GT

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The total average cost is given by

$$TC = \frac{1}{T}[C_1 + \frac{c(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] + (s-c)\alpha\,\frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] + GT + \frac{C_h(a-bs)}{\left(y(s,\tau)\right)^2}\left[e^{y(s,\tau)T} - y\,(s,\tau)T - 1\right]]$$

Now for the trade credit there arises two cases

Case I: - M< T, Case II: - M > T

For case I, when M <T,

Then interest earned = $sI_e \int_0^M Dtdt \;= sI_e(a-bs)\,[\frac{M^2}{2}]$

Interest charge or paid $= cI_c \int_M^T q(t)dt \;= \frac{cI_c(a-bs)}{y(s,\tau)}\left[\frac{-1+e^{y(s,\tau)(T-M)}}{y(s,\tau)} - T + M\right]$

For case 2, M>T,

The interest charge will be zero.

Interest earned is given by $= sI_e[(a-bs)\left[\frac{T^2}{2}\right] + (M-T)(a-bs)T]$

The cost in both the cases are as follows:

For Case I, M< T,

The total average cost is given by

$$TC = \frac{1}{T}[C_1 + \frac{c(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] + (s-c)\alpha\,\frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] + GT + \frac{C_h(a-bs)}{\left(y(s,\tau)\right)^2}\left[e^{y(s,\tau)T} - y\,(s,\tau)T - 1\right] + \frac{cI_c(a-bs)}{y(s,\tau)}\left[\frac{-1+\;e^{y(s,\tau)(T-M)}}{y(s,\tau)} - T + M\right] - sI_e(a-bs)\,[\frac{M^2}{2}]]$$

For Case II, M >T,

The total average cost is given by

$$TC = \frac{1}{T}[C_1 + \frac{c(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] + (s-c)\alpha\,\frac{(a-bs)}{y(s,\tau)}\left[e^{y(s,\tau)T} - 1\right] + GT + \frac{C_h(a-bs)}{(y(s,\tau))^2}\left[e^{y(s,\tau)T} - y\,(s,\tau)T - 1\right] - sI_e[(a-bs)\left[\frac{T^2}{2}\right] + (M-T)(a-bs)T]$$

5. Numerical Solution

For case 1:-

Consider a business situation in which the input parameters are as follows taken from Jaggi et al (2022)

$$C_h = 100\$/unit, a = 100unit, c = 5\$/unit, B = 100, x = 50, y_0 = 0.5, b = 5, K = 0.18,$$
$$J = 0.039\,.m = 2, c = 5, P = 10\$/unit, G = 200\$, \alpha = 0.02$$

Total cost =4205.1265\$, $T = 7.610738months$

For Case 2:-

Consider a business situation in which the input parameters are as follows taken from Jaggi et al (2022),

$$C_h = 100\$/unit, a = 100, unit\ B = 100, x = 50, y_0 = 0.5, b = 5, K = 0.18,$$
$$J = 0.039\,.m = 2, c = 5\$/unit, P = 10\$/unit, G = 200\$, \alpha = 0.02$$

Total cost =3903.067615, $T = 9.466830$

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6. Convexity

For the validation of model globally we find the convexity. The convexity in both the cases are show in figure 2 and 3.

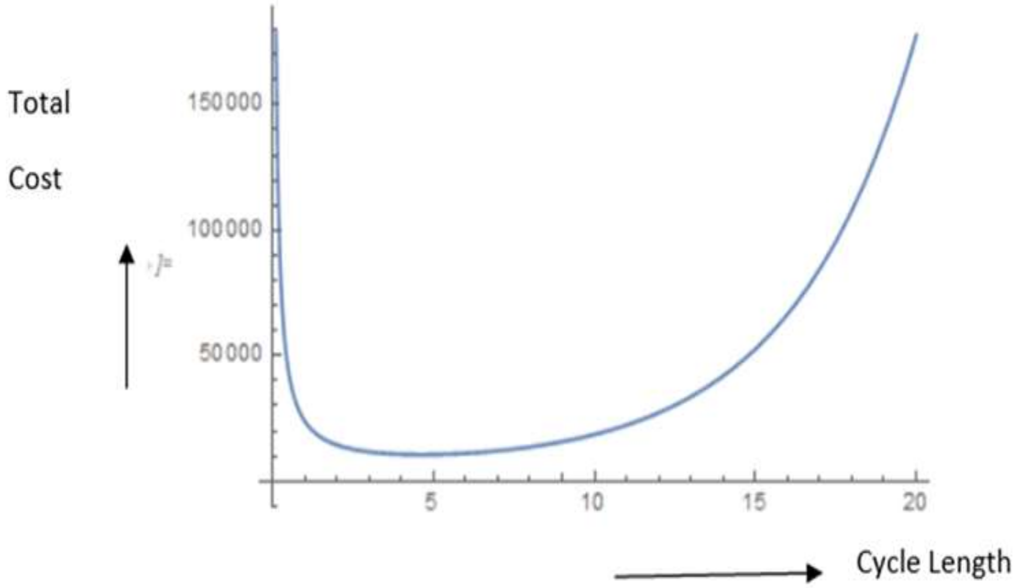

Figure 2 represent the convexity with respect to cycle length and total cost in case 1.

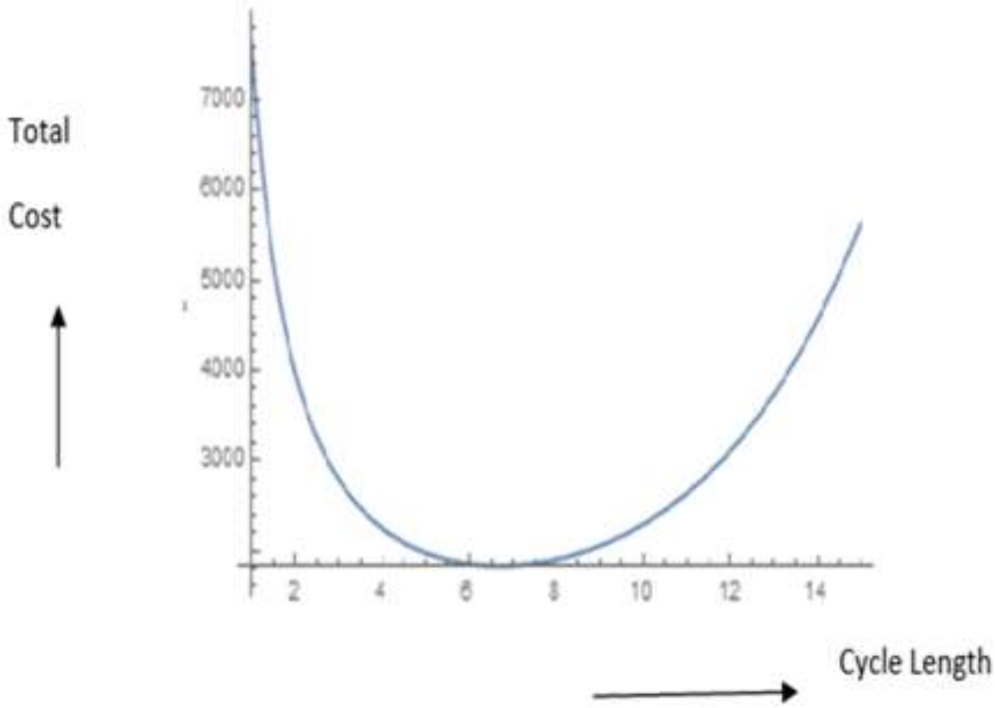

Figure 3 represent the convexity with respect to cycle length and total cost in case 2.

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7. Sensitivity Analysis

The sensitivity analysis for both the cases are given in table 1 and table 2.

Table 1: Sensitivity analysis of various parameter in case 1

Parameters	% Change	T	Total Cost
C_h	+20%	7.98014	4718.22
	+10%	7.80279	4464.61
	-10%	7.40118	3938.71
	-20%	7.17039	3664.25
a	+20%	7.60788	5801.92
	+10%	7.60907	5003.52
	-10%	7.61324	3406.73
	-20%	7.6174.	2608.33
c	+20%	5.95527	3874.36
	+10%	6.69243	4020.43
	-10%	8.75946	4433.3
	-20%	10.2058	4710.13
C_1	+20%	7.61274	4207.75
	+10%	7.61174	4206.44
	-10%	7.60974	4203.81
	-20%	7.60873	4202.5
y_0	+20%	6.22857	3640.47
	+10%	6.85682	3896.42
	-10%	8.53189	4584.44
	-20%	9.68255	5061.13
b	+20%	7.61324	3406.73
	+10%	7.61185	3805.93
	-10%	7.60983	4604.33
	-20%	7.60907	5003.52
I_e	+20%	7.60713	4280.47
	+10%	7.60894	4243.32
	-10%	7.53225	4165.82
	-20%	7.61434	4125.33
I_c	+20%	7.4572	4280.47
	+10%	7.53225	4243.32
	-10%	7.69297	4165.82
	-20%	7.77929	4125.33
M	+20%	7.70518	4123.63
	+10%	7.65885	4163.47
	-10%	7.56084	4248.71
	-20%	7.50917	4294.32
s	+20%	12.6991	5107.82
	+10%	9.6446	4565.85
	-10%	6.25002	3989.28

	-20%	5.35101	3892.28
G	+20%	7.61074	4245.13
	+10%	7.61074	4225.13
	-10%	7.61074	4165.13
	-20%	7.61074	4125.13
α	+20%	8.47781	4568.09
	+10%	8.03347	4381.88
	-10%	7.20858	4037.36
	-20%	6.82603	3878.14

Table 2: Sensitivity analysis of various parameter in case 1

Parameters	% Change	T	Total Cost
C_h	+20%	9.79982	4318.15
	+10%	9.6396	4112.4
	-10%	9.2792	3689.71
	-20%	9.07368	3471.79
a	+20%	9.4626	5380.07
	+10%	9.46533	4641.57
	-10%	9.46908	3164.57
	-20%	9.47281	2426.06
c	+20%	7.16655	3939.49
	+10%	8.17985	3922.31
	-10%	11.1102	3876.54
	-20%	13.224	3835.01
C_1	+20%	9.46863	3905.18
	+10%	9.46773	3904.12
	-10%	9.46593	3902.01
	-20%	9.46503	3900.95
y_0	+20%	7.50681	3690.89
	+10%	8.38664	3790.35
	-10%	10.8202	4032.03
	-20%	12.5584	4181.21
b	+20%	9.46908	3164.57
	+10%	9.46783	3533.82
	-10%	9.46601	4272.57
	-20%	9.46533	4641.57
I_e	+20%	9.53923	3817.54
	+10%	9.50305	3860.39
	-10%	9.2284	4178.83
	-20%	9.19193	4220.27
M	+20%	9.46683	4103.07
	+10%	9.46683	4003.07
	-10%	9.46683	3803.07
	-20%	9.46683	3703.07
	+20%	17.467	3545.37

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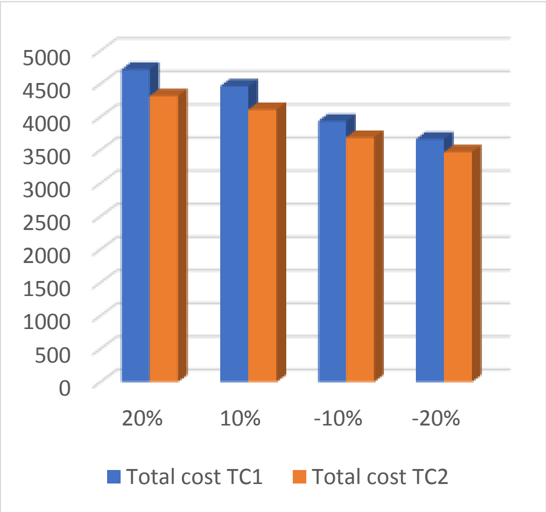
s	+10%	12.5469	3735.44
	-10%	7.50878	4072.97
	-20%	6.26442	4261.55
G	+20%	9.46683	3923.07
	+10%	9.46683	3913.07
	-10%	9.46683	3893.07
	-20%	9.46683	3883.07
α	+20%	10.7357	4031.49
	+10%	10.0817	3966.7
	-10%	8.88892	3840.63
	-20%	8.34575	3779.41

Graphical Representation of Sensitivity Analysis



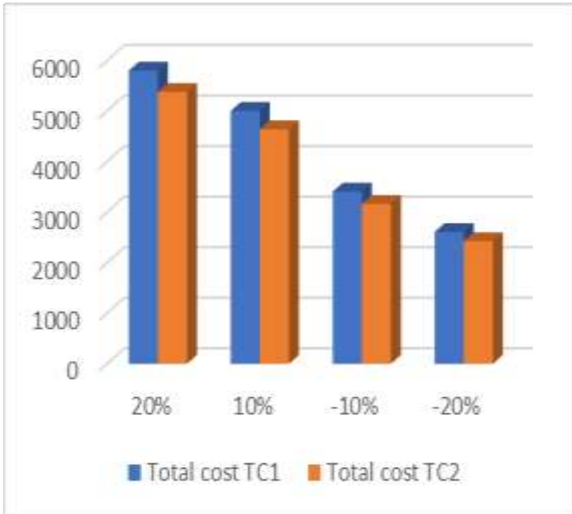
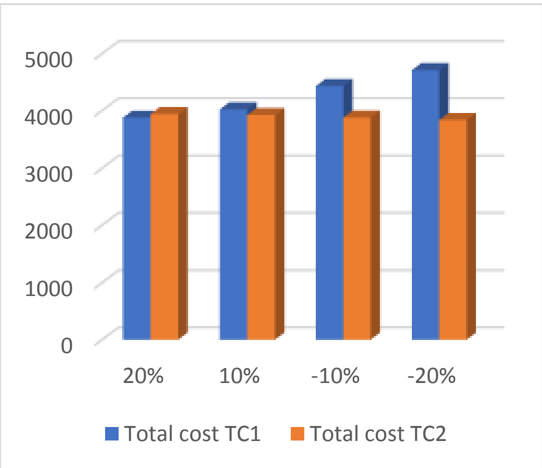


Figure 4 Sensitivity Analysis with respect to holding cost
Figure 5 Sensitivity Analysis with respect to demand parameter



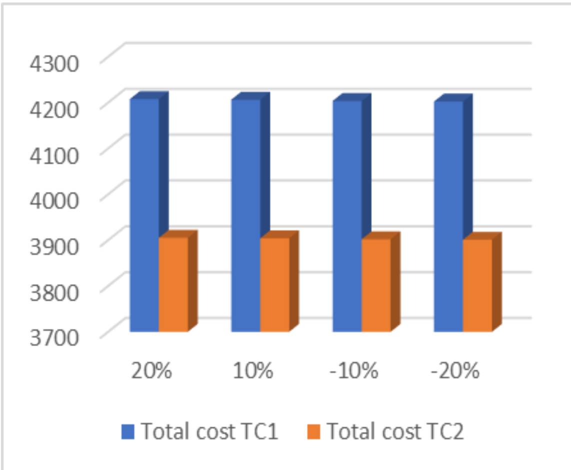


Figure 6 Sensitivity Analysis with respect to purchasing cost
Figure 7Sensitivity Analysis with respect to ordering cost

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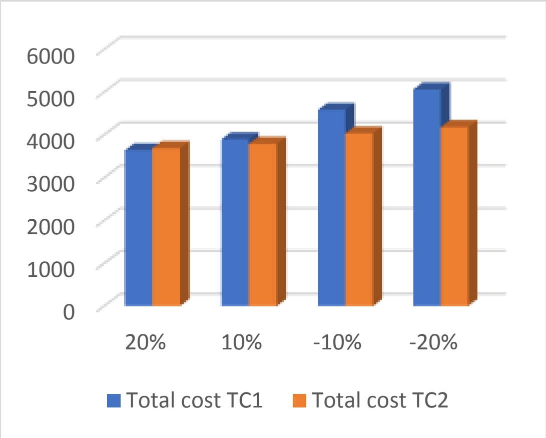


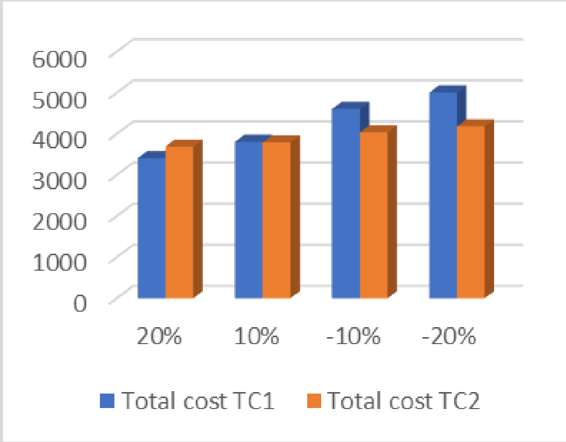


Figure 8 Sensitivity Analysis with respect to deterioration rate

Figure 9 Sensitivity Analysis with respect to demand price sensitive parameter

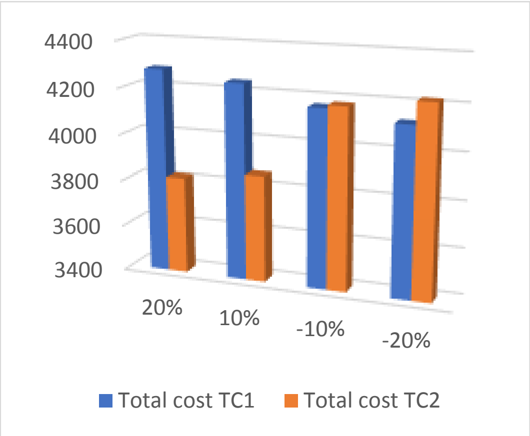
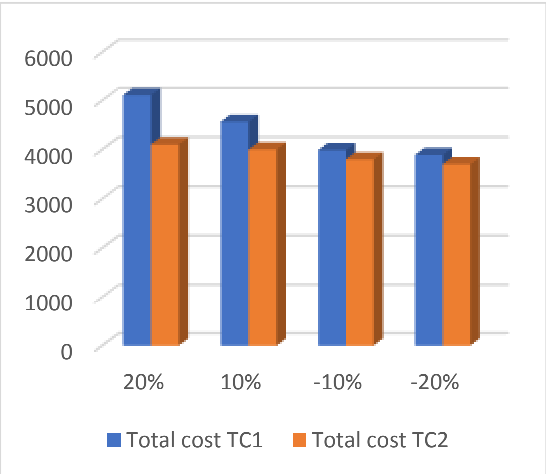


Figure 10 Sensitivity Analysis with respect to rate of interest earn.

Figure 11 Sensitivity Analysis with respect to Trade credit period.



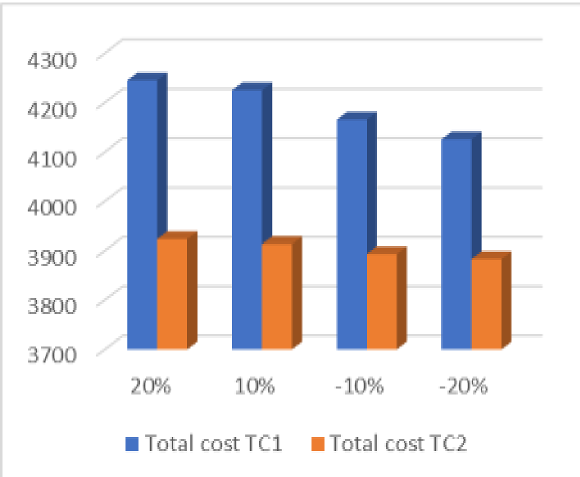


Figure 12 Sensitivity Analysis with respect to selling price.

Figure 13 Sensitivity Analysis with respect to green technology investment.

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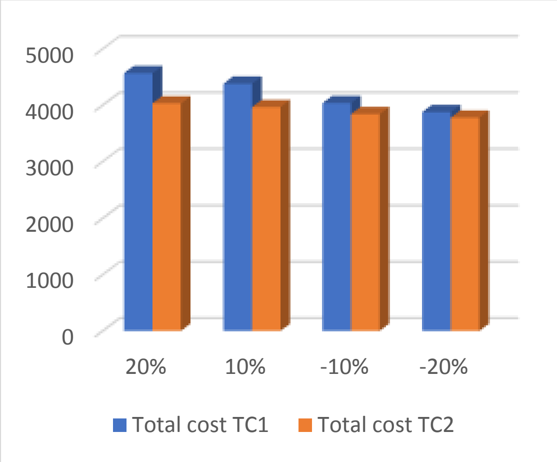

Figure 14 Sensitivity Analysis with respect to preservation technology investment.

8. Observations

1. As holding cost C_h increases the total cost and cycle length increases in both cases.
2. As demand parameter 'a' increases total cost increases while the cycle length decreases in both cases.
3. As purchasing cost increases total cost decreases in case 1 while total cost increases in case 2. Cycle length decreases in both cases.
4. As ordering cost increases cycle length increases while the total cost decreases in both the case.
5. As initial deterioration rate increases total cost and cycle length decrease in both cases.
6. As demand price-sensitive parameter 'b' increases total cost and cycle length decreases.
7. As interest earn rate i_e increases total cost and cycle length both increases in both cases.
8. As interest charge rate i_p increases total cost increases while cycle length decreases in both cases.
9. As the trade credit period increases total cost decreases while cycle length increases in both cases.
10. As selling price increases cycle length and total cost both are increases in both cases.
11. As investment in green technology increases the total cost slightly increases while the cycle length remains the same in both cases.
12. As investment in preservation technology increases the total cost and cycle length both are increases in both cases.

9. Conclusions

The Green Inventory Model with Price Sensitivity, Investment in Preservation Technology, and Trade Credit represents a holistic approach to inventory management that not only addresses environmental concerns but also contributes to long-term profitability and resilience in an ever-evolving marketplace. As businesses continue to navigate the complexities of modern supply chains, this model serves as a valuable tool for achieving sustainability objectives while remaining competitive in an increasingly environmentally-conscious world.In this chapter we developed a green inventory model in which demand is selling price dependent, deterioration is taken into consideration. Investment is preservation technology is depending on selling price. To reduce the carbon emission green technology investment is taken into consideration. Trade credit policy is used from which two cases are arising. Case 21 when trade credit period is less than cycle length and case 2 when trade credit period is greater than cycle length. To validate the model mathematically two numerical examples are carried out by using the software Mathematica 12.0. From the numerical illustration we revealed that the case two is more profitable than the case 1. This chapter can be further extended with effect of inflation, and different carbon emission regulation policies.

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