

Impact of Health Awareness and Price Sensitivity on Inventory Decisions for Organic and Non-Organic Products under Preservation Investment

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Abstract

Driven by post-COVID-19 health awareness, consumer demand for organic food products has surged. As these products lack chemical preservatives, their rapid deterioration necessitates significant investment in specialized preservation technology. To guide retailers managing this complex environment, this study develops a constrained mathematical inventory model for optimizing policies regarding two substitute products, one of which is organic and the other is non-organic. The model advances current literature by uniquely integrating three critical factors: the price differential between the two products, the dynamic impact of health awareness on price-sensitive demand, and the imposition of budgetary restrictions on preservation technology investment. Sensitivity analysis demonstrates that strategically raising consumer health awareness and optimizing preservation investments are effective methods for enhancing overall retailer profitability.

Keywords- Health awareness, Organic product, Non-organic product, Deterioration, Preservation technology investment, Sensitivity analysis.

1. Introduction

In recent years, the organic sector has shown significant worldwide growth. According to *The World of Organic Agriculture: Statistics and Emerging Trends 2026*, global organic food and beverage sales were valued at around €145 billion in 2026, demonstrating increasing consumer interest and market expansion. Meanwhile, the total area under organic farming remained at around 99 million hectares, indicating stability in the production base (FiBL and IFOAM, 2026).

The COVID-19 pandemic significantly heightened consumer awareness of health-related issues, accelerating a shift in consumer inclination toward healthier, more sustainable food options, which sought to strengthen immunity. The growing connection between health awareness and organic consumption is now recognized as a fundamental aspect of consumer behaviour. This trend is clearly reflected in rising sales figures: UK-based retailer Able & Cole reported a 25% increase in organic product sales during the pandemic, while the Indian organic e-commerce platform 'I Say Organic' observed a 100% surge in demand, and Gujarat's 'Suryan Organic' witnessed a 25–30% growth in sales. Studies by Ghufra et al. (2022) and Parashar et al. (2023) further highlight how health consciousness and environmental awareness influence organic purchasing decisions and consumer migration toward organic foods post-pandemic. This encourages us to observe the impact of health awareness on consumer demand.

The U.S. based grocery chain Whole Foods Market sells both natural and organic products at its stores. Online sites like Amazon or Flipkart sell both organic and non-organic products to their customers, like pulses, fruits, vegetables, and dairy products. These platforms enable customers to compare prices and health benefits, allowing them to make informed purchasing decisions based on their preferences and affordability.

This evolving consumer landscape characterized by heightened health awareness, price-sensitive demand for both organic and non-organic items, and the inherent perishability of organic goods, has direct implications for retail operations and inventory management policies. Consequently, retailers stocking both organic and non-organic products must adjust their inventory strategies to efficiently manage this dynamic demand.

This study seeks to examine the following research question by acknowledging that consumer demand is determined not only by product pricing, but also by factors including health consciousness and price variation:

- (i) How does consumer health consciousness influence the demand for organic as well as non-organic products?
- (ii) How does the price gap affect customer substitution behavior?
- (iii) How do preservation technology investments impact retailer profitability under budget constraints?

To address the above questions, a mathematical inventory model is formulated for organic as well as for non-organic products under a preservation technology investment budget constraint. The proposed model considers demand as a function of consumer health awareness and price sensitivity to analyze optimal inventory-related decisions. The remainder of the manuscript is structured as follows: Section 2 reviews a detailed survey of the relevant literature with particular emphasis on demand influenced by pricing and investments in preservation technology within inventory management systems. Section 3 develops the proposed model by specifying the underlying assumptions and introducing the notation employed in the analysis. The mathematical formulation of the profit functions is presented in Section 4. Section 5 describes the solution approach and outlines the algorithms used to obtain the optimal profit decisions. Section 6 demonstrates the model's practicality using a hypothetical numerical case, whereas Section 7 performs an in-depth sensitivity analysis to evaluate how various key parameters affect overall system behaviour. Section 8 presents the managerial takeaways and actionable insights emerging from the study. Section 9 consolidates the major findings of the research. At last, Section 10 discusses the study's constraints and proposes avenues for further investigation.

2. Literature Review

This section examines prior scholarly work related to inventory models that consider demand sensitivity to pricing and the role of investment in preservation technologies.

2.1 Inventory Model with Pricing

It is widely observed that product demand is influenced by its price: as price increases, demand typically decreases, and vice versa. Researchers frequently leverage this economic principle when developing inventory models to mitigate stockouts and excess storage.

Kim et al. (2011) developed coordinated pricing and ordering decisions in a supply chain composed of one retailer and one manufacturer with price-sensitive demand. Maihami and Kamalabadi (2012), developed a non-instantaneous deteriorating item model with price- and time-dependent demand under partial backlogging. Saha and Goyal (2015) proposed a two-stage supply chain model where demand depends on both price and stock, and introduced three coordination contracts: joint rebate, cost sharing, and discount contracts between manufacturers and retailers. Mandal and Giri (2015) formulated an inventory model for a single vendor with multiple buyers under price and stock-dependent demand, considering multiple shipments and consignment stock policies. Hemmati et al. (2017) formulated a model for deteriorating items under the vendor managed inventory with consignment stock (VMI-CS) strategy with price- and stock-dependent demand. Pan and Zhou (2017) analyzed bundling and pricing strategies for complementary products under a two-stage supply chain using a game-theoretic approach. Aneja and Aggarwal (2019) examined inventory models for fixed shelf-life products under inspection policies with demand dependent on price, shelf life, and discounts. Mishra et al. (2019) considered remanufactured products under deterioration and trade credit, using a discounted cash flow approach for price- and stock-dependent demand.

Recent studies have incorporated various advances scenarios such as, Aggarwal et al. (2020) developed a booking system inventory model with price and advertisement dependent demand. Taleizadeh et al. (2020) investigated complementary products with price-dependent demand under three selling strategies. Akhtar et al. (2023) developed an inventory model for deteriorating item which follows a three parameter Weibull distribution, while demand depends on both time and selling price under partially backlogged shortages and hybrid differential evolution and social group optimization (DESGO) algorithm is used to optimize the retailer's profit. Barman et al. (2023) developed a two-echelon inventory model in which demand is price dependent, and the deterioration rate is assumed to be a Weibull distribution. Shah et al. (2023) developed an inventory model for deteriorating product under price, stock and greening effort dependent demand. Sivashankari and Nithya (2024) developed an inventory model for integrated price and stock-dependent demand for a deteriorating item. Loganayaki and Kirupa (2026) developed a two-level trade credit model in which the supplier provides full trade credit to the retailer, while the retailer extends partial trade credit to customers. The model incorporates price-dependent demand and accounts for the effects of preservation technology and green investment decisions. Yadav et al. (2025) developed a two-warehouse inventory model for deteriorating item under investment in green technology to reduce carbon emission with partial backlogged shortages and demand is price and time sensitive.

Most existing studies on price-dependent demand have primarily focused on single-product inventory systems. Although a limited number of researchers have examined substitute products with demand influenced by both own-price and cross-price effects, the combined impact of price difference and consumer health awareness on product demand has received little attention. The present study addresses this research gap by incorporating consumer purchasing behaviour, particularly price sensitivity and health awareness, into the inventory decision-making framework.

2.2 Preservation Technology Investment

Preservation technology investment in inventory management involves applying technologies to increase shelf life, reduce deterioration, and improve overall efficiency and cost-effectiveness. Items sensitive to temperature, humidity, or other environmental factors, such as perishable foods and pharmaceuticals, require technologies such as cold storage and vacuum packaging.

Hsu et al. (2010) developed an inventory model for constantly deteriorating items under shortages and preservation investment. Dye (2013) studied non-instantaneous deteriorating items under time-dependent partial backlogging with preservation investment. Hsieh and Dye (2013) proposed a production-inventory model for deteriorating items with time-dependent demand and preservation investment. Zhang et al. (2015) examined a two-echelon inventory model for deteriorating products with price-dependent demand, incorporating joint preservation investment and revenue-sharing contracts. Yang et al. (2015) considered preservation investment for perishable products under trade credit. Mishra et al. (2017) formulated an economic order quantity (EOQ) model for perishable products with shortages and preservation technology investment. Mohammadi et al. (2019) developed a two-echelon supply chain model for fresh products, incorporating preservation investment to control deterioration and price- and freshness-dependent demand.

More recent contributions include Sepehri et al. (2021), formulated a sustainable economic production quantity (EPQ) model for defective items with preservation investment and carbon-emission costs; and Sebatjane (2022), developed a multi-echelon inventory model for perishable items with preservation investment. Barman et al. (2022) developed a multi-objective EPQ model, in which demand is emergency level dependent under partially backlogged shortages and investment in green technology and preservation technology. Priyamvada et al. (2022) developed an inventory model where demand is price-dependent, and the preservation technology investment depends on the selling price of the product. Hatibaruah and Saha (2023) developed an integrated inventory model for deteriorating item which follows a two parameter Weibull distribution, while demand depends on stock and advertisement frequency under partially backlogged shortages and investment in preservation. Kaushik (2023) developed an inventory model in which demand follows a ramp-type pattern under permissible payment delays and investment in preservation technology. Rana et al. (2023) studied the impact of green and preservation technologies on overall supply chain costs for deteriorating items. Preservation technology is incorporated to reduce deterioration, while shortages are allowed and assumed to be fully backlogged. Kumar et al. (2025) proposed an inventory model for COVID-19 vaccines in which product quality deteriorates over time, while retailers invest in preservation technology to mitigate this degradation. The model assumes a ramp-type demand pattern and incorporates partially backlogged shortages as well as carbon emission considerations.

Although preservation investment has been widely studied in inventory management, its relationship with changing demand patterns in retail markets has not been sufficiently examined. To bridge this gap, the present study develops an inventory model for organic and non-organic food products by integrating preservation technology investment with consumer-driven demand behaviour. The model also considers budget limitations associated with preservation technology investment to enhance its practical applicability.

Table 1. Overview of the existing literature.

Author	Two-product model	Demand is price-dependent	Demand is awareness-dependent	Deterioration	Preservation Investment	Budget restriction on preservation investment
Hsu et al. (2010)	×	×	×	√	√	×
Kim et al. (2011)	×	√	×	×	×	×
Maihami and Kamalabadi (2012)	×	√	×	√	×	×
Hsieh and Dye (2013)	×	×	×	√	√	×
Dye (2013)	×	×	×	√	√	×
Mandal and Giri (2015)	×	√	×	×	×	×
Saha and Goyal (2015)	×	√	×	×	×	×
Zhang et al. (2015)	×	√	×	×	√	×
Yang et al. (2015)	×	×	×	×	√	×
Hemmati et al. (2017)	×	√	×	√	×	×
Pan and Zhou (2017)	√	√	×	×	×	×
Mishra et al. (2017)	×	×	×	√	√	×
Mishra et al. (2019)	×	√	×	√	×	×
Mohammadi et al. (2019)	×	√	×	√	√	×
Aneja and Aggarwal (2019)	×	√	×	×	×	×
Aggarwal et al. (2020)	×	√	×	×	×	×
Taleizadeh et al. (2020)	√	√	×	×	×	×
Sepehri et al. (2021)	×	×	×	√	√	×
Barman et al. (2022)	×	×	×	√	√	×
Priyamvada et al. (2022)	×	√	×	√	√	×
Sebatjane (2022)	×	×	×	√	√	×
Akhtar et al. (2023)	×	√	×	×	×	×
Barman et al. (2023)	×	√	×	√	×	×
Hatibaruah and Saha (2023)	×	×	×	√	√	×
Kaushik (2023)	×	×	×	√	√	×
Rana et al. (2023)	×	×	×	√	√	×
Shah et al. (2023)	×	√	×	√	√	×
Sivashankari and Nithya (2024)	×	√	×	√	×	×
Yadav et al. (2024)	×	×	×	√	√	×
Kumar et al. (2025)	×	×	×	√	√	×
Loganayaki and Kirupa (2025)	×	√	×	√	√	×
Yadav et al. (2025)	×	√	×	×	×	×
This Paper	√	√	√	√	√	√

2.3 Research Gap

Table 1 provides a comparative analysis, illustrating the prevalent focus among researchers on developing inventory models for a single deteriorating item in which demand depends on the product price, and preservation technology is used to mitigate product deterioration. While significant past research has integrated the concepts of price-dependent demand and preservation technology investment into various inventory contexts, there remains limited exploration regarding the management of dual retail categories, specifically organic and non-organic food products.

A comprehensive review reveals that the existing literature largely lacks the simultaneous consideration of three critical elements crucial to optimizing retailer policies in the current market environment:

- (i) Consideration of the price difference between two distinct products (organic and non-organic).
- (ii) Integration of the explicit impact of the awareness level on product demand.
- (iii) The inclusion of budget constraints on preservation technology investment.

To address these shortcomings, this study constructs a novel inventory model for a retailer stocking two distinct products: an organic and a non-organic. The model explicitly incorporates the following dynamic factors:

- **Customer choice and price:** Usually, the price of the organic product is higher than the non-organic product; the customer will make a shift from non-organic to the organic only if the price gap between the products is not very significant.
- **Awareness-driven demand:** In response to the heightened health awareness observed in the post-COVID-19 period, the proposed model integrates a demand function that dynamically reflects the effect of health consciousness on the demand for organic products.
- **Constrained preservation:** Given the perishable nature of the goods, preservation technology investment is integrated to curb the deterioration rate. Crucially, the retailer operates under a budget restriction when allocating funds for this technology across both product categories.

3. Notations and Assumptions

This section discusses the key notations and assumptions used in the development of the mathematical model.

3.1 Notations

For Organic Product:

a_0	Organic product market base
b_0	Organic product price sensitivity
α_1	Price difference sensitivity parameter for the organic product
γ_1	Scale parameter capturing the impact of consumer health awareness on demand for the organic product
β_1	Efficiency parameter of preservation technology for organic products
ρ	Captures the intensity of external health awareness efforts that increase the fraction of informed consumers
δ	Reflects the rate of decline in consumer health awareness due to forgetting, inattention, or information overload
ν_0	Rate of deterioration for the organic products
$\nu_0(\xi_0)$	Reduced the deterioration rate of the organic product after the investment in preservation technology, i.e., $\nu_0(\xi_0) = \nu_0 e^{-\beta_1 \xi_0}$
φ	Fixed price markup of the organic product over the non-organic product
D_0	Demand for the organic product at any time t
A_0	Ordering cost of the Organic product (\$/order)
P_0	Organic product price $P_0 = P_n + \varphi P_n$ (\$/unit)
C_0	Unit cost of the organic product (\$/unit)
C_{od}	Deterioration cost of the organic product (\$/unit)
I_0	Inventory carrying charge of the organic product
$I_0(t)$	Inventory level of the organic product at any time t
Q_0	Ordered quantity of the organic product
U	Total budget available for investment in preservation technology (\$)

For Non-Organic Product:

a_n	Non-organic product market base
b_n	Non-organic product price sensitivity
α_2	Price difference sensitivity parameter for the non-organic product
γ_2	Scale parameter capturing the impact of consumer health awareness on demand for the non-organic product
β_2	Efficiency parameter of preservation technology for non-organic products
ν_n	Rate of deterioration for the non-organic products
$\nu_n(\xi_n)$	Reduced the deterioration rate of the non-organic product after the investment in preservation technology, i.e., $\nu_n(\xi_n) = \nu_n e^{-\beta_2 \xi_n}$
D_n	Demand for the non-organic product at any time t
A_n	Ordering cost of the non-organic product (\$/order)
C_n	Unit cost of the non-organic product (\$/unit)
C_{nd}	Deterioration cost of the non-organic product (\$/unit)
I_n	Inventory carrying charge of the non-organic product
$I_n(t)$	Inventory level of the non-organic product at any time t
Q_n	Ordered quantity of the non-organic product

Decision variables:

T	The common cycle length (Year)
P_n	Non-Organic product price (\$/unit)
ξ_0	Investment in preservation technology for organic products (\$/unit)
ξ_n	Investment in preservation technology for non-organic products (\$/unit)

3.2 Assumptions

- A single retailer sells two substitute products: one is organic, and the other is non-organic.
- Both products are substitutable for each other; each product can substitute for the other in case of a lack of the other product. However, their cost will be different.
- Customer demand is sensitive to health awareness and relative price levels. Higher health awareness motivates customers to substitute non-organic products with organic products, whereas an increase in the price of organic products leads to a partial shift in demand toward non-organic products. Therefore, the demand for non-organic products is negatively affected by rising health awareness.
- Both products are deteriorating in nature. The rate of deterioration of both products is different. Specifically, the organic product deteriorates at a higher rate than non-organic products, i.e., $\nu_0 > \nu_n$.
- The preservation investment reduces the deterioration rate of both organic and non-organic products from ν_0 and ν_n to $\nu_0(\xi_0) = \nu_0 e^{-\beta_1 \xi_0}$ and $\nu_n(\xi_n) = \nu_n e^{-\beta_2 \xi_n}$ respectively. This implies that

$$\frac{\partial \nu_i(\xi_i)}{\partial \xi_i} < 0 \quad (1)$$

$$\text{and } \frac{\partial^2 v_i(\xi_i)}{\partial \xi_i^2} > 0 \quad (2)$$

for $i = \{o, n\}$.

Equation (1) shows increase in investment leads to a reduction in deterioration, and Equation (2) shows the diminishing marginal effectiveness of preservation investment. **Figure 1** shows the impact of preservation technology on reducing the rate of deterioration. As the preservation investment increases, the deterioration rate will decrease.

- vi. The investment required for preservation technology in organic products is significantly higher than that of non-organic products.
- vii. Due to the positive impact of health awareness, the consumer shifts away from non-organic products to organic products.
- viii. Stockouts are not permitted.
- ix. The lead time is assumed to be insignificant.
- x. The planning horizon is assumed to be infinite.
- xi. The retailer maintains a common order cycle for both organic and non-organic products to avoid cannibalisation of one product over another due to unavailability. Also, to provide the possibility of substitution of the products.

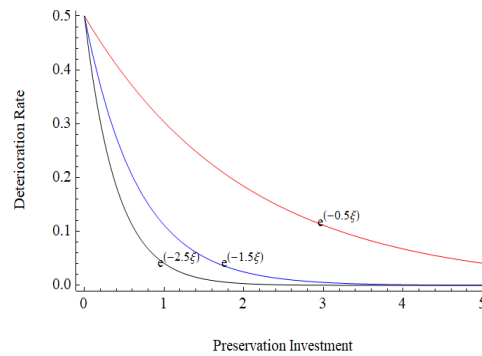


Figure 1. Reduction in the deterioration rate through investment in preservation technology.

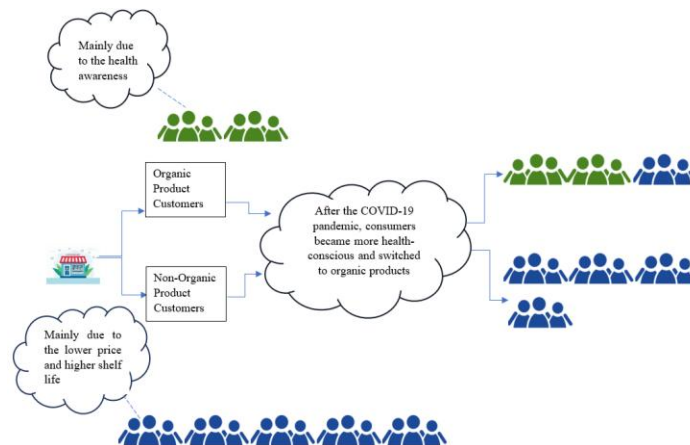


Figure 2. Customer flow due to health awareness.

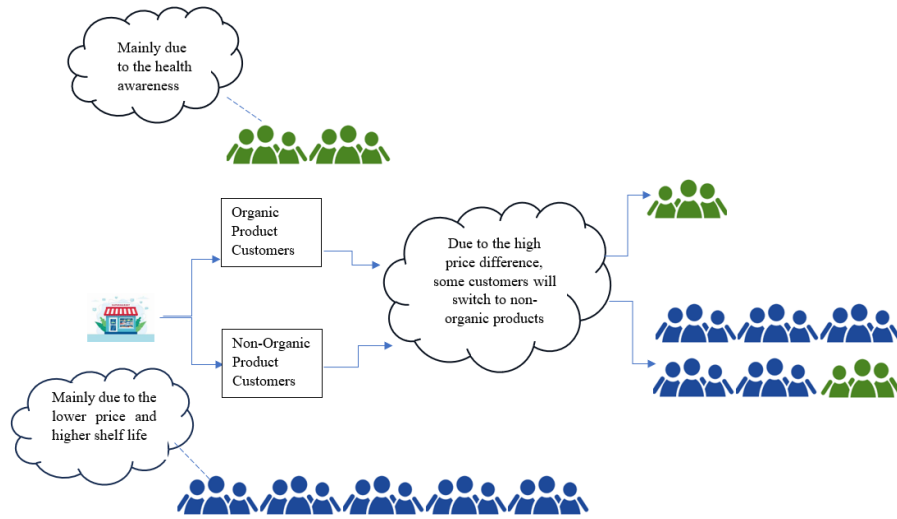


Figure 3. Customer flow due to high price difference.

4. Model Development

This section develops the analytical framework for understanding inventory management decisions when a retailer offers both organic and non-organic products. Organic items such as fruits, vegetables, and grains are cultivated without artificial pesticides or fertilizers, making them inherently more perishable due to the absence of chemical preservatives. The onset of the COVID-19 pandemic has notably heightened consumer health consciousness, accelerating a shift in demand towards organic, health-promoting products. Numerous studies confirm this trend, and it is further reinforced by government and non-government initiatives that support organic agriculture and increase consumer awareness.

A key mechanism in the model is the process by which awareness spreads and impacts purchasing behaviour. As consumers become more health-aware, a segment is motivated to switch from non-organic to organic purchases. This migration path showing how marketing efforts, health information, and perceived product value influence customer decision-making is visualised in **Figure 2**, and **Figure 3** illustrates that, due to the high price of the organic products, customers tend to switch from organic to non-organic products.

Both product categories are assumed to exhibit price-sensitive demand, but organic products deteriorate faster, necessitating higher investment in preservation technology. Following Mahajan and Muller's (1986) modelling approach for awareness dissemination, this study employs a similar differential equation framework to capture the dynamics of consumer awareness over time:

$$\frac{dH_a(t)}{dt} = \rho(1 - H_a(t)) - \delta H_a(t) \quad (3)$$

where, $H_a(t)$ is the fraction of the target market aware of the health benefit of the organic product at time t , ρ is the coefficient of health awareness dissemination, representing the rate at which consumers become aware of the health benefits of the organic product through external influences such as mass media, government initiatives, and health campaigns, etc, and δ is the forgetting (or awareness decay) parameter represents the rate at which consumers ignore or forget health-related information over time. $(1 - H_a(t))$ represents the fraction of consumers who are unaware of the health benefits of the organic product at the time t .

Solving the above differential equation at, $t=0$, $H_a(t)=0$.

$$H_a = \frac{\rho}{(\rho + \delta)} (1 - e^{-(\rho + \delta)t}) \quad (4)$$

As customers become more conscious of the product, some who previously purchased non-organic items are transitioning to organic products. Consequently, the demand function is represented as:

$$D_o = a_0 - b_0 P_o - \alpha_1 (P_o - P_n) + \gamma_1 \frac{\rho}{(\rho + \delta)} (1 - e^{-(\rho + \delta)t}) \quad (5)$$

Demand is linear function with respect to price and non-linear in terms of time (See **Figure 4**). In Equation (5), the first term represents the baseline market demand for the organic product. The second term captures the effect of the organic product's own price on demand, indicating that higher prices lead to a reduction in demand. The third term reflects the impact of the price differential between organic and non-organic products; as the organic product becomes relatively more expensive, a portion of consumers may substitute toward non-organic alternatives. The final term represents the positive influence of health awareness on demand, implying that an increase in health awareness leads to higher demand for organic products.

$$D_n = a_n - b_n P_n + \alpha_2 (P_o - P_n) - \gamma_2 \frac{\rho}{(\rho + \delta)} (1 - e^{-(\rho + \delta)t}) \quad (6)$$

In Equation (6), the first term represents the baseline market demand for the non-organic product. The second term captures the effect of the non-organic product's own price on demand, indicating that an increase in price leads to a decrease in demand. The third term reflects the impact of the price differential between organic and non-organic products; when this gap widens, consumers tend to substitute toward the relatively cheaper non-organic product. The final term represents the negative effect of health awareness on demand, implying that higher levels of health awareness reduce the demand for non-organic products.

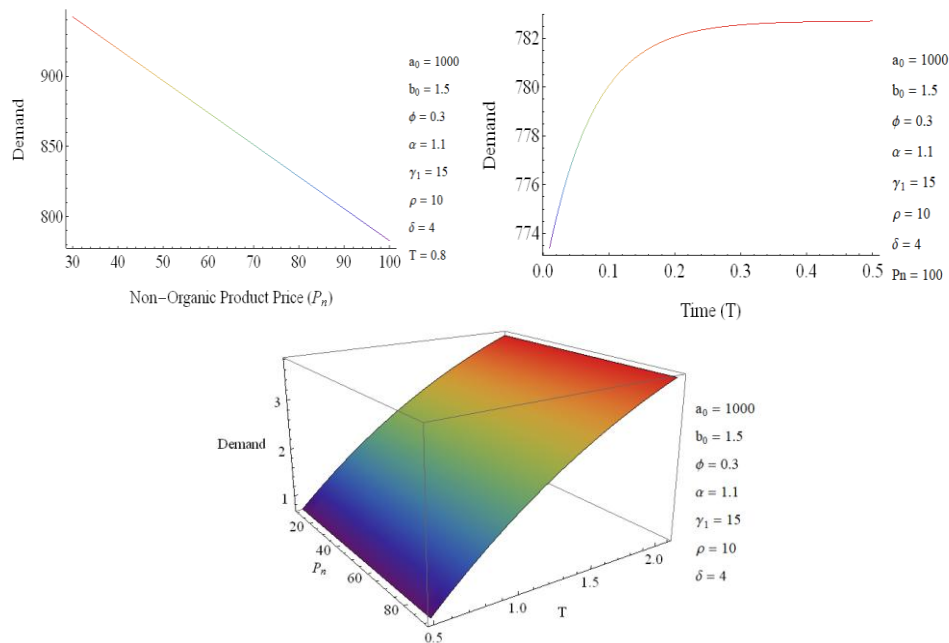


Figure 4. Organic demand function with respect to non-organic product price and time.

To simplify the demand function, it is assumed that $d_1 = a_0 - b_0 P_0 - \alpha_1 (P_0 - P_n)$, $g_1 = \gamma_1 \frac{\rho}{(\rho + \delta)}$, $d_2 = a_n - b_n P_n + \alpha_2 (P_0 - P_n)$ and $g_2 = \gamma_2 \frac{\rho}{(\rho + \delta)}$.

The Equations (5) and (6) can be written as

$$D_0 = d_1 + g_1 (1 - e^{-(\rho + \delta)t}) \quad (7)$$

$$D_n = d_2 - g_2 (1 - e^{-(\rho + \delta)t}) \quad (8)$$

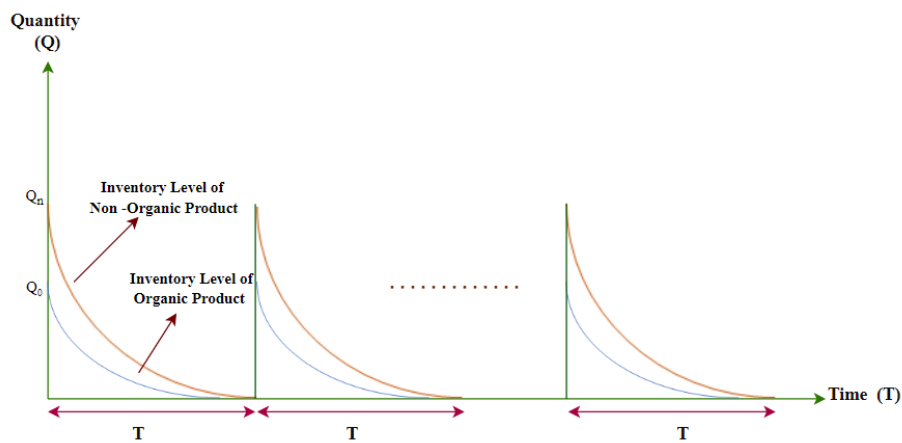


Figure 5. Inventory cycle of organic and non-organic products.

As shown in **Figure 5**, the inventory cycles of both the organic and non-organic products are assumed to be identical, and the inventories are depleted simultaneously at time T . Therefore, the differential equation of inventory depletion of organic and non-organic products can be expressed as,

$$\frac{dI_0(t)}{dt} = -v_0(\xi_0)I_0(t) - D_0 \quad 0 < t < T.$$

$$\frac{dI_n(t)}{dt} = -v_n(\xi_n)I_n(t) - D_n \quad 0 < t < T.$$

By applying the boundary condition at $t = T, I_0(T) = 0$ and $I_n(T) = 0$, the solution of the above differential equation can be expressed as:

$$I_0(t) = \left[\frac{d_1}{v_0(\xi_0)} \left(e^{v_0(\xi_0)(T-t)} - 1 \right) + \frac{g_1}{v_0(\xi_0)} \left(e^{v_0(\xi_0)(T-t)} - 1 \right) + \frac{g_1}{(\rho + \delta - v_0(\xi_0))} \left(e^{-(\rho + \delta)T} e^{v_0(\xi_0)(T-t)} - e^{-(\rho + \delta)t} \right) \right] \quad (9)$$

$$I_n(t) = \left[\frac{d_2}{v_n(\xi_n)} \left(e^{v_n(\xi_n)(T-t)} - 1 \right) - \frac{g_2}{v_n(\xi_n)} \left(e^{v_n(\xi_n)(T-t)} - 1 \right) - \frac{g_2}{(\rho + \delta - v_n(\xi_n))} \left(e^{-(\rho + \delta)T} e^{v_n(\xi_n)(T-t)} - e^{-(\rho + \delta)t} \right) \right] \quad (10)$$

As shortages are not allowed, the order quantities of organic and non-organic products can be evaluated using Equations (9) and (10). By applying the conditions $I_0(0) = Q_0$ and $I_n(0) = Q_n$ the expressions are obtained as:

$$Q_0 = \left[\frac{d_1}{v_0(\xi_0)} \left(e^{v_0(\xi_0)T} - 1 \right) + \frac{g_1}{v_0(\xi_0)} \left(e^{v_0(\xi_0)T} - 1 \right) + \frac{g_1}{(\rho + \delta - v_0(\xi_0))} \left(e^{-(\rho + \delta)T} e^{v_0(\xi_0)T} - 1 \right) \right] \quad (11)$$

$$Q_n = \left[\frac{d_2}{v_n(\xi_n)} \left(e^{v_n(\xi_n)T} - 1 \right) - \frac{g_2}{v_n(\xi_n)} \left(e^{v_n(\xi_n)T} - 1 \right) - \frac{g_2}{(\rho + \delta - v_n(\xi_n))} \left(e^{-(\rho + \delta)T} e^{v_n(\xi_n)T} - 1 \right) \right] \quad (12)$$

The retailer's objective function includes various components, such as the sales revenue generated from product sales and several cost components, including the ordering cost associated with placing an order, the purchasing cost, the inventory holding cost incurred in storing the product at the warehouse, the deterioration cost arising when products deteriorate at the retailer's site, and the preservation investment cost aimed at reducing deterioration and extending the product's shelf life. The following expression is calculated to obtain the retailer's total profit per unit:

$$Z(P_n, T, \xi_0, \xi_n) = \frac{1}{T} \left[\text{Revenue} - \left(\text{Ordering Cost} + \text{Purchasing Cost} + \text{Inventory Holding Cost} \right) + \text{Deterioration Cost} + \text{Preservation Cost} \right] \quad (13)$$

Revenue- The retailer's revenue generated from selling the organic product at a price P_0 and the non-organic product at a price P_n over the planning horizon is given by

$$\begin{aligned} &= P_0 \int_0^T D_0(t) dt + P_n \int_0^T D_n(t) dt \\ &= P_0 \left(d_1 T + g_1 T - \frac{g_1}{(\rho + \delta)} \left(1 - e^{-(\rho + \delta)T} \right) \right) + P_n \left(d_2 T - g_2 T + \frac{g_2}{(\rho + \delta)} \left(1 - e^{-(\rho + \delta)T} \right) \right) \end{aligned} \quad (14)$$

Ordering cost- The retailer's investment associated with placing an order, comprising fixed ordering overheads, administrative expenses, and processing costs, is represented by

$$= A_0 + A_n \quad (15)$$

Purchasing cost- The retailer's purchasing cost of buying Q_0 units of the organic product at the unit price C_0 and Q_n units of the non-organic product at the unit price C_n is given by

$$\begin{aligned}
&= C_0 Q_0 + C_n Q_n \\
&= C_0 \left(\frac{d_1}{v_0(\xi_0)} (e^{v_0(\xi_0)T} - 1) + \frac{g_1}{v_0(\xi_0)} (e^{v_0(\xi_0)T} - 1) \right) + C_n \left(\frac{d_2}{v_n(\xi_n)} (e^{v_n(\xi_n)T} - 1) - \frac{g_2}{v_n(\xi_n)} (e^{v_n(\xi_n)T} - 1) \right) \\
&\quad + \left(\frac{g_1}{(\rho + \delta - v_0(\xi_0))} (e^{-(\rho + \delta)T} e^{v_0(\xi_0)T} - 1) \right) - \left(\frac{g_2}{(\rho + \delta - v_n(\xi_n))} (e^{-(\rho + \delta)T} e^{v_n(\xi_n)T} - 1) \right)
\end{aligned} \tag{16}$$

Inventory holding cost- The retailer's holding cost associated with organic and non-organic products over the planning horizon is given by

$$\begin{aligned}
&= I_0 C_0 \int_0^T I_0(t) dt + I_n C_n \int_0^T I_n(t) dt \\
&= I_0 C_0 \left(\left(\frac{d_1}{v_0(\xi_0)} + \frac{g_1}{v_0(\xi_0)} \right) \left(\frac{e^{v_0(\xi_0)T} - 1}{v_0(\xi_0)} - T \right) + \right. \\
&\quad \left. \frac{g_1}{(\rho + \delta - v_0(\xi_0))} \left(\frac{e^{-(\rho + \delta)T}}{v_0(\xi_0)} (e^{v_0(\xi_0)T} - 1) - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right) \\
&+ I_n C_n \left(\left(\frac{d_2}{v_n(\xi_n)} - \frac{g_2}{v_n(\xi_n)} \right) \left(\frac{e^{v_n(\xi_n)T} - 1}{v_n(\xi_n)} - T \right) - \right. \\
&\quad \left. \frac{g_2}{(\rho + \delta - v_n(\xi_n))} \left(\frac{e^{-(\rho + \delta)T}}{v_n(\xi_n)} (e^{v_n(\xi_n)T} - 1) - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right)
\end{aligned} \tag{17}$$

Deterioration cost- The deterioration cost incurred by the retailer for both organic and non-organic products during the planning horizon is expressed as:

$$\begin{aligned}
&= C_{od} \left(Q_0 - \int_0^T D_0 dt \right) + C_{nd} \left(Q_n - \int_0^T D_n dt \right) \\
&= C_{od} \left(\left(\frac{d_1}{v_0(\xi_0)} + \frac{g_1}{v_0(\xi_0)} \right) (e^{v_0(\xi_0)T} - 1) + \frac{g_1}{(\rho + \delta - v_0(\xi_0))} (e^{-(\rho + \delta)T} e^{v_0(\xi_0)T} - 1) \right. \\
&\quad \left. - d_1 T - g_1 T - \frac{g_1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \\
&+ C_{nd} \left(\left(\frac{d_2}{v_n(\xi_n)} - \frac{g_2}{v_n(\xi_n)} \right) (e^{v_n(\xi_n)T} - 1) - \frac{g_2}{(\rho + \delta - v_n(\xi_n))} (e^{-(\rho + \delta)T} e^{v_n(\xi_n)T} - 1) \right. \\
&\quad \left. - d_2 T + g_2 T - \frac{g_2}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right)
\end{aligned} \tag{18}$$

Preservation cost- To reduce the natural deterioration rate, the retailer invests in preservation technology. We assume the cost of preserving perishable products is not fixed it grows as inventory accumulates and storage time extends. The preservation investment per unit time is proportional to the instantaneous inventory level, since more stock requires greater cooling, packaging, or treatment effort. Therefore, the retailer's preservation technology cost for both organic and non-organic products over the planning horizon is given by

$$= \xi_0 \int_0^T I_0(t) dt + \xi_n \int_0^T I_n(t) dt$$

$$\begin{aligned}
 &= \xi_0 \left[\left(\frac{d_1}{\nu_0(\xi_0)} + \frac{g_1}{\nu_0(\xi_0)} \right) \left(\frac{e^{\nu_0(\xi_0)T} - 1}{\nu_0(\xi_0)} - T \right) \right. \\
 &\quad \left. + \frac{g_1}{(\rho + \delta - \nu_0(\xi_0))} \left(\frac{e^{-(\rho + \delta)T}}{\nu_0(\xi_0)} (e^{\nu_0(\xi_0)T} - 1) - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right] \\
 &+ \xi_n \left[\left(\frac{d_2}{\nu_n(\xi_n)} - \frac{g_2}{\nu_n(\xi_n)} \right) \left(\frac{e^{\nu_n(\xi_n)T} - 1}{\nu_n(\xi_n)} - T \right) \right. \\
 &\quad \left. - \frac{g_2}{(\rho + \delta - \nu_n(\xi_n))} \left(\frac{e^{-(\rho + \delta)T}}{\nu_n(\xi_n)} (e^{\nu_n(\xi_n)T} - 1) - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right]
 \end{aligned} \tag{19}$$

The retailer's total profit per unit time can be obtained by substituting the Equations (14)-(19) into Equation (13), which gives the following expression.

$$\begin{aligned}
 Z(P_n, T, \xi_0, \xi_n) = & \frac{1}{T} \left\{ P_0 \left(d_1 T + g_1 T - \frac{g_1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) + P_n \left(d_2 T - g_2 T + \frac{g_2}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right. \\
 & \left[A_0 + A_n + C_0 \left(\frac{d_1}{\nu_0(\xi_0)} (e^{\nu_0(\xi_0)T} - 1) + \frac{g_1}{\nu_0(\xi_0)} (e^{\nu_0(\xi_0)T} - 1) + \frac{g_1}{(\rho + \delta - \nu_0(\xi_0))} (e^{-(\rho + \delta)T} e^{\nu_0(\xi_0)T} - 1) \right) \right. \\
 & C_n \left(\frac{d_2}{\nu_n(\xi_n)} (e^{\nu_n(\xi_n)T} - 1) - \frac{g_2}{\nu_n(\xi_n)} (e^{\nu_n(\xi_n)T} - 1) - \frac{g_2}{(\rho + \delta - \nu_n(\xi_n))} (e^{-(\rho + \delta)T} e^{\nu_n(\xi_n)T} - 1) \right) \\
 & + I_0 C_0 \left[\left(\frac{d_1}{\nu_0(\xi_0)} + \frac{g_1}{\nu_0(\xi_0)} \right) \left(\frac{e^{\nu_0(\xi_0)T} - 1}{\nu_0(\xi_0)} - T \right) + \frac{g_1}{(\rho + \delta - \nu_0(\xi_0))} \left(\frac{e^{-(\rho + \delta)T}}{\nu_0(\xi_0)} (e^{\nu_0(\xi_0)T} - 1) \right. \right. \\
 & \left. \left. - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right] \\
 & + I_n C_n \left[\left(\frac{d_2}{\nu_n(\xi_n)} - \frac{g_2}{\nu_n(\xi_n)} \right) \left(\frac{e^{\nu_n(\xi_n)T} - 1}{\nu_n(\xi_n)} - T \right) - \frac{g_2}{(\rho + \delta - \nu_n(\xi_n))} \left(\frac{e^{-(\rho + \delta)T}}{\nu_n(\xi_n)} (e^{\nu_n(\xi_n)T} - 1) \right. \right. \\
 & \left. \left. - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right] \\
 & + C_{od} \left[\left(\frac{d_1}{\nu_0(\xi_0)} + \frac{g_1}{\nu_0(\xi_0)} \right) (e^{\nu_0(\xi_0)T} - 1) + \frac{g_1}{(\rho + \delta - \nu_0(\xi_0))} (e^{-(\rho + \delta)T} e^{\nu_0(\xi_0)T} - 1) \right. \\
 & \left. - d_1 T - g_1 T + \frac{g_1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right] \\
 & + C_{nd} \left[\left(\frac{d_2}{\nu_n(\xi_n)} - \frac{g_2}{\nu_n(\xi_n)} \right) (e^{\nu_n(\xi_n)T} - 1) - \frac{g_2}{(\rho + \delta - \nu_n(\xi_n))} (e^{-(\rho + \delta)T} e^{\nu_n(\xi_n)T} - 1) \right. \\
 & \left. - d_2 T + g_2 T - \frac{g_2}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right] \\
 & + \xi_0 \left[\left(\frac{d_1}{\nu_0(\xi_0)} + \frac{g_1}{\nu_0(\xi_0)} \right) \left(\frac{e^{\nu_0(\xi_0)T} - 1}{\nu_0(\xi_0)} - T \right) + \frac{g_1}{(\rho + \delta - \nu_0(\xi_0))} \left(\frac{e^{-(\rho + \delta)T}}{\nu_0(\xi_0)} (e^{\nu_0(\xi_0)T} - 1) \right. \right. \\
 & \left. \left. - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right] \\
 & + \xi_n \left[\left(\frac{d_2}{\nu_n(\xi_n)} - \frac{g_2}{\nu_n(\xi_n)} \right) \left(\frac{e^{\nu_n(\xi_n)T} - 1}{\nu_n(\xi_n)} - T \right) - \frac{g_2}{(\rho + \delta - \nu_n(\xi_n))} \left(\frac{e^{-(\rho + \delta)T}}{\nu_n(\xi_n)} (e^{\nu_n(\xi_n)T} - 1) \right. \right. \\
 & \left. \left. - \frac{1}{(\rho + \delta)} (1 - e^{-(\rho + \delta)T}) \right) \right] \left. \right\}
 \end{aligned} \tag{20}$$

Now, the profit maximization problem is formulated to determine the optimal price, preservation investment for both organic and non-organic products, and their common cycle length is given by,

$$\begin{aligned} &\text{Maximize } Z(P_n, T, \xi_0, \xi_n) \\ &\text{Subject to} \\ &\xi_0 \int_0^T I_0(t) dt + \xi_n \int_0^T I_n(t) dt \leq U \end{aligned} \quad (21)$$

Constraint (21) represents the budget restriction on the preservation technology investment, where, U is the maximum budget the retailer allocates for investing in the preservation of both organic and non-organic products.

5. Optimality and Solution Procedure

This section analyzes the retailer's profit function to establish its concavity and confirm the existence of a unique global optimal solution. However, due to the complex nature of the Equation (20) or the transcendental nature of the profit function, it is challenging to establish the concavity of the profit function analytically. Therefore, the graphical approach is adopted to prove the concavity of the function.

The following algorithm is established to determine the solution (Yu et al., 2009):

$$\text{Maximize } Z(P_n, T, \xi_0, \xi_n) \quad (22)$$

Subject to

$$h_1(P_n, T, \xi_0, \xi_n) = \xi_0 \int_0^T I_0(t) dt + \xi_n \int_0^T I_n(t) dt \leq U \quad (23)$$

The Kuhn-Tucker conditions are used to solve the optimal solutions. Let λ be Lagrange multiplier, Lagrange function L_m can be expressed as

$$\text{Max } L_m(P_n, T, \xi_0, \xi_n) = Z(P_n, T, \xi_0, \xi_n) + \lambda(U - h_1(P_n, T, \xi_0, \xi_n)) \quad (24)$$

Then the Kuhn-Tucker Condition for the model is

$$\begin{aligned} &\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial P_n} - \lambda \frac{\partial h_1(P_n, T, \xi_0, \xi_n)}{\partial P_n} = 0, \\ &\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial T} - \lambda \frac{\partial h_1(P_n, T, \xi_0, \xi_n)}{\partial T} = 0, \\ &\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial \xi_0} - \lambda \frac{\partial h_1(P_n, T, \xi_0, \xi_n)}{\partial \xi_0} = 0, \\ &\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial \xi_n} - \lambda \frac{\partial h_1(P_n, T, \xi_0, \xi_n)}{\partial \xi_n} = 0, \\ &\lambda(U - h_1(P_n, T, \xi_0, \xi_n)) = 0 \end{aligned} \quad (25)$$

For $\lambda = 0$, we have

$$\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial P_n} = 0,$$

$$\begin{aligned}
\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial T} &= 0, \\
\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial \xi_0} &= 0 \\
\frac{\partial Z(P_n, T, \xi_0, \xi_n)}{\partial \xi_n} &= 0, \\
h_1(P_n, T, \xi_0, \xi_n) &= U
\end{aligned} \tag{26}$$

Solution procedure:

Step 1. In Equation (24), all fixed inventory parameters are assigned predetermined values, while the decision variables remain unaltered.

Step 2. Calculate the optimal value of P_n^* , T^* , ξ_0^* and ξ_n^* with Equation (26) for $\lambda = 0$ and Equation (25) for $\lambda > 0$, respectively, with Mathematica 7.0.

Step 3. Substitute the values of P_n^* , T^* , ξ_0^* and ξ_n^* into the Equation (20) to obtain the total profit.

Note: To handle the complexity arising from the non-linearity of the Karush-Kuhn-Tucker (KKT) conditions, numerical optimization is carried out using the "NMaximize" solver within the Mathematica 7.0 environment. It uses "Differential Evolution", which is effective in solving nonlinear, constraint problems (Weisstein, n.d.).

6. Numerical Analysis

Due to the lack of availability of a real-life dataset, this section presents a numerical example using hypothetical data to determine the price of the non-organic product and the optimal delivery time. The hypothetical values of the parameters are as follows:

Organic product parameters value:

market base, $a_0 = 1000$, price sensitivity, $b_0 = 1.5$, price gap sensitivity, $\alpha_1 = 1.1$, awareness scale, $\gamma_1 = 15$, deterioration rate, $v_0 = 0.65$, unit cost, $C_0 = \$50 / unit$, deterioration cost, $C_{od} = \$4 / unit$, inventory carrying charge, $I_0 = 35\% / unit\ time$, ordering cost, $A_0 = \$900 / order$, preservation effectiveness, $\beta_1 = 0.1$.

Non-organic product parameters value:

market base, $a_n = 2780$, price sensitivity, $b_n = 2.7$, price gap sensitivity, $\alpha_2 = 1.5$, awareness scale, $\gamma_2 = 12$, deterioration rate, $v_n = 0.45$, unit cost, $C_n = \$30 / unit$, deterioration cost, $C_{nd} = \$2 / unit$, inventory carrying charge, $I_n = 20\% / unit\ time$, ordering cost, $A_n = \$500 / order$, preservation effectiveness, $\beta_2 = 0.9$.

Common parameter values:

fixed markup, $\varphi = 30\%$, coefficient of external influence, $\rho = 10$, forgetting parameter, $\delta = 4$, budget for investment in preservation technology, $U = \$5000$.

Solution:

Using the above data, the optimal solution for the retailer's profit is obtained with the help of Mathematica 7.0. The optimal cycle length is : $T^*=1.275$, the optimal price of the non-organic product is: $P_n^* = \$417.71$, the optimal price of the organic product is $P_o^* = \$543.02$, the optimal preservation investment in the organic product is: $\xi_o^* = \$14.19$, the optimal preservation investment in the non-organic product is $\xi_n^* = \$3.07$, and the retailer's optimal profit is $Z(P_n^*, T^*, \xi_o^*, \xi_n^*) = \$737,385$. **Figure 6**, shows the concavity of the retailer's profit with respect to the different decision variables, including the optimal cycle length, investments in preservation technologies for organic and non-organic products, and the price of the non-organic product.

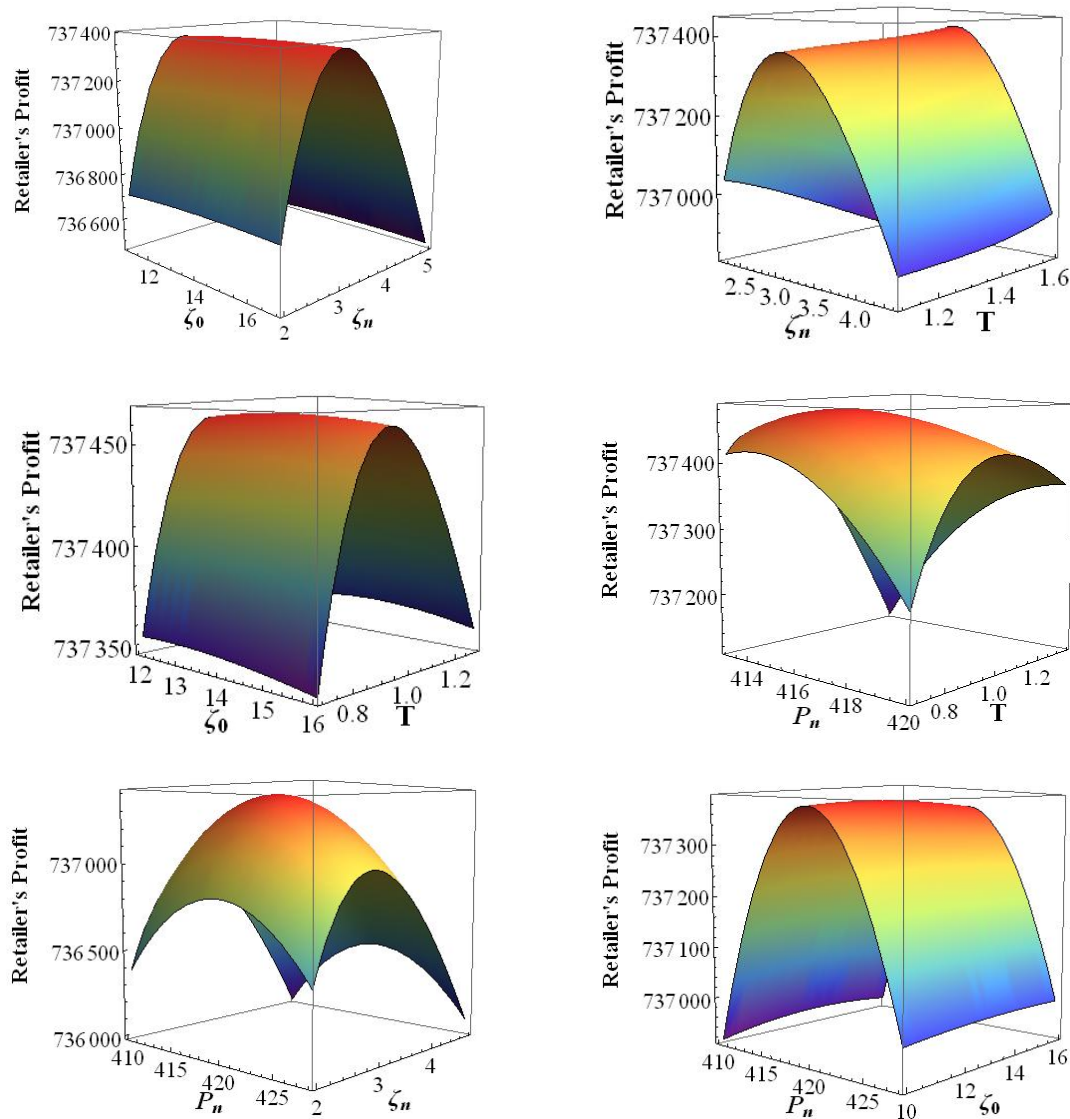


Figure 6. Graphical representation of retailer's profit w.r.t non-organic product price, cycle Length, preservation investment in organic product and non-organic product.

Table 2. Different demand scenarios.

Different demand scenarios	Order cycle length, T^*	Price of non-organic product, P_n^*	Price of organic product, P_o^*	Preservation investment in organic product, ξ_o^*	Preservation investment in non-organic product, ξ_n^*	Ordered quantity of non-organic product Q_n	Ordered quantity of organic product Q_o	Profit, Z^*
Demand is independent of health awareness	0.343	409.36	532.17	12.85	2.89	1870	69	731,605
Demand is independent of the price difference	0.906	413.21	537.18	16.34	3.27	1719	273	730,700
Demand is influenced by both health awareness and the price difference	1.275	417.71	543.02	14.19	3.07	1932	148	737,385

As indicated in **Table 2**, when Scenario 1 (without health awareness) is compared with Scenario 3 (with health awareness), the organic ordered quantity decreases from 148 to 69 units, and the optimal profit declines from \$737,385 to \$731,605. This confirms that the absence of health-awareness-driven demand reduces organic consumption.

Similarly, when Scenario 2 (without the price difference effect) is compared with Scenario 3 (with the price difference effect), the organic ordered quantity increases significantly from 148 to 273 units. This occurs because the elimination of the price barrier encourages consumers to switch toward organic products, while health awareness alone continues to drive demand for organic items.

7. Sensitivity Analysis

This section is conducted to assess the influence of parameter variation on the objective function. To facilitate well-informed decision-making, decision-makers must discern the relative importance of different parameters and quantify their potential impact on the objective function.

Table 3. Sensitivity analysis w.r.t. price parameters.

Parameters	Percentage change	Order cycle length, T^*	Price of non-organic product, P_n^*	Price of organic product, P_o^*	Preservation investment in organic product, ξ_o^*	Preservation investment in non-organic products, ξ_n^*	Ordered quantity of non-organic product Q_n	Ordered quantity of organic product Q_o	Profit, Z^*
Organic product price sensitivity, b_o	-30%	0.887	482.39	627.11	13.66	2.97	1753	62	872909
	-20%	1.208	460.69	598.89	14.01	3.06	1828	101	823059
	-10%	1.238	436.98	568.07	14.11	3.01	1869	174	777948
	0	1.275	417.71	543.02	14.19	3.07	1932	198	737385
	10%	1.301	398.51	518.06	14.94	3.09	1954	239	700532
	20%	1.400	382.89	497.76	14.51	3.28	1991	247	667073
	30%	4.030	375.22	487.79	14.65	3.76	2207	257	642628
Non-organic product price sensitivity, b_n	-30%	3.251	485.89	631.22	60.99	3.27	2337	75	902906
	-20%	2.367	459.75	597.35	80.01	3.11	2182	89	838766
	-10%	1.506	443.45	576.25	15.36	3.09	2018	100	783508
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	0.629	393.75	511.01	12.59	2.85	1827	155	696877
	20%	0.536	375.19	487.58	12.47	2.84	1764	191	660253
	30%	0.481	358.62	466.23	12.40	2.83	1708	226	626994

Table 3 continued...

Price gap sensitivity in organic demand, α_1	-30%	0.982	426.38	554.3	13.88	2.99	1889	149	757436
	-20%	1.200	424.98	552.47	14.41	3.05	1909	154	750682
	-10%	1.147	421.20	547.56	14.28	3.04	1914	144	743963
	0	1.275	417.71	543.02	14.19	3.07	1932	138	737385
	10%	1.067	414.04	538.25	14.29	3.09	1934	125	730872
	20%	1.035	410.62	533.81	14.41	3.11	1949	117	724492
Price gap sensitivity in non-organic demand, α_2	30%	1.296	408.55	531.12	14.45	3.18	1954	108	718232
	-30%	0.779	404.58	525.96	13.41	2.95	1867	141	716408
	-20%	0.847	408.49	531.04	13.57	2.96	1881	137	723247
	-10%	0.985	413.08	536.99	13.89	2.99	1900	136	730224
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.333	420.43	546.56	14.01	3.01	1926	122	744599
fixed markup, φ	20%	1.363	425.17	552.72	14.32	3.04	1945	120	752058
	30%	1.471	430.49	559.64	14.76	3.09	1968	121	759766
	-30%	0.532	431.78	522.46	12.87	2.88	1780	162	756434
	-20%	0.606	426.07	528.33	13.03	2.90	1819	145	750376
	-10%	0.729	420.72	534.31	13.31	2.93	1862	132	743967
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.890	409.10	545.11	13.67	2.97	1939	104	730347
	20%	1.940	403.89	549.29	14.03	3.01	1982	95	723336
	30%	1.214	398.90	554.47	15.05	3.05	2025	88	716316

Table 4. Sensitivity analysis w.r.t. deterioration and preservation parameters.

Parameters	Percentage change	Order cycle length, T^*	Price of non-organic product, P_n^*	Price of organic product, P_0^*	Preservation investment in organic product, ξ_0^*	Preservation investment in non-organic product, ξ_n^*	Ordered quantity of non-organic product, Q_n	Ordered quantity of organic product, Q_0	Profit, Z^*
Deterioration rate of the organic product, ν_0	-30%	1.496	417.89	543.26	9.19	3.12	1949	166	737504
	-20%	1.362	417.99	542.09	11.85	3.02	1957	133	737400
	-10%	1.294	417.69	542.99	13.15	3.08	1934	150	737412
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.097	417.59	542.88	15.12	3.03	1919	134	737340
	20%	1.092	417.64	542.93	15.97	3.03	1918	133	737322
Deterioration rate of the non-organic product, ν_n	30%	1.089	417.69	542.99	16.77	3.03	1917	133	737305
	-30%	1.034	416.92	544.99	14.01	2.61	1915	131	737651
	-20%	0.995	416.58	544.56	14.92	2.75	1912	129	737525
	-10%	1.179	417.23	543.69	14.36	2.93	1923	139	737473
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.046	417.06	542.18	14.04	3.12	1915	131	737270
Preservation-sensitive parameter in organic products, β_1	20%	1.196	417.68	542.98	14.19	3.25	1926	141	737204
	30%	1.070	417.28	542.47	14.10	3.31	1917	132	737128
	-30%	1.202	417.66	542.95	12.12	3.05	1900	146	737248
	-20%	1.030	417.20	542.36	14.71	3.01	1890	131	737283
	-10%	1.092	417.60	542.88	14.55	3.02	1894	134	737328
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
Preservation-sensitive parameter in non-organic products, β_2	10%	1.306	417.69	542.99	13.79	3.08	1909	150	737421
	20%	1.335	417.68	542.98	13.39	3.09	1912	152	737454
	30%	1.363	417.66	542.96	13.99	3.09	1915	154	737484
	-30%	0.738	414.35	538.66	13.33	3.63	1905	114	736547
	-20%	0.831	415.17	539.72	13.54	3.39	1908	119	736834
	-10%	1.004	416.70	541.71	13.95	3.21	1916	129	737099
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.014	416.75	541.77	13.96	2.83	1911	129	737554
	20%	1.094	417.45	542.69	14.15	2.69	1913	134	737773
	30%	1.179	418.19	543.64	14.35	2.57	1917	139	737991

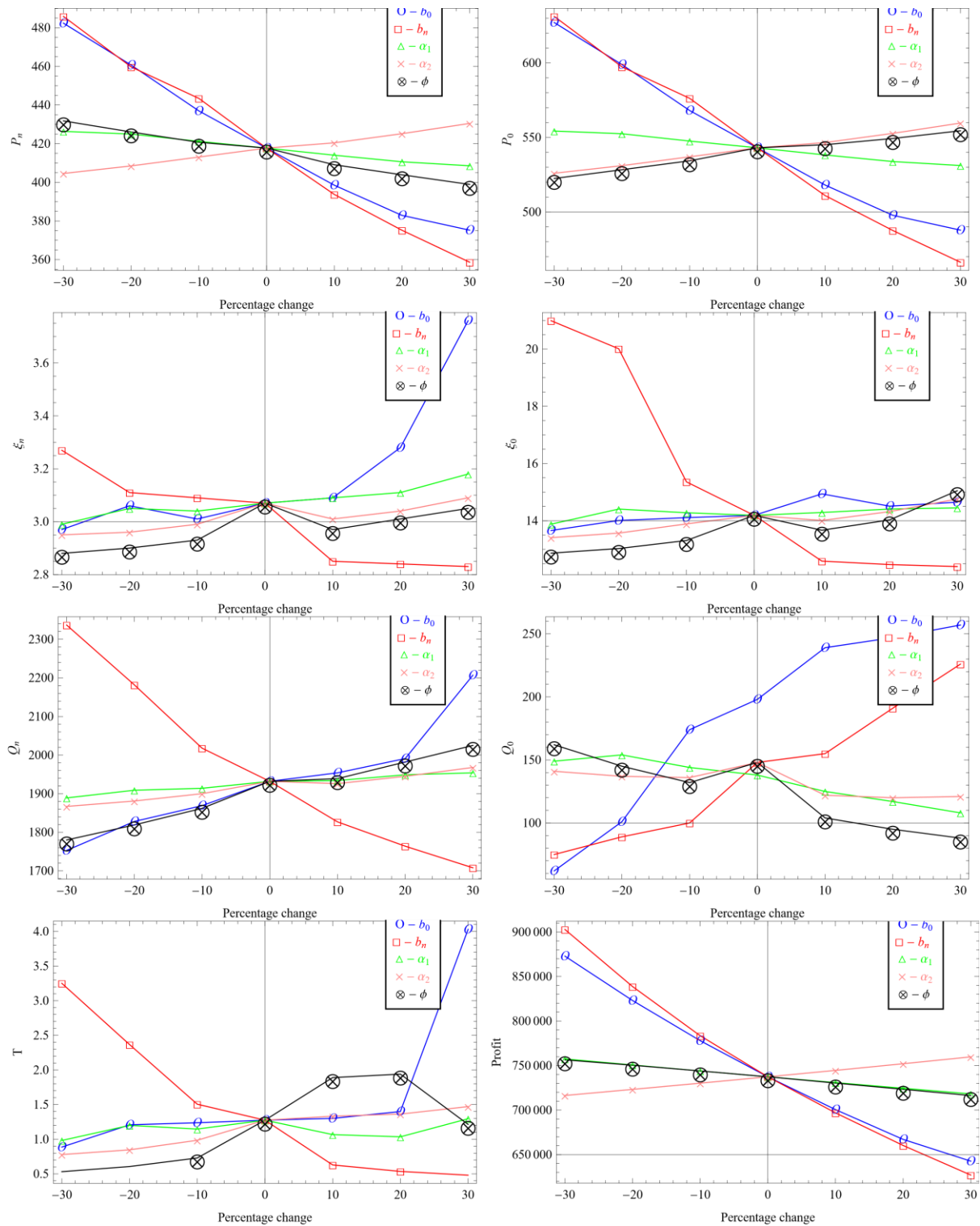


Figure 7. Graphical representation of the sensitivity analysis illustrating the impact of various price parameters on the P_n , P_0 , Q_n , Q_0 , ξ_n , ξ_0 , T , and total profit.

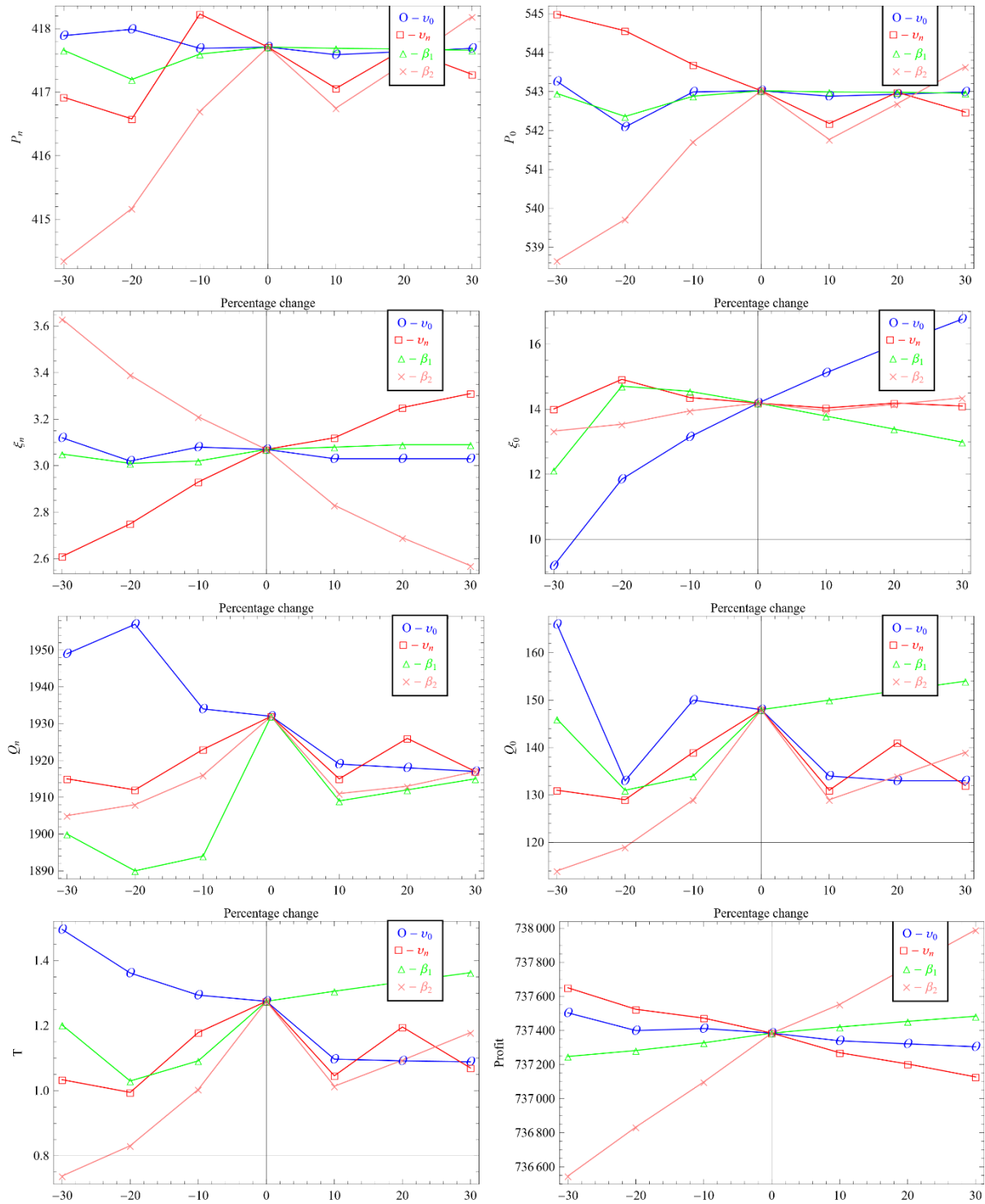


Figure 8. Graphical representation of the sensitivity analysis illustrating the impact of deterioration and preservation parameters on the $P_n, P_0, Q_n, Q_0, T, \xi_n, \xi_0$, and total profit.

Table 5. Sensitivity analysis w.r.t. awareness level parameters.

Parameters	Percentage change	Order cycle length, T^*	Price of non-organic product, P_n^*	Price of organic product, P_0^*	Preservation investment in organic product, ξ_0^*	Preservation investment in non-organic product, ξ_n^*	Ordered quantity of non-organic product Q_n	Ordered quantity of organic product Q_0	Profit, Z^*
Health awareness generation coefficient, ρ	-30%	0.525	411.74	535.26	12.86	2.88	1876	91	735320
	-20%	0.592	412.51	536.26	13.00	2.90	1882	98	735873
	-10%	0.709	413.75	537.88	13.26	2.93	1891	107	736508
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.919	418.27	543.15	13.73	2.98	1912	130	738225
	20%	1.930	418.66	544.26	14.22	3.03	1931	151	739592
	30%	1.957	416.31	541.20	14.62	2.96	1916	138	739820
Health awareness decay (forgetting) coefficient, δ	-30%	1.276	417.71	543.02	14.19	3.07	1930	148	737443
	-20%	1.276	417.71	543.02	14.19	3.07	1931	148	737422
	-10%	1.276	417.71	543.02	14.19	3.07	1932	148	737403
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.274	417.70	543.02	14.19	3.07	1933	148	737368
	20%	1.273	417.70	543.01	14.19	3.07	1933	148	737352
	30%	1.273	417.70	543.01	14.19	3.07	1934	148	737337
Health awareness impact on organic demand, γ_1	-30%	0.322	409.51	532.37	12.43	2.83	1874	88	712177
	-20%	0.491	441.26	573.63	12.73	2.59	1880	95	716437
	-10%	0.486	411.49	534.94	12.77	2.87	1889	105	734924
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	0.937	417.99	543.09	13.81	2.98	1907	152	740339
	20%	0.814	418.54	544.50	13.73	2.95	1897	167	742861
	30%	1.083	420.55	546.72	14.25	3.02	1939	181	748535
Health awareness impact on non-organic demand, γ_2	-30%	0.866	416.99	542.09	13.84	2.97	1891	117	744138
	-20%	1.151	419.39	545.21	14.31	3.04	1908	134	743489
	-10%	1.339	420.49	546.64	14.71	3.09	1925	145	740992
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.537	412.11	535.74	12.88	2.88	1885	103	735533
	20%	2.079	420.65	546.85	12.47	2.47	1735	102	721799
	30%	2.941	422.39	549.11	12.94	2.33	1656	98	708872

Table 6. Sensitivity analysis w.r.t. inventory parameters.

Parameters	Percentage change	Order cycle length, T^*	Price of non-organic product, P_n^*	Price of organic product, P_0^*	Preservation investment in organic product, ξ_0^*	Preservation investment in non-organic product, ξ_n^*	Ordered quantity of non-organic product Q_n	Ordered quantity of organic product Q_0	Profit, Z^*
Inventory carrying charge of organic product, I_0	-30%	1.207	417.79	543.13	14.43	3.06	1926	142	737528
	-20%	1.169	417.69	543.01	14.36	3.05	1924	140	737469
	-10%	1.365	417.81	543.15	14.26	3.09	1939	154	737455
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	1.076	417.52	542.78	14.11	3.02	1917	133	737311
	20%	1.050	417.49	542.74	14.05	3.01	1915	131	737263
	30%	1.027	417.47	542.71	13.99	3.01	1913	129	737216
Inventory carrying charge of non-organic product, I_n	-30%	1.061	417.01	542.11	14.06	3.02	1917	133	739112
	-20%	1.944	416.04	540.85	13.79	2.98	1910	126	738374
	-10%	1.239	418.72	544.33	14.49	3.06	1927	142	738070
	0	1.275	417.71	543.02	14.19	3.07	1932	148	737385
	10%	0.808	414.96	539.44	13.49	2.95	1900	118	736830
	20%	0.689	413.91	538.09	13.22	2.92	1893	111	736418
	30%	0.619	413.31	537.29	13.06	2.90	1888	107	736057

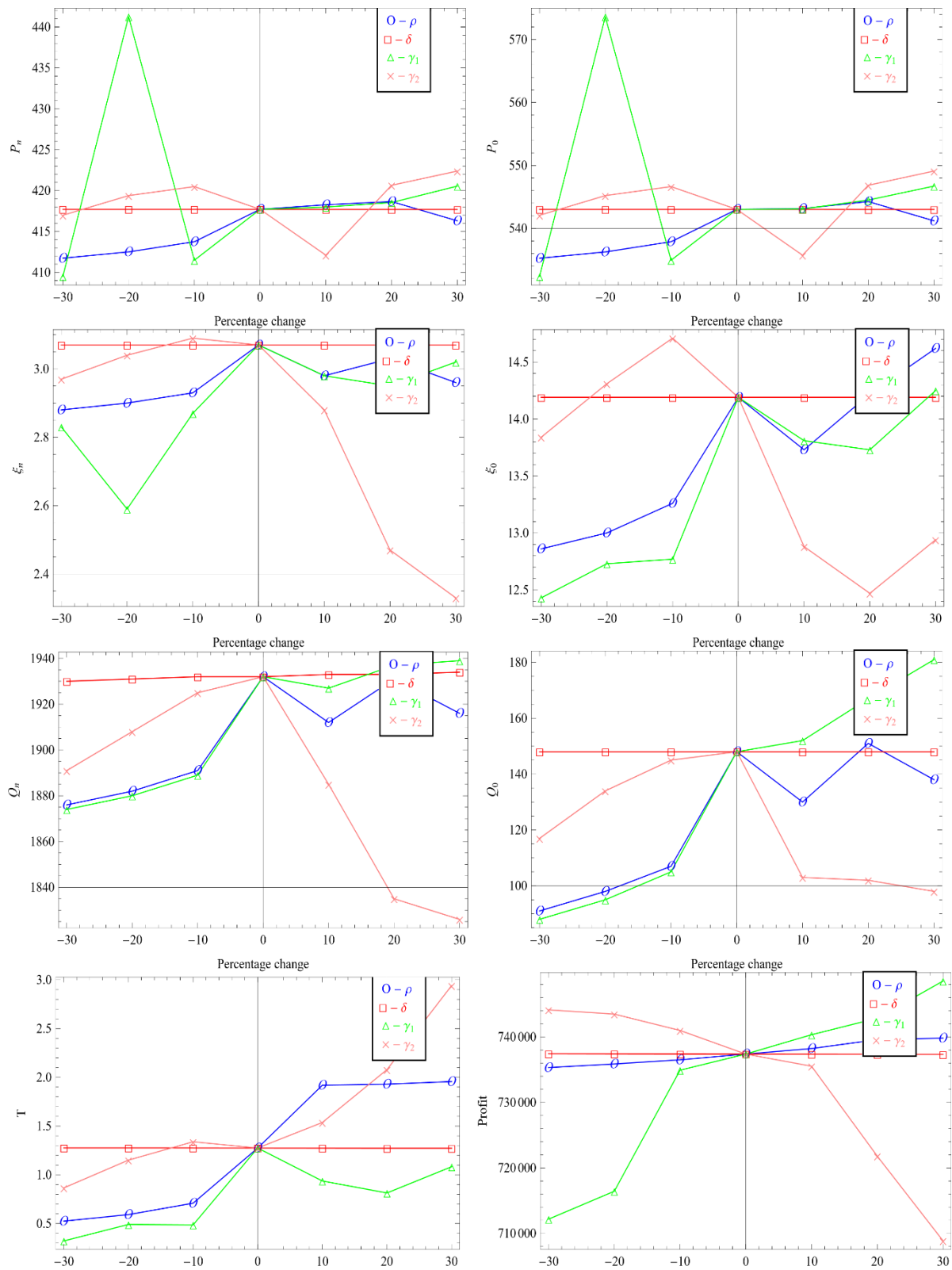


Figure 9. Graphical representation of the sensitivity analysis illustrating the impact of awareness parameters on the $P_n, P_0, Q_n, Q_0, \xi_n, \xi_0, T$, and total profit.

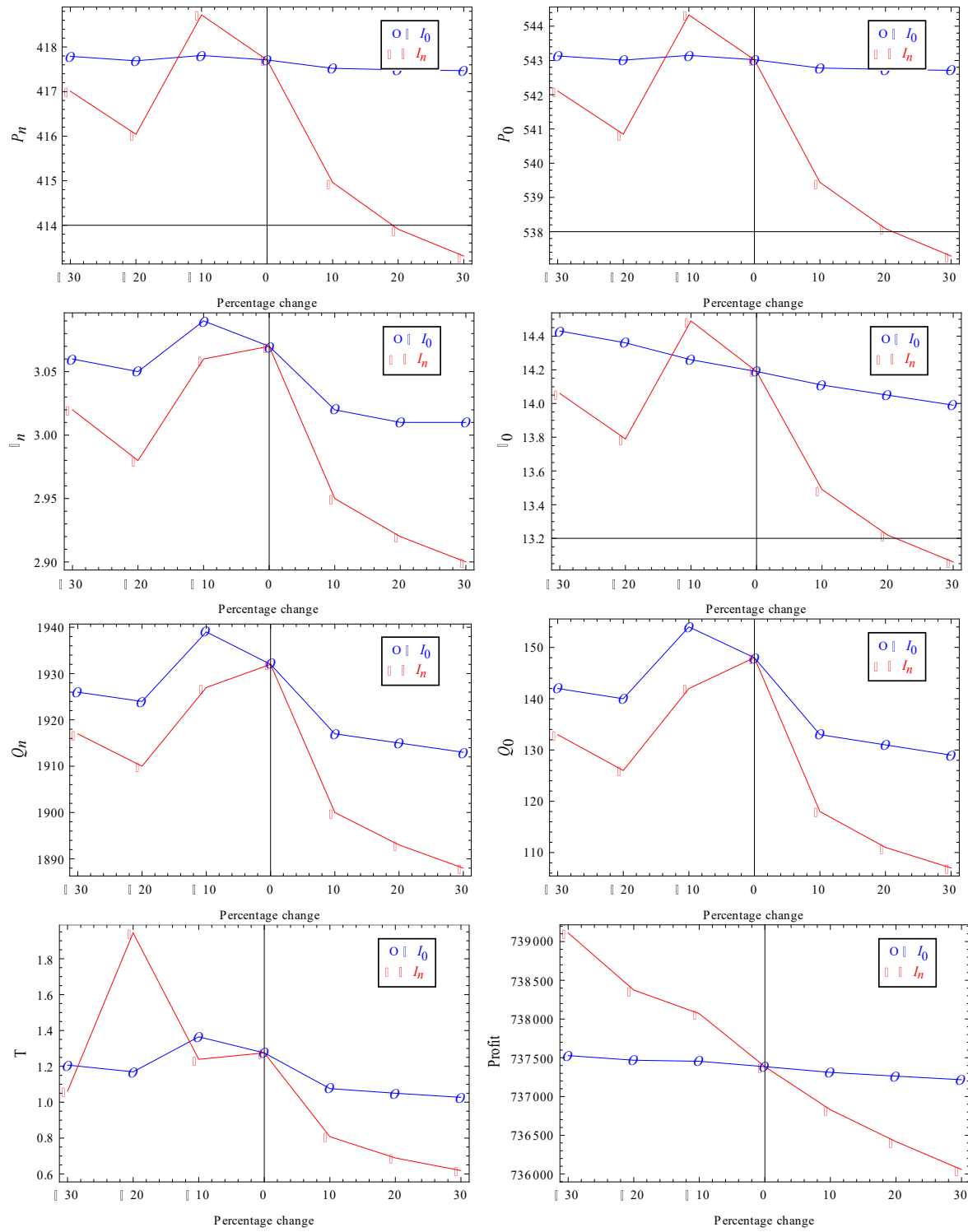


Figure 10. Graphical representation of the sensitivity analysis illustrating the impact of inventory carrying charge on the P_n , P_0 , Q_n , Q_0 , ξ_n , ξ_0 , T , and total profit.

The sensitivity analysis presented in **Tables 3-6** and illustrated in **Figures 7-10** shows the following observation:

- (i) **Table 3** and **Figure 7** examine the sensitivity of the optimal decision variables and system profit to changes in price-related parameters, namely the organic product price sensitivity (b_0), non-organic product price sensitivity (b_n), price gap sensitivity in organic demand (α_1), price gap sensitivity in non-organic demand (α_2), and the fixed markup parameter (φ). An increase in own-price sensitivity parameters (b_0 and b_n) leads to reductions in optimal prices and profit, reflecting higher consumer price responsiveness, while order quantities adjust accordingly. Variations in the price gap sensitivity parameters (α_1 and α_2) significantly influence cross-demand effects, with higher sensitivity intensifying product substitution and moderating profitability. Changes in the fixed markup parameter affect pricing and ordering decisions, where higher markup levels reduce demand and system profit. Overall, the results indicate that the proposed model is particularly sensitive to price-related parameters, highlighting the critical role of pricing and cross-price effects in determining optimal inventory, preservation, and profitability decisions.
- (ii) **Table 4** and **Figure 8** analyzes the sensitivity of the optimal decisions and system profit with respect to the deterioration rates of organic (v_0) and non-organic (v_n) products, as well as the preservation-sensitive parameters for organic (β_1) and non-organic (β_2) products. An increase in the deterioration rate of the organic product leads to higher optimal preservation investment in the organic product, while prices, order quantities, and profit remain relatively stable, indicating robustness of the system to moderate changes in v_0 . Similarly, variations in the deterioration rate of the non-organic product primarily affect the preservation investment in the non-organic item, with negligible impact on pricing and ordering decisions. Changes in the preservation-sensitive parameters (β_1 and β_2) significantly influence preservation investment levels and, at higher magnitudes, may alter ordering decisions and profitability, as observed under extreme parameter variations. Overall, the results demonstrate that deterioration and preservation-related parameters mainly affect preservation investment decisions, while the model remains stable in terms of prices, order quantities, and profit under moderate parameter changes.
- (iii) **Table 5** and **Figure 9** examine the impact of health awareness-related parameters on optimal pricing, ordering, preservation investment, and system profit. An increase in the health awareness generation coefficient (ρ) significantly raises the demand for organic products, leading to higher organic prices, increased preservation investment in organic items, larger order quantities, and a steady improvement in total profit, while non-organic decisions change moderately. In contrast, variations in the health awareness decay (forgetting) coefficient (δ) have a negligible effect on all decision variables, indicating that short-term memory loss of health awareness does not substantially influence the system's performance. The health awareness impact parameter on organic demand (γ_1) strongly enhances organic demand, resulting in higher prices, preservation investment, order quantities, and a noticeable increase in profit. Conversely, an increase in the health awareness impact on non-organic demand (γ_2) reduces reliance on non-organic products, leading to lower non-organic order quantities and preservation investment, and consequently decreasing overall profit at higher levels. Overall, the results highlight that health awareness generation and its impact on organic demand are key drivers of profitability, whereas awareness decay plays a minimal role.

- (iv) **Table 6** and **Figure 10** illustrate the sensitivity of the optimal decision variables and profit to variations in the inventory carrying charges of organic (I_o) and non-organic (I_n) products. An increase in either carrying charge leads to a rise in the optimal order cycle length and selling prices, indicating cost pass-through to consumers. Higher carrying costs also result in marginal increases in preservation investment to mitigate deterioration effects. While the ordered quantities exhibit moderate changes, the overall system profit shows a slight upward trend, demonstrating that the proposed model is robust to variations in inventory holding costs. These results suggest that coordinated pricing and preservation decisions enable the system to effectively absorb fluctuations in carrying charges.

8. Managerial Implication

The sensitivity results establish that as health awareness coefficient (ρ) increases by 50%, profit rises from \$737,385 to \$744,054, organic ordered quantity grows from 148 to 193 units, non-organic ordered quantity expands from 1,932 to 1,972 units, and prices increase across both product categories confirming that awareness campaigns grow the total retail market rather than merely redistributing demand between categories. Managers can therefore allocate a dedicated and protected budget for health awareness activities including in-store organic health displays, digital campaigns highlighting the nutritional and immunity benefits of organic consumption, collaborations with certified nutritionists and health influencers, and participation in government-led organic promotion initiatives.

As price gap sensitivity parameter (α_1) increases by 50%, profit declines to \$702,214 as organic consumers increasingly switch to non-organic alternatives when the price gap widens. Simultaneously, as α_2 increases by 50%, profit rises to \$769,844 as non-organic consumers migrate toward organic products when the gap narrows to an acceptable level. These opposing effects establish that narrowing the organic and non-organic price gap is simultaneously beneficial from both sides retaining price-sensitive organic consumers while attracting price-responsive non-organic consumers toward the higher-value organic category. Managers should therefore determine non-organic prices in direct relation to organic prices rather than independently, maintaining a price gap narrow enough to encourage upward migration while still preserving meaningful product differentiation.

Overall, the sensitivity analysis demonstrates that health awareness, pricing, and preservation investment are not independent managerial decisions but deeply interconnected strategic variables whose interaction determines overall profitability. Awareness campaigns increase organic demand and justify premium pricing, but simultaneously create additional preservation requirements; pricing decisions alter demand allocation between categories and thereby influence preservation budget allocation; and effective preservation investment supports product quality, which sustains the premium prices consumers are willing to pay for organic products. Consequently, retailers who coordinate these three strategic dimensions using real-time market information on consumer awareness, price responsiveness, and deterioration characteristics will be better positioned to sustain profitability and competitive advantage in increasingly health-conscious and price-sensitive food retail markets.

9. Conclusion

This research presents an integrated inventory optimization framework for retailers managing both organic and non-organic products in a market characterized by increasing health awareness and strong price sensitivity. The customer demand depends on the product's individual prices, relative price differentials, and consumer health awareness, thereby reflecting the primary factors shaping purchasing decisions. The proposed model simultaneously determines optimal pricing strategies, preservation technology investment and inventory cycle lengths to optimize the overall profit of the retailer for both the organic and non-

organic products under the preservation technology investment budget restriction. The results show that an increase of 50% in the organic product price sensitivity reduces the retailer's profit from \$986,165 to \$580,270, indicating that profitability is highly sensitive to customer price responsiveness toward organic products. Similarly, higher non-organic product price sensitivity significantly decreases optimal selling prices and retailer profit. The analysis further reveals that a 50% increase in a health awareness parameter raises the retailer's profit to \$744,054 and increases the order quantity of organic products. Moreover, preservation investment decisions remain relatively stable across most scenarios, highlighting the importance of preservation technology in reducing deterioration and maintaining product quality. These findings demonstrate that integrated pricing, health awareness, and preservation investment strategies can substantially improve retailer performance in dual-channel organic and non-organic food systems.

10. Limitations and Future Scope

Despite its contributions, this study has a few limitations that should be acknowledged. First, the proposed model is developed under the assumption of deterministic, price and health awareness dependent demand, which may not fully reflect demand uncertainty in real markets. Second, the analysis is based on a hypothetical dataset, and therefore, the numerical results may differ when applied to real-world data. The proposed solution methodology does not incorporate various metaheuristic approaches, nor does it compare the results with other nonlinear optimization techniques. Additionally, the model considers a single retailer setting and does not account for competitive market structures. These limitations suggest that future research could extend the model by incorporating stochastic demand, real empirical data, and competitive dynamics to enhance its practical applicability. Additionally, meta-heuristic approaches may be employed in future studies to compare and validate the analytical results obtained from the proposed model.

Conflicts of Interest

The authors declare no competing interests that could have influenced this work.

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AI Disclosure

During the preparation of this manuscript, the authors used generative AI tools to help improve the language and readability. All content was thoroughly reviewed and revised by the authors, who remain fully responsible for the accuracy and integrity of the final version.

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