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Pricing Decisions with Effect of Advertisement and Greening Efforts for a Greengocer

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Abstract: Organic farming has become popular and in demand among health-conscious people nowadays. Organic vegetables are grown using organic seeds and natural fertilizers. People have turned to using organic food products not only due to them being fresh and full of nutrition but also being eco-friendly. The present study is carried out to outline pricing decisions for a greengrocer of organic products. The grocer grows and sells fresh vegetables with the input of greening efforts. The grocer uses advertisements to promote sales. Product demand is influenced by the selling price of the product, greening efforts, and advertising efforts. The problem is formulated into a mathematical model to obtain optimum policies to maximize the total profit of the greengrocer. The model is validated by an illustration. The impact of small-scale changes in inventory parameters on decision variables is studied to analyze managerial aspects. The results show that the sales volume increases due to advertisements and greening efforts up to a certain level. Once the peak sales level is achieved, such investments are of no use, and they cause a drop in overall profit. The selling price of the product can be reduced in the absence of advertisement efforts, but, eventually, it causes a fall in the sales volume.

Keywords: advertisement; greening efforts; deterioration; organic products; greengrocer

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Citation: Shah, N.; Shah, P.; Patel, M. Pricing Decisions with Effect of Advertisement and Greening Efforts for a Greengocer. *Sustainability* **2022**, *14*, 13807. https://doi.org/10.3390/su142113807

Academic Editors: Hui-Ming Wee, Yosef Daryanto, Mauricio F. Blos and Yugowati Praharsi

Received: 30 September 2022
Accepted: 21 October 2022
Published: 25 October 2022

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1. Introduction

In the present scenario, the globe is surrounded by many kinds of pollutants. The average age of human beings is affected by unhealthy food products and lack of nutrients in their daily diet.

1.1. Background

Generally, many farming individuals use hybrid seeds, inorganic fertilizers, and pesticides to increase production and profitability. They are interested in the increase in crop production and in saving the crop from pests and insects. They are less concerned about the quality of the crop. Excessive use of pesticides and inorganic fertilizers not only causes air, water, and soil pollution but also harms the quality of the crop. In the last two decades, organic farming has become very popular as it has shown a variety of benefits, such as being useful for preserving nutrients in food, improving the fertility of the soil, and controlling air, water, and soil pollution. The use of organic food in the daily diet keeps many diseases away. Moreover, organic food contains antioxidants and nutrients that improve the immunity level of the human body. Governments, non-government organizations, and people have come forward together to fight against the global warming issues caused by carbon emissions. Customers have turned towards eco-friendly and organic products. Greening efforts are a small but effective step in producing healthy and nutrient-rich food. They also help to reduce all kinds of pollution.

1.2. Significance of the Study

In the present scenario, advertising is an essential tool to sustain in a competitive business environment. It is a very effective tool for creating awareness of a product and promoting products on a large scale. An advertisement gives exposure to business enterprises and increases product demand. With consideration of all these aspects, a model for a greengrocer who grows and sells organic vegetables is developed. Vegetable demand is the function of the selling price, advertising efforts, and green investments. The study aims to find out the optimum cycle time, selling price, advertisement cost, and greening investment amount to maximize the total profit of the greengrocer. The mathematical model is authenticated by a numerical example. An investigation has is accomplished to study the effect of small changes in fixed parameters associated with the model on decision variables that are responsible for the maximization of the total profit.

1.3. Review of Related Studies

Our study focuses on two streams of literature. (1) Literature on green supply chains, in which the research on different strategies to improve or maintain the greenness of a product has is included. (2) Literature that concerns marketing strategies which include advertisements in order to promote sales and increase consumer awareness about the product.

1.3.1. Green Supply Chain

Several reviews have been carried out on the green supply chain. A green supply chain deals with green design and green operations, which include green manufacturing, reverse logistics, proper waste management, reuse, and recycling [1]. Plambeck [2] presented a review of the greening policies of Walmart's supply chain with the argument that 'being a good steward of the environment and being profitable are the same'. Walmart emphasizes renewable energy and sells products that sustain the environment. Plambeck and Denend [3] revisited [2] as an analysis of what Walmart has accomplished to date and what still needs to be done. Strong support for protecting the environment from the public enhances the environmental regulations' success ratio even in a weak institutional situation [4]. Meemken and Qaim [5] presented an annual review on organic farming, food security, and the environment. They studied the growth of organic farming in the duration from the year 2000 to 2015. They collected data regarding the percentage of different kinds of crops being included in organic agriculture in various countries. They compared the relationship between the total organic area, the number of organic farmers, and volume of organic retail sales. They considered the effect of various parameters such as the soil quality, biodiversity, and environmental effects on organic farming. Many researchers [6–9] considered cost-sharing contracts as a policy of green efforts in their respective studies. Additionally, ref. [7] focused on redesigning a product to achieve a reduction in carbon level during production, whereas [8,9] worked out a model with product demand influenced by greening efforts for deteriorating and non-deteriorating products respectively. Some researchers [10–12] considered the concept of recycling or remanufacturing as a greening policy and obtained the optimal decisions for an inventory system. Shah et al. [13] considered an inventory model for perishable products with price- and stock-dependent demand. They used greening efforts and showed that carbon gases can be controlled to a certain limit with the help of green technology investments. Shan et al. [14] investigated the influence of a bundling strategy for a green supply chain with complementary products. They constructed different models based on the Stackelberg game and analyzed them. Many researchers [15–18] have kept carbon emission at the center of their studies and have given various inventory models with the influence of carbon emission on product demand. Several kinds of research have been produced with consideration of carbon tax policy [19–21]. Green credit financing at a discounted rate motivates the supplier to improve the reduction in carbon emission levels [22]. Green marketing innovations are very important to improve environmental performance in terms

of resource utilization [23,24]. From the micro data collected during the years 2008 to 2016 for Ireland's industry sector, [25] concluded that industrial competition incentivizes industries to invest in cleaner technologies. The competitive environment in the market encourages the greenness level of the product [26]. Hamza and Elhady [27] carried out a field experiment to evaluate the effects of inorganic and organic fertilizers on growth, volatile oil, and nutrient uptake. Organic fertilizers yielded higher stalks of sunflower oil compared to inorganic fertilizers [28]. Nutrient recovery can be achieved for agricultural products by promoting the utilization of organic fertilizers [29].

1.3.2. Advertisement

Advertisement is one of the most powerful tools used to promote a product on a large scale. It is also one kind of essential tool for sustaining and staying robust in a competitive market environment. Advertising with proper planning and execution may lead to unforeseen hikes in product sales. The authors of [30–32] gave a model with price-sensitive and advertisement-influenced demand and gave optimal policies for pricing considering different scenarios. Advertisement helps to enhance the sales volume and to increase profitability [33,34]. However, none of them examined the model with regard to the green technology aspect. Zeng et al. [35] considered the green supply chain with advertisement and concluded that advertising motivates customers to buy green products for a low-carbon supply chain. Promoting public environmental awareness is more significant for large enterprises compared to medium enterprises [36,37].

A structured comparison of related research works with the present study is presented in Table 1.

Table 1. Comparison of different aspects in related articles.

Authored by	Advertisement	Demand Affected by		Greening Efforts	Deterioration	Environmentally Friendly Approach
		Selling Price	Green Investment			
Swami and Shah (2013) [6]		✔	✔	✔		Cost-sharing contract
Ghosh and Shah (2015) [7]		✔	✔	✔		Cost-sharing contract
Li et al. (2015) [8]			✔	✔		Cost-sharing contract
Giri et al. (2020) [9]		✔	✔	✔		Cost-sharing contract
Mota et al. (2015) [10]				✔		Recycling
Wang et al. (2014) [11]		✔		✔		Re-manufacturing
Iqbal et al. (2020) [12]				✔	✔	Re-manufacturing
Shah et al. (2022) [13]		✔	✔	✔	✔	Quantity Discount
Shan et al. (2020) [14]		✔	✔	✔		Green manufacturing degree
Shaofu et al. (2015) [15]				✔		Carbontax
Hovelaque and Laurent (2015) [16]		✔	✔			Carbontax
Ouardighi et al. (2016) [18]		✔		✔		Pollution reduction
Choudhury et al. (2021) [19]		✔			✔	Carbontax
Kim and Sim (2016) [20]		✔	✔	✔		Carbontax
Taleizadeh et al. (2020) [21]		✔		✔		Carbontax
Khan et al. (2020) [30]	✔	✔			✔	
Shah et al. (2021) [31]	✔	✔			✔	
Udaykumar et al. (2021) [32]	✔	✔			✔	
This paper	✔	✔	✔	✔	✔	Organic manufacturing

1.4. Research Gap

In previous, related research works, the green supply chain is mostly regarded as a redesign, remanufacturing, recycling, cost-sharing, or carbon tax policy. In particular, food products should be nutrients rich and healthfriendly. This study deals with organic farming as a greening policy. Moreover, advertisement is considered as a promotional strategy to enhance the sales of a product and to create awareness among consumers. The deteriorating nature of the product is also a matter of concern for inventory managers. None of the studies considered all these aspects together in their work. The present study aims to maximize the total profit of the grocer considering all the factors together. This distinguishes the present work from previous, related works.

1.5. Aim of the Study

The work is carried out to answer the following research objectives:

- To examine the impact of advertisement efforts on product demand;
- Is it worth it to invest in advertisements? What is the influence of the advertisements on the total profit of the grocer?
- To analyze the functionality of green investments in overall sales with a focus on the following points:
  - (a) What is the impact of green investments on product price?
  - (b) How are green investments correlated to total profit?
- To find out the optimum values of decision parameters in order to maximize the total profit of the greengrocer.

2. Materials and Methods

This section presents the model and solution procedure. First, we provide a list of notations used followed by assumptions made when carrying out the study.

2.1. Notations

The following notations were used throughout the study to develop the mathematical model.

Demand function:

R Price-sensitive, greening efforts, and promotional efforts affecting demand rate.

Decision variables:

M Advertisement/promotional cost (in US dollars);
T Cycle length of inventory system;
p Selling price (in US dollars) per unit;
μ Greening efforts cost (in US dollars).

Objective function:

TP Average total profit (in US dollars) of the greengrocer.

Other parameters:

A Ordering cost (in US dollars) per order;
C Purchase cost (in US dollars) per unit;
h Inventory carrying/holding cost (in US dollars) per unit per unit time;
ψ Greening efforts effectiveness parameter $(\psi > 0)$;
HC Total holding cost of inventory (in US dollars);
MC Total advertisement cost (in US dollars);
GI Total greening investments (in US dollars) during the cycle $[0, T]$;
PC Total purchase cost (in US dollars);
SR Total sales revenue (in US dollars);
θ Deterioration rate of product $(0 < \theta < 1)$;
$I(t)$ Inventory level at time t during the time interval $[0, T]$;
Q Total quantity of products at $t = 0$.

2.2. Assumptions

In addition, we made the following assumptions to develop the inventory model:

(1) The planning horizon is infinite and there is no lead time;
(2) The greengrocer grows and sells organic vegetables;
(3) The grocer uses green investments to produce organic products and puts advertisement efforts into promoting and increasing sales of the product;
(4) The demand rate $R = \alpha - \beta \cdot p + \gamma \cdot \mu + \eta \cdot M$ is dependent on selling price and greening efforts as well as advertisement costs. Here, $\alpha > 0$ is constant demand, $\beta > 0$ represents price elasticity factor, $\gamma > 0$ is greening investments effectiveness scale, and $\eta > 0$ denotes the advertisement effectiveness scale;
(5) There is a quadratic relationship between the greening effort μ per unit time [7]. Therefore, total greening investments per unit time t is $\int_0^t \int_0^\mu \psi \cdot \mu \, d\mu \, dt = \frac{\psi \cdot \mu^2 \cdot t}{2}$. Thus, the total investment for the time period T is $\frac{\psi \cdot \mu^2 \cdot T}{2}$;
(6) Products deteriorate at a constant rate of deterioration $\theta (0 \leq \theta \leq 1)$. The deteriorated products have no salvage value.

2.3. Mathematical Model

Initially, at $t = 0$, the stock level is Q. Products in the system deteriorate at a constant rate θ. Thus, the stock level decreases due to product demand and deterioration. At $t = T$, the stock level reaches zero. Hence, the product stock level at any time $t (0 \leq t \leq T)$ can be represented by the following differential equation:

$$\frac{d}{dt} I(t) = -\theta \cdot I(t) - R \, , \; 0 \leq t \leq T \tag{1}$$

Equation (1) is a first-order, linear ordinary differential equation. Solving the equation and using the boundary conditions $I(T) = 0$ and $I(0) = Q$, inventory level $I(t)$, and ordering quantity Q can be written as shown in Equations (2) and (3), respectively. (see Appendix A).

$$I(t) = \frac{\alpha - \beta p + \gamma \mu + \eta M}{\theta} \cdot \left(e^{\theta \cdot (T-t)} - 1 \right) \; ; \; 0 \leq t \leq T \tag{2}$$

$$Q = \frac{\alpha - \beta p + \gamma \mu + \eta M}{\theta} \cdot \left(e^{\theta \cdot T} - 1 \right) \tag{3}$$

Various costs incurred by the grocer are shown below:
Set-up cost: $OC = A$;
Advertisement cost: $MC = M$;
Total purchase cost: $PC = C \cdot Q = \frac{C(\alpha - \beta p + \gamma \mu + \eta M)}{\theta} \left[e^{\theta T} - 1 \right]$;
Total holding cost:

$$\begin{aligned} HC &= h \cdot \int_0^T I(t) \, dt \\ &= \tfrac{h}{\theta^2} \left[-MT\eta\theta - T\gamma\mu\theta + T\beta p\theta - \gamma\mu + \beta p - \alpha + e^{\theta T} (\eta M + \gamma\mu - \beta p + \alpha) - T\alpha\theta - \eta M \right]; \end{aligned}$$

Greening investment cost is as shown in Equation (4):

$$GI = \frac{\psi \cdot \mu^2 \cdot T}{2} \tag{4}$$

Hence, the total cost of the grocer is as given in Equation (5):

$$\begin{aligned} TC &= OC + MC + PC + HC + GI \\ &= A + M + \frac{C(\alpha - \beta p + \gamma\mu + \eta M)}{\theta}\left[e^{\theta T} - 1\right] + h \cdot \int_0^T I(t)\, dt + \frac{\psi \cdot \mu^2 \cdot T}{2} \end{aligned} \tag{5}$$

The sales revenue is shown in Equation (6):

$$SR = p \cdot \int_0^T R\, dt = p \cdot \int_0^T (\alpha - \beta p + \gamma\mu + \eta M)\, dt = p(\alpha - \beta p + \gamma\mu + \eta M)T \tag{6}$$

The total profit of the retailer per unit cycle can be obtained by: $TP = \frac{1}{T}(SR - TC)$.

By substituting the values of Equations (5) and (6), total profit TP can be obtained as mentioned below in Equation (7):

$$TP = \frac{1}{T}\left[p(\alpha - \beta p + \gamma\mu + \eta M)T - A - M - \frac{C(\alpha - \beta p + \gamma\mu + \eta M)}{\theta}\left[e^{\theta T} - 1\right] - h \cdot \int_0^T I(t)\, dt - \frac{\psi \cdot \mu^2 \cdot T}{2}\right] \tag{7}$$

Equation (7) denotes the objective function with four decision parameters: selling price (p), cycle time (T), greening efforts (μ), and advertisement cost (M).

2.4. Solution Procedure

We now describe the procedure to obtain the optimum values of the decision variables. To obtain an optimal solution, follow the steps mentioned below:

Step 1: Allocate values to all inventory parameters other than decision variables in the objective function;

Step 2: Differentiate Equation (7) partially with respect to the decision variables p, T, μ, and M, respectively, to obtain $\frac{\partial TP}{\partial p}$, $\frac{\partial TP}{\partial T}$, $\frac{\partial TP}{\partial \mu}$, $\frac{\partial TP}{\partial M}$;

Step 3: Set all these first-order, partial derivatives of the profit function equal to zero, i.e., $\frac{\partial TP}{\partial p} = 0$, $\frac{\partial TP}{\partial T} = 0$, $\frac{\partial TP}{\partial \mu} = 0$, and $\frac{\partial TP}{\partial M} = 0$. Solve them to obtain values of p, T, μ, and M, respectively;

Step 4: Check the concavity of the profit function;

Step 5: Substitute values of p, T, μ, and M in Equations (4) and (7) to obtain total greening investments and total profit, respectively.

3. Model Validation

In this section, we provide a real case to visualize the present study with a realistic situation. Next, we validate the model with the help of numerical data.

3.1. Real Case

The present study deals with organic manufacturing and is applicable firsthand to a greengrocer who grows and sells organic vegetables and fruits. Nowadays, many customers have turned towards healthy, natural, and nutrient-rich food. They have adopted a health-conscious approach and are ready to pay higher amounts for natural and organic food products. The grocer avoids the use of inorganic fertilizers and harmful pesticides; instead, the grocer uses nature-based organic fertilizers and bio-pesticides to meet customers' demands. The grocer may promote the product and create awareness among a large volume of people through advertisement.

3.2. Numerical Example

In this section, the authors illustrate an example to authenticate and elucidate the model developed in Section 2.3. Consider the following hypothetical values:

Example: Let $A = \$\,100, \alpha = 400$ units, $\beta = 25, \gamma = 3, \psi = 2, \eta = 0.05, C = \$\,3$ per unit, $h = \$\,0.1$ per unit/day, and $\theta = 0.1$.

We use the process stated in Section 2.4 to obtain the optimum solution.

By following steps 1 to 3, authors obtain $p = \$\,10.69$ per unit, $M = \$\,242.53$, $T = 2.83$ days, $\mu = \$\,10.6$ per unit time, and $Q = 578$ units.

The verification of the concavity of the profit function using the Hermitian matrix is given in Appendix B.

Moreover, the concavity of the profit function is also examined by the graph of total profit to decision variables.

Figure 1 consists of two figures, Figure 1a,b. Figure 1a shows that the total profit function is concave for the decision variables selling price and cycle time, whereas Figure 1b demonstrates that the total profit is concave for the decision variables greening effort and advertisement cost.

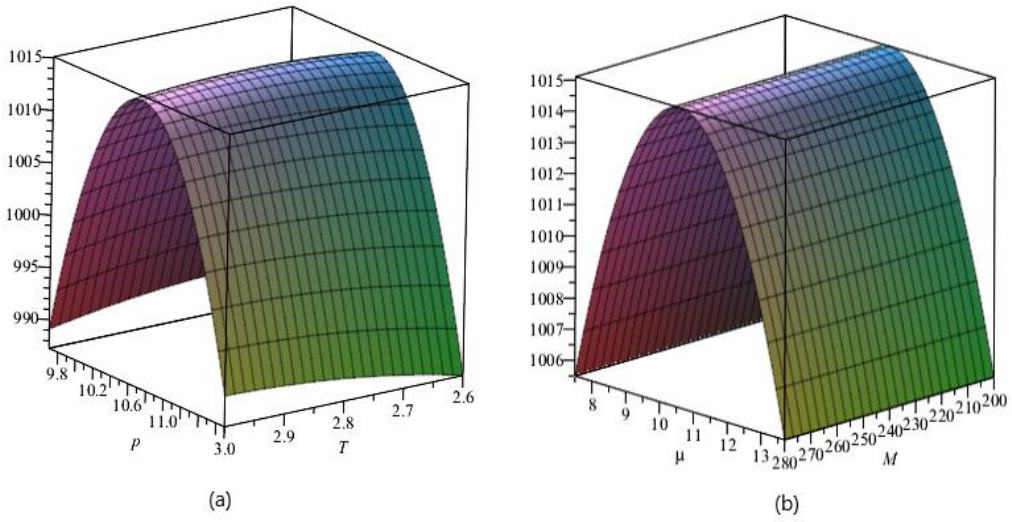


Figure 1. Concavity of total profit to decision variables: (**a**) p, T, and (**b**) μ, M.

Now, substitute all the values in Equations (4) and (7). Hence, $GI = \$318$ and $TP = \$1015.10$. Next, the authors proceed to check the effect on total profit and the decision variables concerning compact changes in other inventory parameters. Then, we compare the results for different cases, as shown in Table 2.

Table 2. Comparison of results in different cases.

Parameters / Model	Advertisement	Green Investment	Advertisement Cost	Green Inv. Cost	Total Sales Units	Total Profit
Model1	Yes	Yes	\$242.53	\$318.00	578	\$1015.10
Model2	Yes	No	\$283.17	NA	456	\$912.75
Model3	No	Yes	NA	\$274.28	303	\$903.18
Model4	No	No	NA	NA	289	\$839.76

4. Sensitivity Analyses and Results

In this section, we carry out sensitivity analyses, and, based on the analyses, we discuss managerial insights.

4.1. Sensitivity Analyses

Now, the authors proceed to check the effect of minor changes in various demand parameters and the deterioration rate on total advertisement cost, greening investment cost, and total profit. Authors change the values of α, β, γ, and θ gradually by $-20\%, -10\%, 10\%$, and 20% and keep the values of other parameters unchanged to analyze how they affect

the total profit of the grocer, green investments, and advertisement cost. The results are expressed in multi-axes graphs, as shown in Figures 2 and 3. TheX-axes represent the value of the parameter that is changed on a small scale. The primary Y-axes show values of total greening investments and advertisement costs, whereas the secondary Y-axes denote the value of total profit. Greening investment and advertisement costs are represented by bar graphs, and the line graph shows the total profit of the grocer in each of the figures, Figures 2 and 3.

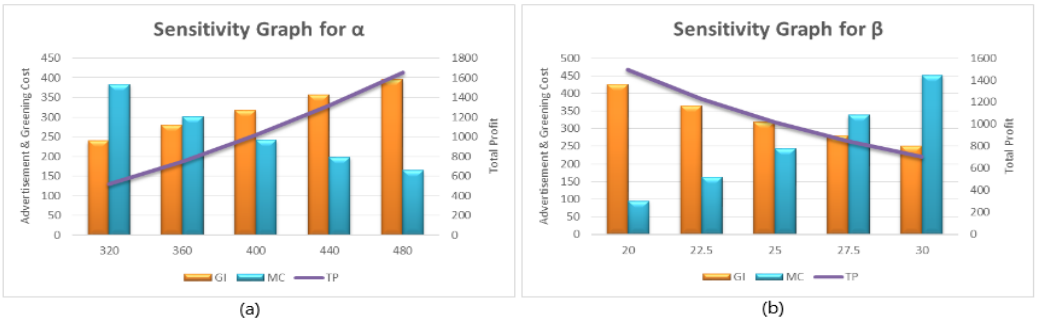


Figure 2. Sensitivity of advertisement, greening investment, and profit: (**a**) for α, and (**b**) for β.

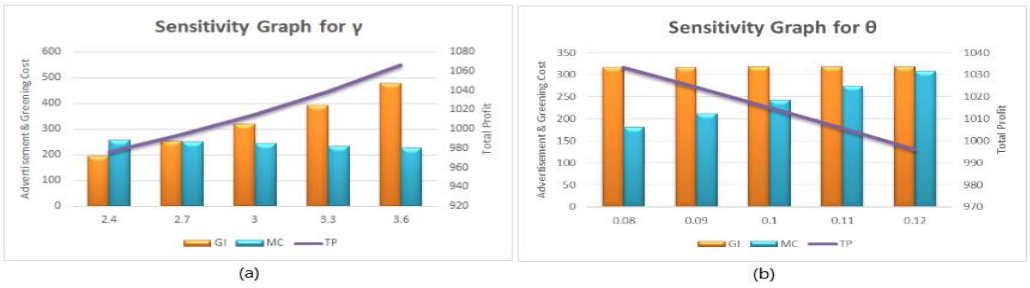


Figure 3. Sensitivity of advertisement, greening investment, and profit: (**a**) for γ, and (**b**) for θ.

Figure 2 shows the sensitivity graphs of demand parameters α and β. The effects of changes in α are characterized in Figure 2a, whereas the effects of changes in β are represented in Figure 2b.

Figure 3 denotes the changes in advertisement cost, greening investments, and profit concerning the change in γ and θ.

Figure 4 shows the change in total sales and selling price per unit for models 1–4. Total sales volume is very much affected by advertisement and greening efforts. The selling price of the product decreases if we do not use advertisements or a greening policy.

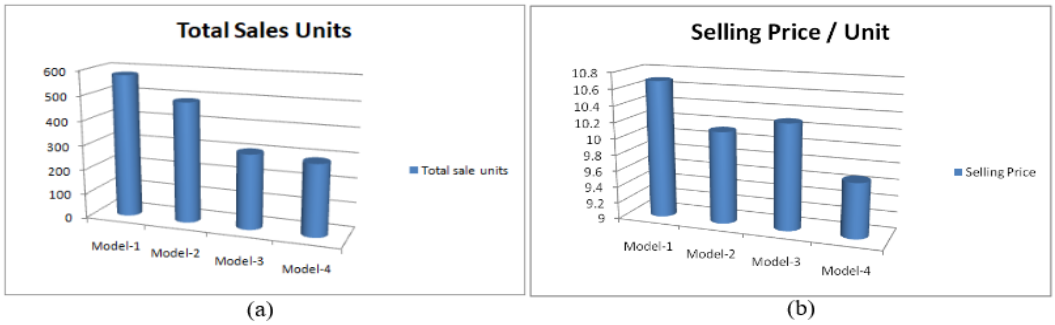


Figure 4. Comparison of different models: (**a**) total sales units; and (**b**) selling price per unit.

4.2. Results

We obtained some important results based on the numerical example, comparison of different cases in Table 1, and the sensitivity analyses carried out. Advertisement is useful

to the grocer to increase the awareness of the product among the customers. It results in an increase in overall sales of the product and, hence, the total profit. Since the product demand is directly associated with the greening efforts, the sale of the product increases due to greening investments, and it results in a hike in total sales. However, from Figure 1, we can observe that advertisement and greening investments help the grocer to increase the total profit up to a certain level. Afterward, over-investment in advertisement or green efforts becomes futile. From Figures 2 and 3 (sensitivity analyses) we can see the behavior of the profit function and decision variables. Naturally, an increase in total profit is noted with an increase in the constant demand. As the demand is sensitive to the product price, we can note a drop in the total profit due to an increase in the price elasticity factor. With the increase in the advertisement effectiveness parameter, the total profit rises. An increase in the deterioration rate causes an increase in the number of spoiled products. It leads to a short inventory cycle time, and, hence, the total revenue is reduced.

5. Discussion

In this section, we discuss the theoretical and practical implications obtained from the study.

5.1. Theoretical Implications

In the literature, most research has been carried out by considering either remanufacturing, redesigning, recycling, costsharing, carbon reduction, or carbon trading as a greening policy. In our work, we considered organic farming where the grocer avoids the use of inorganic fertilizers and pesticides. From Figure 2, it can be noted that the greening investments increase in relation to an increase in the constant demand, while they decrease in relation to an increase in the price sensitivity factor. A decrease is observed in advertisement cost, with an increase in α, and the advertisement cost increases with an increase in β. From Figure 3a, it can be concluded that, with an increase in γ, greening investments increase, advertisement cost shows a marginal decrease, and total profit increases. Figure 3b shows that, with an increase in θ, advertisement cost increases, and the total profit decreases. However, there is no change in the greening investment cost.

5.2. Practical Implications

We worked out four different models: (1) with advertisement and with greening investments; (2) with advertisement and without greening investments; (3) without advertisement and with greening investments; (4) without advertisement and without greening investments. The results obtained show that the grocer obtains maximum profit in the first model, and the total sales units are also highest in this model. Practically, advertisement gives exposure to the novelty and quality of the product, and the grocer can achieve a hike in sales volume. Figure 4a admits that the total sales decrease in the absence of an advertisement policy or greening investments or both. Figure 4b highlights that if we do not use advertisements, then the selling price can be reduced. Moreover, an increase in the deterioration rate causes a decrease in the total profit of the grocer, which is reflected in Figure 3b.

6. Conclusions

The proposed model was developed for a greengrocer who grows and sells organic vegetables. The grocer uses greening investments to carry out organic farming and sells nutrient-rich and eco-friendly products. To promote the product on a large scale and to increase the sales of the product, the grocer uses advertisement. Constant product demand is influenced by the selling price, greening investments, and advertising efforts. The problem was formulated into a mathematical model, and a solution procedure was provided with an example to elucidate the model. Sensitivity analysis was carried out to check the effect of changes in demand parameters and deterioration rate on greening investments, advertisement cost, and total profit of the grocer. The results showed that, with

an increase in the constant demand α and greening sensitivity parameter γ, the greening investments increases, and the total profit of the grocer increases too. However, with the increase in the values of the price elasticity factor β and the deterioration rate θ, the total profit of the greengrocer decreases.

There are certain limitations to the present work. The study was carried out with the assumption that there is no shortage of goods at any point in time, so, as a future scope, the present study can be extended by allowing shortages and backorder policy to include a more realistic situation. The grocer may provide trade credit to customers to have strong bonding with customers. The study can be studied by considering a fuzzy environment.

Author Contributions: Conceptualization: N.S.; Methodology: P.S.; Software: N.S.; Validation: N.S., P.S. and M.P.; Formal analysis, M.P.; Data validation: N.S.; Writing—original draft preparation: P.S.; Writing—review and editing: P.S. and M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Authors thank DST-FIST file # MSI-097 for technical support to the Department of Mathematics, Gujarat University.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

$$\begin{array}{l} \frac{d}{dt}I(t) = -\theta \cdot I(t) - R \\ \Rightarrow \frac{d}{dt}I(t) + \theta \cdot I(t) = -R \end{array}$$

which is a linear differential equation.

Hence, the integrating factor is: $IF = e^{\int_0^t \theta \, dt} = e^{\theta t}$.

Therefore, the solution can be obtained by simplifying the following standard solution:

$$I(t) \cdot e^{\theta t} = -R \int_0^t e^{\theta t} dt + k$$

where k is an arbitrary real constant.

Integrating, we obtain: $I(t) \cdot e^{\theta t} = -\frac{R}{\theta}\left(e^{\theta t} - 1\right) + k$.

Using the boundary condition $I(T) = 0$, we obtain:$k = \frac{R}{\theta}\left(e^{\theta T} - 1\right)$.

Hence,

$$I(t) = \frac{R}{\theta}\left(e^{\theta(T-t)} - 1\right) = \frac{\alpha - \beta p + \gamma\mu + \eta M}{\theta}\left(e^{\theta(T-t)} - 1\right). \quad \text{(A1)}$$

Now, using the condition $I(0) = Q$ in (a), we obtain:

$$Q = \frac{\alpha - \beta p + \gamma\mu + \eta M}{\theta} \cdot \left(e^{\theta \cdot T} - 1\right) \quad \text{(A2)}$$

Appendix B

To check the concavity of the profit function, we considered the Hessian matrix, as shown below.

$$H = \begin{bmatrix} \frac{\partial^2 TP}{\partial p^2} & \frac{\partial^2 TP}{\partial p \partial T} & \frac{\partial^2 TP}{\partial p \partial \mu} & \frac{\partial^2 TP}{\partial p \partial M} \\ \frac{\partial^2 TP}{\partial T \partial p} & \frac{\partial^2 TP}{\partial T^2} & \frac{\partial^2 TP}{\partial T \partial \mu} & \frac{\partial^2 TP}{\partial T \partial M} \\ \frac{\partial^2 TP}{\partial \mu \partial p} & \frac{\partial^2 TP}{\partial \mu \partial T} & \frac{\partial^2 TP}{\partial \mu^2} & \frac{\partial^2 TP}{\partial \mu \partial M} \\ \frac{\partial^2 TP}{\partial M \partial p} & \frac{\partial^2 TP}{\partial M \partial T} & \frac{\partial^2 TP}{\partial M \partial \mu} & \frac{\partial^2 TP}{\partial M^2} \end{bmatrix}$$

For this matrix, calculate the principal minors: $D_1 = \frac{\partial^2 TP}{\partial p^2}$, $D_2 = \begin{vmatrix} \frac{\partial^2 TP}{\partial p^2} & \frac{\partial^2 TP}{\partial p \partial T} \\ \frac{\partial^2 TP}{\partial T \partial p} & \frac{\partial^2 TP}{\partial T^2} \end{vmatrix}$,

$D_3 = \begin{vmatrix} \frac{\partial^2 TP}{\partial p^2} & \frac{\partial^2 TP}{\partial p \partial T} & \frac{\partial^2 TP}{\partial p \partial \mu} \\ \frac{\partial^2 TP}{\partial T \partial p} & \frac{\partial^2 TP}{\partial T^2} & \frac{\partial^2 TP}{\partial T \partial \mu} \\ \frac{\partial^2 TP}{\partial \mu \partial p} & \frac{\partial^2 TP}{\partial \mu \partial T} & \frac{\partial^2 TP}{\partial \mu^2} \end{vmatrix}$, $D_4 = \begin{vmatrix} \frac{\partial^2 TP}{\partial p^2} & \frac{\partial^2 TP}{\partial p \partial T} & \frac{\partial^2 TP}{\partial p \partial \mu} & \frac{\partial^2 TP}{\partial p \partial M} \\ \frac{\partial^2 TP}{\partial T \partial p} & \frac{\partial^2 TP}{\partial T^2} & \frac{\partial^2 TP}{\partial T \partial \mu} & \frac{\partial^2 TP}{\partial T \partial M} \\ \frac{\partial^2 TP}{\partial \mu \partial p} & \frac{\partial^2 TP}{\partial \mu \partial T} & \frac{\partial^2 TP}{\partial \mu^2} & \frac{\partial^2 TP}{\partial \mu \partial M} \\ \frac{\partial^2 TP}{\partial M \partial p} & \frac{\partial^2 TP}{\partial M \partial T} & \frac{\partial^2 TP}{\partial M \partial \mu} & \frac{\partial^2 TP}{\partial M^2} \end{vmatrix}$

For concavity of the profit function, the required conditions are: $D_1 < 0$, $D_2 > 0$, $D_3 < 0$ and $D_4 > 0$.

Due to the complexity of the calculation, we used Maple18 software to obtain values of minors. Thus, by substituting values of decision variables and solving the above minors we obtain: $D_1 = -50 < 0$, $D_2 = 1620.29 > 0$, $D_3 = -2942.34 < 0$, and $D_4 = 30.03 > 0$.

Thus, the profit function is concave concerning the obtained values of the decision variables.

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