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# GREEN DUAL-CHANNEL SUPPLY CHAIN MODEL WITH CONSIDERING PRODUCT RETURNS AND REMANUFACTURING PROCESS

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***ABSTRACT***

*The development of information and communication technology causes internet users to increase, so consumers are increasingly accustomed to buying products through online channels. This can encourage business people to carry out a sales strategy using two channels (offline and online) or commonly called Dual-Channel Supply Chain (DCSC). In its application, it is hoped that business people will create an environmentally friendly company to reduce carbon emissions. Therefore, business people create companies that implement the Green Dual-Channel Supply Chain (GDCSC) model. GDCSC in online channels has one drawback, namely that consumers cannot evaluate products accurately. This allows consumers to obtain defective products resulting in product returns. Returned defective products can be reprocessed through the remanufacturing process. To provide solutions to these conditions, centralization scenario is used to determine the optimal solution so that maximum profit is obtained. Based on the analysis, it shows that changes in price elasticity and product returns cause system profits to get smaller, while changes in price elasticity and energy efficiency levels cause system profits to get bigger.*



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## 1. INTRODUCTION

Climate change is a growing problem that has a major impact on life. One indicator of climate change is the increase in carbon dioxide gas and other gases, causing the greenhouse effect [1]. In paper [1] was also argued that greenhouse gases cause the earth to heat up due to the emergence of gas emissions produced by human activities, one of which is industrial activities. Industrial activities are one of the main factors that participate in the destruction of nature because the raw materials used contain various chemicals and emissions that are emitted [2]. Raw materials used contain various chemicals and emissions that have the potential to pollute the air[3]. One of the strategies that can be used to reduce the greenhouse gas effect is by implementing green investment.

Eyraud et al[4] stated that green investment is the investment needed to reduce greenhouse gases and air pollution and includes the technology needed to provide products and services. Sani[5] applied green technology that can help address environmental issues. To support the successful launch of green products or environmentally friendly products, Waskito[6] argues that manufacturers must realize that consumers are not only focused on the issue of environmentally friendly products, sales strategies also affect consumer attractiveness. The rapid development of information and communication technology has caused the number of internet users to increase, so consumers are increasingly accustomed to buying products online. This can encourage manufacturers to carry out sales strategies using two channels, namely offline and online channels[3], [7], [8]. The sales strategy with two channels is called Dual-Channel Supply Chain (DCSC).

In 2019, Ranjan and Jha[9] explained that DCSC can encourage manufacturers to build online sales media to meet consumer demand that cannot be reached through offline sales channels. According to Dumrongsiri et al [10], consumers can choose purchasing channels based on price and service quality. Purchasing on online channels has the disadvantage that consumers cannot evaluate products accurately, allowing consumers to obtain defective products so that the product return process can occur. Li et al [11] showed that there are four return strategies consisting of manufacturers and retailers, namely no refunds in both channels, full refunds in offline channels only, full refunds in online channels only, and full refunds in both media. Defective products returned from consumers can be reprocessed through the remanufacturing process. Statham[12] states that remanufacturing is a process where used or returned defective products can be reprocessed into new products with minimum expenditure on materials and energy. Remanufacturing describes a recycling process that produces products of the same quality and price as new products.

Zhang et al[13] conducted research on the DCSC model with manufacturers and retailers serving green product returns. Then, Reiman et al[14] researched the remanufacturing process carried out by manufacturers or retailers and manufacturers have the opportunity to reduce remanufacturing costs. Based on these two studies, a GDCSC model will be developed by considering product returns and remanufacturing processes.

## 2. RESEARCH METHODS

The research method used in this research is the literature review method. Literature review was carried out using references in the form of books and articles in journals regarding the GDCSC model. The operational steps carried out in this research are as follows. first, constructing the GDCSC model with two structures, namely remanufacturing products that are resold through offline media in model (a) and remanufacturing products that are resold through online media in model (b). After obtaining the GDCSC model in a centralized scenario, it was then determined that the model obtained was a strict concave function to guarantee a single solution. The next step is to determine the optimal solution for model (a) and model (b) using the first partial derivative of the model to the independent variable equal to zero. Next, the model and optimal solution obtained are applied to a case and a sensitivity analysis is carried out.

In this research, optimization theory is used to determine the minimum and maximum extreme points in multivariable functions without constraints from Taha[15] and Winston[16]. To determine the optimal solution, the necessary and sufficient conditions theorem is used for a function to have extreme points. Given a multivariable function $\boldsymbol{f}(\boldsymbol{x})$ with $\boldsymbol{x} = (\boldsymbol{x_1}, \boldsymbol{x_2}, \cdots, \boldsymbol{x_n}) \in \boldsymbol{S} \subseteq \mathbb{R}^{\boldsymbol{n}}$.

**Theorem 1.** The necessary condition for $x_0$ to be the extreme point of the function $f(x)$ is $\nabla f(x_0) = 0$.

**Definition 2.** The Hessian matrix of $f(x)$ is an $n \times n$ matrix with the $i$-th row and $j$-th column elements as $\frac{\partial^2 f}{\partial x_i x_j}$.

**Theorem 3.** The sufficient condition for a stationary point $x_0$ to become an extreme point is to determine the Hessian matrix $H$ at $x_0$ so that it fulfills the following conditions,

1. $H$ is positive definite if point $x_0$ is the minimum extreme point,
2. $H$ is negative definite if point $x_0$ is the maximum extreme point.

**Definition 4.** The $i^{\text{th}}$ principal minor determinant of an $n \times n$ matrix is the determinant of a matrix of size $i \times i$ obtained by deleting $n - i$ rows and $n - i$ columns related to the Hessian matrix $H$.

**Theorem 5.** If $f''(x)$ is continuous for all $x \in S$, then $f(x)$ is a concave function on $S$ if and only if for every $x \in S$ and all non-zero principal minor determinants have the value $(-1)^i$ with $i = 1, 2, 3, \cdots, n$.

## 3. RESULTS AND DISCUSSION

### 3.1 Model Construction

The green two-channel supply chain (GDCSC) model consists of one manufacturer and one retailer. Manufacturers sell products to retailers through offline channels and directly to consumers through online channels and retailers sell products to consumers through offline channels. In this study, the strategy of returning product return strategy. The returned products are then reprocessed by the manufacturer through the remanufacturing process. The structure of product return and remanufacturing process in the green dual-channel supply chain model is shown in Figure 1.

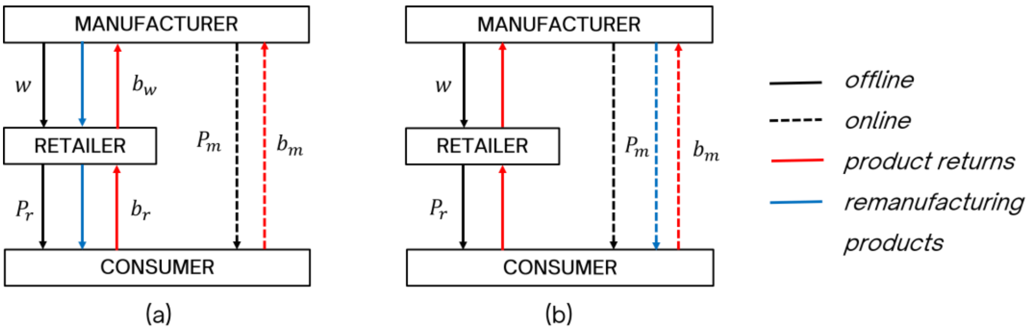


**Figure 1. Green Dual-Channel Supply Chain Structure**

Figure 1(a) is a model (a) with a green dual-channel supply chain structure where remanufacturing results are resold through offline channels. While Figure 1(b) is a model (b) with a green dual-channel supply chain structure where remanufacturing results are resold through online channels. The notation used in the green dual-channel supply chain structure is presented in Table 1.

**Table 1. Notation and Description**

| Notation | Description |
|---|---|
| $\rho_m$ | Potential market demand for online channels |
| $\rho_r$ | Potential market demand for offline channels |
| $w$ | Product prices from manufacturers on offline channels |
| $P_m$ | Product prices from manufacturers on online channels |
| $P_r$ | Product prices from retailers |
| $b_w$ | Number of product returns from retailers |
| $b_m$ | Number of product returns from online consumers |
| $b_r$ | Number of product returns from offline consumers |
| $\alpha_m$ | Selling price elasticity of the manufacturer |

| Notation | Description |
|---|---|
| $\alpha_r$ | Selling price elasticity of the retailer |
| $\beta$ | Demand sensitivity to cross price |
| $g$ | Energy efficiency level elasticity |
| $c_m$ | Production cost |
| $c_o$ | Retailer operating costs |
| $c_r$ | Remanufacturing process cost |
| $x$ | Energy efficiency level |
| $n$ | Energy efficiency level scale parameter |

Based on the structure in **Figure 1** and the notation in **Table 1**, the assumptions used in the modeling are given as follows.

1. The number of products produced is equal to the amount of demand, so there is no shortage of products and no storage costs.
2. The product price $P_m$ is greater than the product price $w$ and less than the product price $P_r$ so $w < P_m < P_r$.
3. The selling price of the product from the manufacturer contains production costs and remanufacturing costs.
4. Refunds on product returns are made in full.
5. In the offline channel, product returns to the manufacturer correspond to consumer product returns to the retailer with $b_r = b_w = b$.
6. The elasticity of the energy efficiency level is smaller than the elasticity of demand ($g < \alpha$).
7. The demand elasticity, energy efficiency elasticity, and cross-price sensitivity are in the interval (0,1).
8. The value of $\min\{\alpha_m, \alpha_r\} > \max\{\beta\}$ to satisfy the negative Hessian matrix.
9. The cost of remanufacturing is less than the manufacturing cost ($c_r < c_m$).
10. All parameters are positive.

Based on the assumptions that have been made, we can determine the amount of demand for manufacturers and retailers. The amount of demand in the green dual-channel supply chain structure consists of the amount of demand on the online channel and the amount of demand on the offline channel.

### A. Amount of Demand on Online Channels

Consumer demand to producers is expressed by $D_m$ and potential market demand on online channels is $\rho_m$. Demand is linear to the price elasticity at the producer by $\alpha_m$. Demand in the online channel decreases as the selling price of the product from the producer increases by $P_m$ so that $\alpha_m P_m$ is obtained. In addition, demand on the online channel is also affected by the cross-price sensitivity $\beta$ between offline and online channels. The selling price in the online channel $P_m$ is affected by the selling price in the offline channel $P_r$, so the demand in the online channel increases by $\beta P_r$. Then, the demand increases with the energy efficiency level denoted by $x$ multiplied by the elasticity of the energy efficiency level denoted by $g$, resulting in $gx$. Thus, the total demand for the online channel is

$$D_m = \rho_m - \alpha_m P_m + \beta P_r + gx. \quad (1)$$

### B. Amount of Demand on Offline Channels

Retailers sell products to retailers through offline channels with consumer demand to retailers expressed by $D_r$ and potential market demand by $\rho_r$. The linear elasticity of demand concerning the price at the retailer is $\alpha_r$ . Consumer demand in the offline channel decreases when the selling price of the product from the retailer $P_r$ increases, resulting in $\alpha_r P_r$. The selling price from retailers to consumers is affected by the cross-price sensitivity $\beta$ and the selling price from producers to consumers $P_m$, so demand in the offline channel increases by $\beta P_m$. Furthermore, the demand in the offline channel is affected by the energy efficiency level and the elasticity of the energy efficiency level, so the demand at retailers increases by $gx$. Thus, the total demand in the offline channel is

$$D_r = \rho_r - \alpha_r P_r + \beta P_m + gx. \tag{2}$$

At this stage, the amount of demand on the online and offline channels has been obtained. The next step is to determine the amount of profit for manufacturers and retailers in the model (a) and model (b).

Profit is obtained from total revenue minus total expenditure. The total profit in the green dual channel supply chain structure consists of the total profit of the manufacturer and the total profit of the retailer.

### C. Manufacturer Profit Amount

The manufacturer's profit is earned from selling products through the online channel at a price $P_m$ for $D_m$ and through the offline channel at a price $w$ for $D_r$, so the total revenue of the manufacturer is

$$TR_m = P_m D_m + wD_r \tag{3}$$

The manufacturer conducts production activities at a cost of $c_m$. The cost incurred by the producer is $c_m$ multiplied by the total demand from online and offline channels, so the production cost is $c_m(D_m + D_r)$. Eyraud said that the cost of green technology is usually assumed to be a quadratic function, where $\frac{nx^2}{2}$ represents the cost of energy efficiency. The producer receives $b_m$ of returned products directly from consumers at a return cost of $P_m$. In addition, the manufacturer also receives $b_m$ of returned products from retailers with a return cost of $w_m$. The manufacturer remanufactures the returned products with a remanufacturing cost of $c_r(b + b_m)$, so the total cost incurred by the manufacturer is

$$TC_m = c_m(D_m + D_r) + P_m b_m + wb + c_r(b_m + b) + \frac{nx^2}{2}. \tag{4}$$

From **Equation (3)** and **Equation (4)**, the total manufacturing profit is obtained, namely

$$\begin{aligned}\Pi_m &= TR_m - TC_m \\ &= P_m(D_m - b_m) + w(D_r - b) - c_m(D_m + D_r) - c_r(b_m + b) - \frac{nx^2}{2}.\end{aligned} \tag{5}$$

In model (a), remanufacturing products are resold through offline channels at the same selling price as the selling price of new products, which is $w$, so the cost of selling remanufacturing products obtained by the manufacturer is

$$TR_m^a = w(b_m + b). \tag{6}$$

Based on **Equation (5)** and **Equation (6)**, the total manufacturing profit for model (a) is obtained, namely

$$\begin{aligned}\Pi_m^a &= \Pi_m + TR_m \\ &= P_m(D_m - b_m) + w(D_r + b_m) - c_m(D_m + D_r) - c_r(b_m + b) - \frac{nx^2}{2}.\end{aligned} \tag{7}$$

Then in model (b), remanufacturing products are resold through online channels at the same selling price as the selling price of new products, which is $P_m$, so that the manufacturer earns the cost of selling remanufacturing products amounting to

$$TR_m^a = P_m(b_m + b). \tag{8}$$

From **Equation (5)** and **Equation (8)**, the total manufacturing profit in model (b) is obtained

$$\Pi_m^b = \Pi_m + TR_m^b \tag{9}$$

$$= P_m(D_m + b) + w(D_r - b) - c_m(D_m + D_r) - c_r(b_m + b) - \frac{nx^2}{2}.$$

### D. Retailer Profit Amount

Retailers sell their products to consumers through offline channels at a price of $P_r$ . Retailer revenue is obtained from selling products to consumers multiplied by the amount of consumer demand, namely $D_r$. Furthermore, on product returns, the retailer gets a refund from the manufacturer of $wb$, so that the retailer's income is obtained, namely

$$TR_r = P_r D_r + wb \tag{10}$$

Retailers buy products from manufacturers at a price of w multiplied by the amount of demand in the offline channel of $D_r$ . The retailer uses operating costs of co, so the cost incurred by the retailer in selling products to consumers is $c_o$ multiplied by the amount of demand from consumers in the offline channel. The retailer receives returned products from consumers of $b$ with a return cost of $P_r$, so the total cost incurred by the retailer is

$$TC_r = wD_r + c_o D_r + P_r b. \tag{11}$$

From **Equation (10)** and **Equation (11)**, the total profit of the retailer is obtained

$$\Pi_r = TR_r - TC_r = D_r(P_r - w - c_o) - b(P_r - w). \tag{12}$$

In model (a), the product that has been processed by the manufacturer through the remanufacturing process is purchased by the retailer at a price of $w$, so the retailer incurs a product purchase cost of $w(b_m + b)$. Then the retailer uses operating costs of $c_o(b_m + b)$, so the total cost incurred by the retailer is

$$TC_r^a = w(b_m + b) + c_o(b_m + b). \tag{13}$$

The retailer resells the product purchased from the manufacturer to the consumer at a price of $P_r$ multiplied by the amount of product reprocessed which is $b_m + b$. The total cost earned by the retailer is

$$TR_r^a = P_r(b_m + b). \tag{14}$$

Based on **Equation (12), (13)** and **(14)**, the total profit of retailers in model (a) is obtained, namely

$$\Pi_r^a = (P_r - w)(D_r - b) - c_o D_r + (P_r - w - c_o)(b_m + b). \tag{15}$$

In model (b), the sales of remanufacturing products are only resold through online channels, so the total profit of retailers in the model (b) is the same as **Equation (12)**, namely

$$\Pi_r^b = D_r(P_r - w - c_o) - b(P_r - w). \tag{16}$$

In the centralized scenario, manufacturers and retailers make pricing decisions together. The resulting profit is obtained from the combined profit of the manufacturer and retailer. Based **Equation (7)**,and **(15)**, the GDCSC model in the model (a) is obtained,

$$\max \Pi^a (P_m, P_r, x) = \Pi_m^a + \Pi_r^a. \tag{17}$$

Then in the model (b), the GDCSC model in the decentralization scenario can be constructed by using **Equation (9)** and **(16)**, thus obtaining

$$\max \Pi^b (P_m, P_r, x) = \Pi_m^b + \Pi_r^b. \tag{18}$$

In this section, the GDCSC model has been obtained in model (a) and model (b) using the centralized scenario. Next, the optimal solution for each model obtained is determined.

### 3.2 Optimal Solution

The optimal solution in the centralization scenario can be determined by maximizing the profit of the system consisting of manufacturers and retailers. Since the profit function in the centralization scenario that has an optimal solution must have a strictly concave function, then in the model (a) and model (b), the Hessian matrix obtained from the second partial derivative of **Equation (17)** and **Equation (18)** on $P_m$, $P_r$, and $x$ can be constructed, where

$$H(\Pi^a) = H(\Pi^b) = \begin{pmatrix} -2\alpha_m & 2\beta & g \\ 2\beta & -2\alpha_r & g \\ g & g & -n \end{pmatrix}. \tag{19}$$

From the Hessian matrix in **Equation (19)**, the principal minor determinant is obtained, namely

$$\begin{aligned} H_{11} &= -2\alpha_m, \\ H_{22} &= 4\alpha_m\alpha_r - 4\beta^2, \\ H_{33} &= 2g^2(\alpha_m + \alpha_r) + 4(\beta(g^2 + n\beta) - n\alpha_m\alpha_r). \end{aligned} \tag{20}$$

Based on the 8th assumption, the values of $H_{11} < 0$,$H_{22} > 0$, and $H_{33} < 0$ with the condition that $\alpha_m > \frac{-g^2\alpha_r - 2g^2\beta - 2n\beta^2}{g^2 - 2n\alpha_r}$, so it can be said that the system profit function is strictly concave and there is a single optimal solution. The optimal solution is obtained by deriving **Equation (17)** and **Equation (18)** concerning $P_m$, $P_r$, and $x$ which are then made equal to zero. The optimal solution in the model (a) is written as

$$\begin{aligned} P_m^{a*} &= \frac{A_1 + c_m\left(g^2(\alpha_m + 3\alpha_r + 4\beta) + A_2 + \rho_m(g^2 - 2n\alpha_r) - (g^2 + 2n\beta)\right)}{2(A_2 + A_5)}, \\ P_r^{a*} &= \frac{c_o(A_2 + a_3) + g^2(2b_m - \rho_m + \rho_r) + 2n\left(\beta(b_m - \rho_m) - \alpha_m(b_m + \rho_m)\right)}{2(A_2 + A_5)}, \\ x^{a*} &= \frac{\alpha_r(\alpha_m(2c_m + c_o) + b_m - \rho_m) - \alpha_m(b_m + \rho_r) - \beta\left(\beta(2c_m + c_o + \rho_m + \rho_r)\right)}{A_2 + A_5} \end{aligned} \tag{21}$$

with

$$\begin{aligned} A_1 &= c_o g^2(\alpha_r + \beta) - 2b_m\left(g^2 + n(\beta - \alpha_r)\right), \\ A_2 &= 2n(\beta^2 - \alpha_m\alpha_r), \\ A_3 &= g^2(2\alpha_m + \alpha_r + 3\beta), \\ A_4 &= g^2(3\alpha_m + \alpha_r + 4\beta), \\ A_5 &= g^2(\alpha_m + \alpha_r + 2\beta). \end{aligned}$$

The optimal demand and profit function in model (a) are determined by substituting **Equation (21)** to **Equation (1)**, **Equation (2)**, **Equation (7)**, and **Equation (15)**. Next, they are written as follows

$$\begin{aligned} D_m^{a*} &= \rho_m - \alpha_m P_m^{a*} + \beta P_r^{a*} + g x^{a*}, \\ D_r^{a*} &= \rho_r - \alpha_r P_r^{a*} + \beta P_m^{a*} + g x^{a*}, \\ \Pi_m^{a*} &= P_m^{a*}(D_m^{a*} - b_m^{a*}) + w(D_r^{a*} + b_m^{a*}) - c_m(D_m^{a*} + D_r^{a*}) - c_r(b_m + b) - \frac{n(x^{a*})^2}{2}, \\ \Pi_r^{a*} &= (P_r^{a*} - w)(D_r^{a*} - b) - c_o D_r^{a*} + (P_r^{a*} - w - c_o)(b_m + b). \end{aligned} \tag{22}$$

Meanwhile, the optimal solution for model (b) is written as

$$\begin{aligned} P_m^{b*} &= \frac{G_1 - 2\alpha_r n(b + \rho_m + c_m\alpha_m) + 2n\beta(b + c_m\beta - \rho_r)}{2G_3}, \\ P_r^{a*} &= \frac{G_2 - 2\alpha_m n(b_m + \alpha_r(c_m + c_o) + \rho_r) + n\beta\left(b_m + 2(\beta(c_m + c_o) - \rho_m)\right)}{2G_3}, \\ x^{a*} &= \frac{g\left(\alpha_r\left(\alpha_m(2c_m + c_o + b_m - \rho_m)\right) - \alpha_m\rho_r + b_m\right) - \beta(\beta(2c_m - c_o) - \rho_m - \rho_r)}{G_3} \end{aligned} \tag{23}$$

with

$$G_1 = g^2(c_m(\alpha_m + 3\alpha_r + 4\beta) + c_o(\alpha_r + \beta) + 2b + \rho_m - \rho_r),$$
$$G_2 = g^2(c_m(3\alpha_m + \alpha_r + \beta) + c_o(2\alpha_m + \alpha_r + 3\beta) - \rho_m + \rho_r + 2b_m),$$
$$G_3 = g^2(\alpha_m + \alpha_r + 2\beta) + 2n(b^2 - \alpha_m\alpha_r).$$

Furthermore, the optimal demand function and optimal profit function are determined by substituting **Equation (23)** into **Equation (1)**, **Equation (2)**, **Equation (9)**, and **Equation (16)**. Thus, the optimal demand function and optimal profit function are obtained, namely

$$\begin{aligned}
D_m^{b*} &= \rho_m - \alpha_m P_m^{b*} + \beta P_r^{b*} + g x^{b*},\\
D_r^{b*} &= \rho_r - \alpha_r P_r^{b*} + \beta P_m^{b*} + g x^{b*},\\
\Pi_m^{b*} &= P_m^{b*}\left(D_m^{b*} + b\right) + w\left(D_r^{b*} - b\right) - c_m\left(D_m^{b*} + D_r^{b*}\right) - c_r(b_m + b) - \frac{n(x^{b*})^2}{2},\\
\Pi_r^{b*} &= D_r^{b*}\left(P_r^{b*} - w - c_o\right) - b\left(P_r^{b*} - w\right).
\end{aligned} \tag{24}$$

At this stage, the optimal solution has been obtained for model (a) and model (b) in the centralization scenario. Next, the model and optimal solution obtained are applied to a case and sensitivity analysis is carried out on changes in product return sensitivity parameters to the optimal solution model.

### 3.3 Application

An application is given by performing numerical simulations on a green dual-channel supply chain model considering product returns and remanufacturing processes. The parameter values are taken from the research of Chang et al.[17] and Zhang et al.[18], and numerical simulations. The parameter values used in this study are presented in **Table 2**.

**Table 2. Parameter Value**

| Parameter | Value |
|---|---|
| $\rho_m$ | 150 unit |
| $\rho_r$ | 200 unit |
| $\alpha_m$ | 0.4 unit$^2$/\$ |
| $\alpha_r$ | 0.5 unit$^2$/\$ |
| $\beta$ | 0.1 unit$^2$/\$ |
| $g$ | 0.02 unit$^2$/\$ |
| $c_m$ | \$70 |
| $c_o$ | \$20 |
| $c_r$ | \$25 |
| $b_m$ | 5 unit |
| $b$ | 5 unit |
| $n$ | 5 |

The optimal selling price in the centralized and decentralized scenarios is determined by substituting the parameter values in **Table 2** into **Equation (21)** and **Equation (23)**. The energy efficiency level is obtained by substituting into equations **Equation (21)** and **Equation (23)**.The optimal demand function and optimal profit function are obtained by substituting **Equation (22)** and **Equation (24)**. The optimal solution of the green dual-channel supply chain model is presented in **Table 3**.

**Table 3. Optimal solution of GDCSC Model**

| Decision variable | Model (a) | Model (b) |
|---|---|---|
| $w$ | \$269.1 | \$262.0 |
| $P_m$ | \$279.8 | \$290.3 |

| Decision variable | Model (a) | Model (b) |
|---|---|---|
| $P_r$ | \$299.0 | \$291.1 |
| $x$ | 0.84 | 0.86 |
| $D_m$ | 68 | 63 |
| $D_r$ | 78 | 83 |
| $\Pi_m$ | \$29589.8 | \$29801.6 |
| $\Pi_r$ | \$724.2 | \$612.5 |
| Total profit | \$30314.0 | \$30414.1 |

Based on **Table 3**, the optimal values of $P_m$, $x$, $D_r$,$\Pi_m$ and total profit for model (b) are greater than model (a). While the values of $w$, $P_r$, $D_m$, and $\Pi_r$ model (b) are smaller than model (a). When viewed from the total profit and manufacturer's profit obtained, model (b) gains greater profits than model (a). However, this does not apply to retailers' profits. Model (a) provides more profits for retailers than model (b). Furthermore, a sensitivity analysis was conducted to determine the effect of product return sensitivity changes on the solution of the GDCSC model.

Product returns can be made by consumers to retailers through offline channels and directly to manufacturers through online channels. The number of returned products affects the amount of demand and profit of each actor. The effect of changes in the number of product returns in the centralized scenarios is shown in **Table 4**.

**Table 4. Changes in $b_m$ and $b$ Towards The Optimal Solution In Model (a) and model (b)**

| $b_m$ | $w^a$ | $P_m^a$ | $P_r^a$ | $x^a$ | $D_m^a$ | $D_r^a$ | $\Pi_m^a$ | $\Pi_r^a$ | $\Pi_c^a$ |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 256.5 | 285.0 | 295.0 | 0.84 | 65 | 81 | 29796.3 | 669.8 | 30466.1 |
| 1 | 266.2 | 284.0 | 295.8 | 0.84 | 66 | 80 | 29751.0 | 680.9 | 30431.9 |
| 2 | 266.9 | 282.9 | 296.6 | 0.84 | 66 | 80 | 29707.5 | 692.2 | 30399.7 |
| 3 | 267.6 | 281.9 | 297.4 | 0.84 | 67 | 79 | 29655.8 | 703.5 | 30369.3 |
| 4 | 268.4 | 280.8 | 298.2 | 0.84 | 67 | 79 | 29625.8 | 715.0 | 30340.7 |
| 5 | 269.1 | 279.8 | 299.0 | 0.84 | 68 | 78 | 29587.6 | 726.5 | 30314.0 |
| 6 | 269.8 | 278.7 | 299.8 | 0.84 | 68 | 78 | 29551.1 | 738.1 | 30289.2 |
| 7 | 270.5 | 277.7 | 300.5 | 0.84 | 69 | 77 | 29516.4 | 749.7 | 30266.1 |
| 8 | 271.2 | 276.6 | 301.3 | 0.84 | 69 | 77 | 29483.5 | 761.5 | 30244.9 |
| $b$ | $w^b$ | $P_m^b$ | $P_r^b$ | $x^b$ | $D_m^b$ | $D_r^b$ | $\Pi_m^b$ | $\Pi_r^b$ | $\Pi_c^b$ |
| 0 | 265.5 | 285.0 | 295.0 | 0.84 | 65 | 81 | 29796.3 | 795.8 | 30566.0 |
| 1 | 264.8 | 286.1 | 294.2 | 0.84 | 65 | 81 | 29793.3 | 738.6 | 30532.0 |
| 2 | 264.1 | 287.1 | 293.4 | 0.84 | 64 | 82 | 29792.1 | 707.6 | 30499.7 |
| 3 | 263.4 | 287.1 | 293.4 | 0.84 | 64 | 82 | 29792.7 | 676.7 | 30469.3 |
| 4 | 262.7 | 289.2 | 291.9 | 0.84 | 63 | 83 | 29795.0 | 645.8 | 30440.8 |
| 5 | 262.0 | 290.3 | 291.1 | 0.84 | 63 | 83 | 29799.1 | 615.0 | 30414.1 |
| 6 | 261.2 | 291.3 | 290.3 | 0.84 | 62 | 84 | 29804.9 | 584.3 | 30389.2 |
| 7 | 260.5 | 292.4 | 289.5 | 0.84 | 62 | 84 | 29812.5 | 553.7 | 30366.2 |
| 8 | 259.8 | 293.4 | 288.7 | 0.84 | 61 | 85 | 29812.9 | 523.1 | 30345.0 |

Based on **Table 4,** it can be seen that the number of returned products increases, the profitability of the system decreases. Based on the 2nd assumption, in the centralization scenario the value of $w^a < P_m^a < P_r^a$ is obtained when the value of $b_m \leq 12$ and the value of $w_s^b < P_m^b < P_r^b$ is obtained when the value of b $\leq 5$. In the centralization scenario model (a) the maximum return of consumer products to the manufacturer is 7.35% and the return of consumer products to retailers is 6.41%, while in the model (b) the maximum return of consumer products to the manufacturer is 7.94% and the return of consumer products to retailers is 6.02%.

## 4. CONCLUSIONS

Based on the results of the discussion, a GDCSC model can be constructed using a centralized scenario that considers the return of goods and the remanufacturing process. The model was developed based on two structures, namely model (a) where remanufactured products are resold in offline media and model (b) where remanufactured products are resold in online media. The optimal solution for model (a) and model (b) is determined based on the principle of mutual agreement in the Nash Equilibrium. Based on numerical simulations using a maximum product return of 5, the optimal system profit is obtained in the centralized scenario model (a) of $30314.0 with a total demand of 146 units, then in the centralized scenario model (b) of $30414.1 with a total demand of 146 units. The analysis of changes in the increase in product return sensitivity resulted in smaller system profits. In the application of the model by conducting numerical simulations using certain parameter values, it is found that the system profit of model (b) is greater than model (a).

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