This study explores pricing and order interval decisions for competing manufacturers in a circular supply chain. With a growing focus on environmental sustainability in a business, two duopolistically competing manufacturers offer different products to their customers, involving both new and remanufactured products. This research investigates the impact of various products on market demand by considering selling prices and inventories. It highlights how the selling price in the demand function is influenced not only by its price but also by competitors' prices. Additionally, it emphasizes the pivotal role of the order interval in determining product inventory. This research performs a quantitative method in the operational research. Initially, it structures the demand and profit functions for each manufacturer. By developing a Nash equilibrium model on the game theory, this study determines the optimal decisions for pricing and ordering interval to maximize profit for each manufacturer. The numerical results confirmed that the optimal prices and profits for the manufacturer selling new products (p_1=67, π_1=1443.96) are higher than the manufacturer (p_2=65, π_2=1435.22). Meanwhile, the comprehensive sensitivity analysis demonstrates that increasing the selling price (p_i= 45~85) and order interval (T_i=5.2~6) will reduce the manufacturer's profit. On the other hand, increasing the competitors' selling price and order interval will strategically increase the manufacturer's profit. Furthermore, increasing the wholesale price (w_i=35~70) and holding cost (h_i=0~15) will decrease the order interval, increase the selling price, and ultimately reduce profit. The managerial insights summarize that it is imperative for a manufacturer to determine the optimal selling price and order interval to gain a competitive advantage when making pricing and ordering interval decisions

Keywords: circular economy, duopoly competition, Nash game, pricing strategy, remanufacturing, supply chain design

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OPTIMIZATION OF PRICING AND ORDERING DECISIONS UNDER DUOPOLY COMPETITION FOR NEW AND REMANUFACTURED PRODUCTS IN A CIRCULAR SUPPLY CHAIN

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1. Introduction

Most industrial businesses adopted the linear economic model at this time. A linear economy is one where consumers purchase goods, utilize them, and then discard them [1]. This system involves the extraction of raw materials from the environment, their conversion into products, and their final disposal as trash following consumption. This model relies heavily on the continuous consumption of finite natural resources and generates significant waste and pollution. As a result, various problems emerged, especially environmental issues. Therefore, both the government and manufacturer then begin to initiate the circular economy implementation.

A circular economy is an economic system designed to minimize waste and make the most of resources [1, 2]. It aims to redefine growth by focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Unlike the traditional linear economy, a circular economy is a model of resource production and consumption in any economy that involves sharing, leasing, reusing, repairing, remanufacturing, and recycling existing materials and products for as long as possible [3]. One form of circular economy is remanufacturing.

Remanufacturing is the process of restoring worn-out or used items, components, or materials to a "like-new" state while meeting or exceeding the performance and quality standards of newly manufactured products in a circular economy [4, 5]. To extend the product's useful life, it must be removed, cleaned, repaired, and reassembled, with any damaged components replaced. In real life, an internationally well-known company, Apple, has a trade-in program where old devices are refurbished and resold or disassembled for parts. Generally speaking, remanufacturing not only reduces costs and waste but also preserves energy and materials, making industries more sustainable [6]. Thus, remanufacturing plays a crucial role in achieving sustainability by keeping products in circulation and reducing environmental impact. However, when companies start to initiate the production of remanufactured products, they should realize that there is an established market for new products from the linear economy [2, 7–9]. Therefore, a study on exploring pricing and ordering decisions for competing manufacturers is relevant to the present development and implementation of remanufacturing in the circular supply chain.

2. Literature review and problem statement

Increasing environmental problems and sustainability awareness are encouraging various industries and governments to adopt the circular economy concept. In this context, the development of the remanufacturing industry as part of a circular economy model becomes very relevant and offers significant potential to reduce environmental problems [6, 10]. Several previous studies have discussed the contribution of the circular economy [10–13] and remanufacturing [6, 14] in overcoming environmental problems. The study [10] evaluated the contribution of remanufacturing to material circularity and the analysis indicated that remanufacturing could save resources and reduce the environmental impact. Work [11] also explained that supply chain management plays a vital role in the use of circular economy for value addition of waste products and achieving maximum profits. However, paper [12] critically reviewed the status quo of the circular economy and shows that circular economy strategies are still very underrepresented in research activities. Furthermore, the study [13] analyzed potential barriers to the circular economy implementation based on waste reduction and environmental perspective.

In the context of remanufacturing, paper [6] measured the impact of end-of-life product remanufacturing on environmental performance. By using the cumulative energy consumption method, the benefits to remanufactured products are measured to improve product design. Meanwhile, the study [14] evaluated the impact of remanufacturing and direct reuse to assess resource efficiency and promote circular economy. Other studies more comprehensively investigated the potential for remanufacturing adoption as a form of circular economy [15, 16]. Furthermore, there are also studies that examined government regulations on remanufacturing adoption [17].

Despite the studies above, consumers have an important role in the successful adoption of remanufacturing to run a circular economy [18–21]. On the one hand, the research [18] explained how companies can influence consumers' perceptions, thus contributing to the marketing of remanufactured products. Moreover, research [19] presented that companies can provide discounts and extend warranties to increase consumer utility towards remanufactured products. On the other hand, the paper [20] suggested that consumer knowledge and intention toward remanufactured products can help remanufacturers and closed-loop supply chain managers develop management policies and marketing strategies. The work [21] pointed out that increasing the proportion of consumers' willingness to pay for remanufactured products can affect retailers' sales strategies. To encourage the adoption of circular economy models, it is important to understand consumer preferences for remanufactured products [22]. The paper [23] demonstrated that effective pricing strategy is a key determinant influencing consumer purchasing decision there should be a critical analysis of each source. Meanwhile, the key to community decision making in supporting the adoption of new innovations, including remanufacturing, is through pricing and investment strategies [9]. Optimal pricing strategies are a crucial aspect in the successful adoption of the transportation remanufacturing industry. Prices must be adequate to cover production and investment costs while remaining competitive with the new product market [24, 25]. Therefore, an in-depth understanding of investment levels is necessary to find solutions to reduce financial obstacles that may be faced by stakeholders, including industry, government and investors [26, 27].

Current studies in this area focus on the adoption and contribution of remanufacturing in the circular economy without considering pricing strategy as a key consumer decision-making factor in supporting the adoption of new innovations. In addition, the issue of competition between manufactured and remanufactured products, as well as the combined effects of pricing and inventory strategies on the supply chain have not been explored. Therefore, exploring pricing strategies and ordering intervals under duopoly competition is necessary to fill this gap. All these allow to argue that the study of designing pricing and ordering decision strategies in remanufactured products is appropriate.

3. The aim and objectives of the study

The aim of this study is to construct a Nash equilibrium model on the game theory for determining optimal price and order interval in a circular supply chain under the duopoly competition. This will allow a manufacturer to practically gain a competitive advantage when making pricing and ordering decisions.

To accomplish the aim, the following objectives have been set:

– to develop the optimal decisions model for pricing and ordering interval to maximize profit for each manufacturer under duopoly competition;

– to determine the optimal decision yields for pricing and ordering interval in maximizing profit for each manufacturer under duopoly competition;

– to perform sensitivity analysis for investigating the impact of various products on market demand by considering selling prices and inventories.

4. Material and methods

This study attempts to examine the optimal pricing and ordering strategies for various products in a circular supply chain. To observe this hypothesis, this research performed a quantitative method with game theory in the operational research. It is possible to construct a supply chain including consumers and two competing manufacturers ($i=1, 2$) that sell different products, new and remanufactured. In real case, an internationally well-known company, Hewlett-Packard Development Company (HP), recycles used computers and printers and resells them after processing. It is possible to structure the demand Q and profit π functions for each manufacturer. By developing a Nash equilibrium model, it is possible to solve the game theory problem and generate the optimal decision for pricing p_i and order intervals t_i. Afterward, it is possible to conduct a numerical analysis to obtain the optimal decision properties and profits for each manufacturer. Let's also examine the effect of some key parameters on the manufacturer's optimal decision variables, such as the holding cost h_i, and wholesale price w_i. In this study, let's assume the manufacturer selling remanufactured products has lower costs than the manufacturer selling new products. Nevertheless, the demand for new products is higher than for remanufactured products.

The manufacturers will determine the order interval, T_i, and the selling price, p_i. Order interval indicates the time interval required for a manufacturer to order a product and affect the number of manufacturer's inventory as follow:

$$I_i\left(t\right)=\frac{\left(\alpha_i-\gamma_i p_i+\delta_i p_j\right)}{\beta_i}\left[e^{\beta_i\left(T_i^I-t\right)}-1\right],\text{ for }0\leq t\leq T_i^I. \quad (1)$$

Meanwhile, the selling price shows the price of the products they will sell to customers. The supplier offers the manufacturers a wholesale price of w_i dollars/unit, assumed $p_i>w_i$. Therefore, the selling price and inventory dependent demand function is:

$$q_i=\alpha_i+\beta_i I_i-\gamma_i p_i+\sigma_i p_i, \quad (2)$$

where I_i denotes the manufacturer inventory, p_i and p_j denotes the selling price by manufacturer i to consumers and its competitor j, respectively. Meanwhile, α_i is the primary demand, β_i is the coefficient of inventory, $0\leq\beta_i\leq 1$, γ_i is the price coefficient p_i, $0\leq\gamma_i\leq 1$, σ_i is the competitor price coefficient, $0\leq\sigma_i\leq 1$. From those settings, the profit of manufacturer is defined as follows:

$$\pi_i=p_i q_i-\left(h_i-w_i\right)I_i-c. \quad (3)$$

The primary purpose of this study is to maximize each manufacturer's profit π_i by considering different pricing and order interval decisions. Without loss of generality, it is possible to assume that the production cost is constant and normalized to zero [7], [9]. In addition, there is no asymmetric information for both manufacturers. To this end, it is possible to construct the model in the next section. Let's summarize all notations for this study as follows:

i, j – index for manufacturer types, 1 – manufacturer, 2 – remanufacturer;

q_i – customer demand;

I_i – manufacturer's inventory;

p_i – selling price;

T_i – order interval of manufacturer;

w_i – wholesale price;

h_i – holding cost;

c – ordering cost;

α_i – primary demand;

βi – inventory coefficient;

γ_i – sell price coefficient;

σ_i – competitor sell price coefficient;

π_i – profit of manufacturer.

5. Results and analysis for optimal decision-making model in a circular supply chain

5. 1. Developing optimal decisions model for pricing and ordering interval in a circular supply chain under duopoly competition

Regarding the structure of demand and profit functions in the previous section, let's develop the decision-making models to obtain optimal decisions. It is possible to substitute (1) and (2) to (3) and get the manufacturer profit functions as follows:

$$\pi_1=\begin{pmatrix}\left(h_1 T_1-2c+\left(w_1-p_1\right)\left(2+\beta_1 T_1\right)\right)\times\\ \times\left(\alpha_1-\gamma_1 p_1+\sigma_1 p_2\right)\end{pmatrix}T_1^{-1}, \quad (4)$$

$$\pi_2=\begin{pmatrix}\left(h_2 T_2-2c+\left(w_2-p_2\right)\left(2+\beta_2 T_2\right)\right)\times\\ \times\left(\alpha_2-\gamma_2 p_2+\sigma_2 p_1\right)\end{pmatrix}T_2^{-1}. \quad (5)$$

By take the first derivative of (4) and (5) to T_i, and solve it equals to 0, let's acquire the optimal order intervals T_i for both manufacturers as follows:

$$T_1^*=\left(\frac{2c}{\left(h_1+\beta_1\left(w_1-p_1\right)\right)\left(\alpha_1-\gamma_1 p_1+\sigma_1 p_2\right)}\right)^{\frac{1}{2}}, \quad (6)$$

$$T_2^*=\left(\frac{2c}{\left(h_2+\beta_2\left(w_2-p_2\right)\right)\left(\alpha_2-\gamma_2 p_2+\sigma_2 p_1\right)}\right)^{\frac{1}{2}}. \quad (7)$$

Meanwhile, by substitute (6) and (7) into (4) and (5), respectively, let's obtain the optimal price for both manufacturers through the partial differential as follows:

$$p_1^*=\frac{c\left(\gamma_1 h_1+\beta_1\left(\alpha_1+\gamma_1\left(w_1-p_1\right)+\sigma_1 p_2\right)\right)}{2\left(h_1+\beta_1\left(w_1-p_1\right)\left(\alpha_1-\gamma_1 p_1+\sigma_1 p_2\right)\right)^{\frac{1}{2}}}, \quad (8)$$

$$p_2^*=\frac{c\left(\gamma_2 h_2+\beta_2\left(\alpha_2+\gamma_2\left(w_2-p_2\right)+\sigma_2 p_1\right)\right)}{2\left(h_2+\beta_2\left(w_2-p_2\right)\left(\alpha_2-\gamma_2 p_2+\sigma_2 p_1\right)\right)^{\frac{1}{2}}}. \quad (9)$$

Lastly, let's substitute (6)–(9) to (4) and (5) to get the optimal profit π_i for both manufacturers and analyze the effect of the decision variables to the profit.

In subsequence, numerical and sensitivity analysis is conducted to validate the previously developed model and demonstrate the impact of key parameters on optimal decisions. A real case is analyzed as a benchmark for model development. A manufacturer engaged in the transportation sector initiated to produce its products through a remanufacturing process. All this time, transportation products produced as new products are better known and trusted than remanufactured products. However, due to the increasing demand for sustainability awareness, a manufacturer has difficulty in determining the optimal strategy for pricing and ordering remanufactured and new products under competition.

5. 2. Determining optimal decisions yields using numerical analysis for a circular supply chain under duopoly competition

Let's conduct the analysis using numerical calculations to verify the prior model constructed. Regarding the previous studies, it is possible to set the value for some relevant parameters to keep the analysis effectively, as follows: $w_1=40$, $w_2=30$, $h_1=9$, $h_2=7.5$, $\alpha_1=55$, $\alpha_2=50$, $\beta_1=0.3$, $\beta_2=0.2$, $\gamma_1=0.7$, $\gamma_2=0.5$, $\sigma_1=0.4$, and $\sigma_2=0.6$. By applying the parameter settings given in (6)–(9), let's obtain the optimal decisions yields for order intervals and prices for both manufactures. In subsequence, let's also acquire the optimal profits π_i as summarized in Table 1.

Based on the numerical results, this study confirmed that the price p_i for the manufacturer selling new products is higher than the manufacturer selling remanufactured products. Conversely, the optimal order interval T_i of the remanufactured product is longer than the other. As a result, the optimal profits π_i gained by the manufacturer become higher than the remanufacturer. These situations occur since the wholesale price w_i and holding cost h_i for the new product are assumed to be higher than for remanufactured products. Thus, the optimal order interval T_i for the remanufactured product is longer. Furthermore, the coefficient of customer demand α_i for new products is also set higher, so the manufacturer has higher returns.

Table 1

Optimal decision yields for duopoly competition in a circular supply chain

Type of industry	T_i	p_i	π_i
Manufacturer	4.9	67	1443.96
Remanufacturer	5.2	65	1435.22

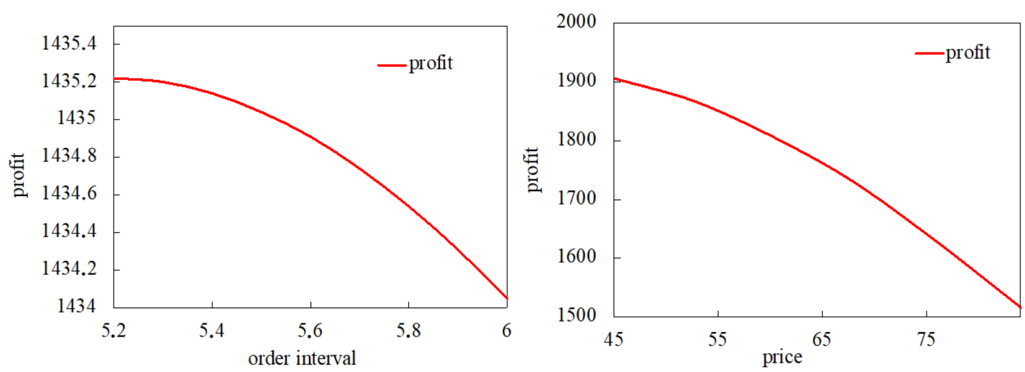
5. 3. Performing sensitivity analysis to investigate the impact of parameters in a circular supply chain under duopoly competition

To support the previous analysis, let's perform the sensitivity analysis in this section. This analysis demonstrates the impact of changes in both decision variables, order interval T_i and price p_i, on profits π_i. Afterward, it is possible to explore the effect of duopoly competition through changes in decision variables on the manufacturers' profit π_i. Let's also append detailed analysis for changes in other variables considered in the ordering decision, consisting of wholesale price w_i and holding cost h_i.

At first, it is possible to analyze changes from the decision variables, both the interval order and price, for the profit. By setting changes in the order interval T_i from 5.2 to 6 in units of time, Fig. 1, *a* shows that an increase in the order interval causes a decrease in the profit. Likewise, an increase in the price, p_i=45~85, induces a decrease in the profit as illustrated in Fig. 1, *b*. Meanwhile, Fig. 2 demonstrates that the increase in the order interval and price from the competitor strategically increases the manufacturer's profit. This situation intuitively occurs because after all the customer will select the product that provide shorter order time and cheaper price. Thus, the amount of customer demand will increase and also the profit. The manufacturer ultimately should determine the optimal order interval and price in order to maximize its profit.

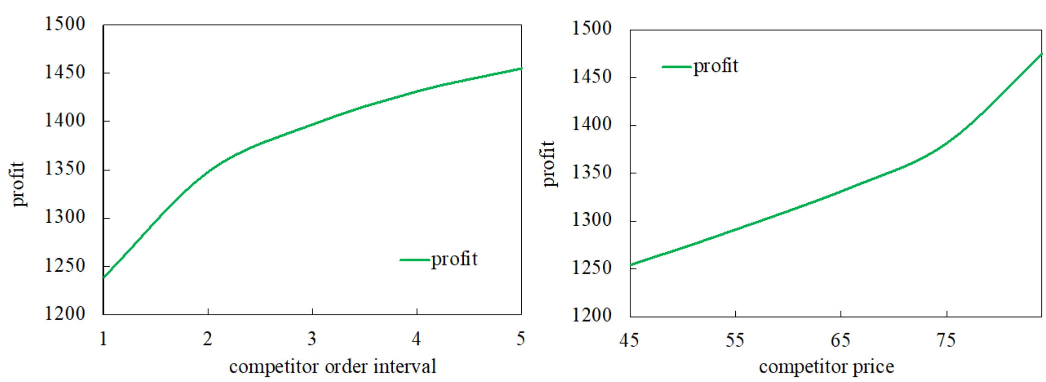
In this study, the supply chain constructed not only involves two competing manufacturers and consumers, but also involves a supplier. The further sensitivity analysis investigates the impact of changes in key variables on the manufacturer's decision to supply its products from the supplier, i.e. wholesale price w_i and holding costs h_i. It is possible to explore the impact of both variables to the order interval T_i, price p_i, and profit π_i. In Fig. 3–5, increasing the wholesale price and holding cost will decrease the order interval, increase the selling price, and ultimately reduce profit.

The changes in wholesale price, w_1=35~70, and holding cost, h_1>7.5, indicate a negative relationship between the two variables and the order interval (Fig. 3). When the wholesale price and holding cost are higher, the order interval is lower. This is because these two variables will cause the manufacturer to consider the order interval because of the costs they have to incur. If the manufacturer cannot efficiently capture the market demand, the order interval will decrease to avoid losses and deplete the remaining inventory first.



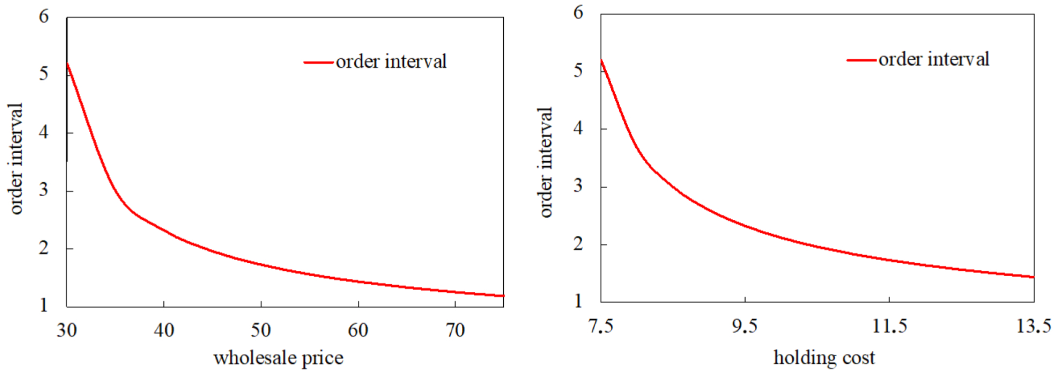
a *b*

Fig. 1. The effect of the order interval and price on the profit: *a* – the order interval; *b* – the price



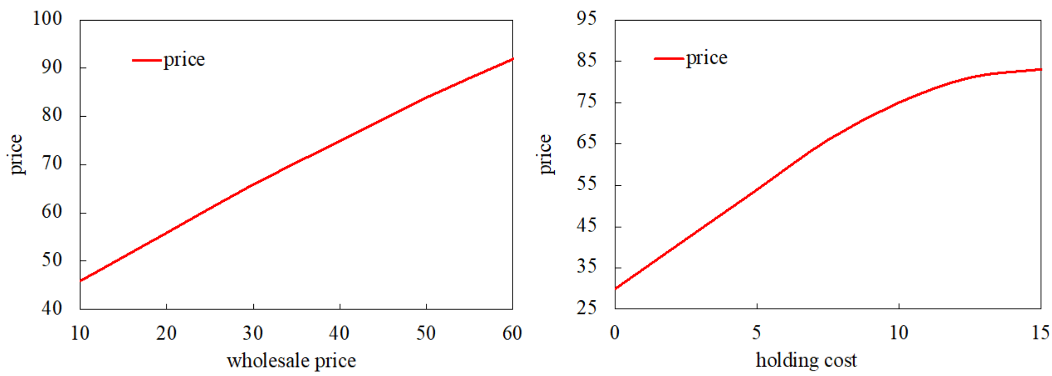
a *b*

Fig. 2. The effect of the competitor's order interval and price on the profit: *a* – the order interval; *b* – the price



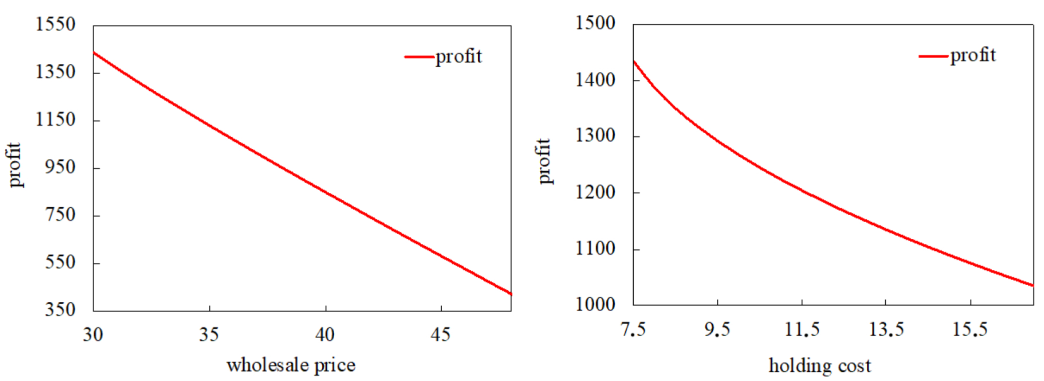
a *b*

Fig. 3. The effect of the wholesale price and holding cost on the order interval: *a* — the wholesale price; *b* — the holding cost



a *b*

Fig. 4. The effect of the wholesale price and holding cost on the selling price: *a* — the wholesale price; *b* — the holding cost



a *b*

Fig. 5. The effect of the wholesale price and holding cost on the profit: *a* — the wholesale price; *b* — the holding cost

In contrast, when to set the wholesale price change from 10 to 60, Fig. 4, *a* shows a positive relationship between wholesale price and selling price. It means that the increase in wholesale price will increase the selling price. Similarly, the change in holding cost from 0 to 15 also results in an increase in selling price as shown in Fig. 4, *b*. Nevertheless, the manufacturer will avoid losses. It will cover the costs incurred due to the higher wholesale price and holding cost by selling the product at a higher selling price.

As a result, the increase in the wholesale price and holding cost leads to the lower profit because the manufacturer has to bear higher costs as shown in Fig. 5. In light of the analysis above, the managerial insight generated from these results is that, on the one hand, the manufacturer should be careful in determining decisions for optimal ordering intervals and prices. With low wholesale prices and holding costs, it can reduce the manufacturer's costs. On the other hand, decisions taken by the competitor will also affect the manufacturer's optimal decisions. Thus, managers and decision-makers should consider competition when developing a pricing strategy, which further enhances their competitive position in the market.

6. Discussion of optimal decision-making results with pricing and ordering decisions for new and remanufactured products in a circular supply chain under duopoly competition

With a growing focus on environmental sustainability in business, let's examine duopoly competition between the manufacturer and remanufacturer. Similar to research [8, 9], the customer demand is influenced not only by its own decisions, but also by competitors' decisions. This paper determines pricing and order interval decisions for competing manufacturers in a circular supply chain. By developing a Nash equilibrium model, it is possible to solve the game theory problem and generated the optimal decision for the pricing and order interval to maximize the profit as demonstrated in (6)–(9). Hence, the first aim of this study has been achieved, (6) and (7) present the optimal formula for order interval T_i^*, while (8) and (9) present the optimal formula for price p_i^*. Afterwards, let's investigate the impact of various products on market demand by considering selling prices and inventories using numerical and sensitivity analyses.

Table 1 illustrates the numerical analysis to verify the developed optimal decision model. The results confirm that the price p_i for manufacturers selling new products is higher than that for manufacturers selling remanufactured products, $p_1=67>p_2=65$. On the other hand, the optimal ordering interval T_i for remanufactured products is longer than that for manufactured products, $T_2=5.2<T_1=4.9$. As a result, the optimal profit π_i obtained by manufacturing is higher than that of remanufacturing, $\pi_1=1443.96>\pi_2=1435.22$. These situations occur because the wholesale price w_i and the holding cost h_i for new products are assumed to be higher than those for remanufactured products. Thus, the optimal ordering interval T_i for remanufactured products is longer. Furthermore, the customer demand coefficient α_1 for new products is also set higher, so that manufacturing has a higher return.

The sensitivity analysis for the change of the optimal decision of the competitor is further demonstrated in Fig. 1, 2. Both figures show the impact of the change of the optimal order interval and price on the profit. On the one hand, Fig. 1, *a* shows that the increase in the order interval of remanufacturer, $T_i=5.2$~6, causes a decrease in the profit. Correspondingly, an increase in price of remanufacturer, $p_i=45$~85, leads to a decrease in profits as illustrated in Fig. 1, *b*. On the other hand, Fig. 2 indicates that the increase in the order interval and price from the competitor strategically increases the manufacturer's profit. Fig. 1, *a* illustrates that the increase in the order interval, $T_i=1$~5, results in an increase in the profit. In addition, an increase in price, $p_i=45$~85, also causes an increase in profits as illustrated in Fig. 1, *b*. This situation occurs because in the end customers will buy products that provide shorter ordering times and lower prices. According to the prior numerical analysis, a manufacturer can provide shorter order intervals. With a strategy of lowering prices, the number of customer demands and the profits of a manufacturer will also increase. Therefore, a remanufacturer should ultimately determine the optimal order interval and price to maximize its profits and compete with a manufacturer.

Furthermore, sensitivity analysis investigates the impact of changes in the main variables on a manufacturer's decision to source its products from suppliers, wholesale price w_i and holding cost h_i, on the order interval T_i, price p_i, and profit π_i. First, Fig. 3 shows that an increase in the wholesale price, $w_i=35$~70, and holding cost, $h_i>7.5$, leads to a decrease in the order interval. Intuitively, an increase in these two variables causes a manufacturer to consider the order interval because of the costs they have to incur. In order to avoid losses and to deplete the remaining inventory first, a manufacturer reduces the order interval. Thus, a manufacturer can meet market demand efficiently. Second, Fig. 4 depicts an increase in the wholesale price, $w_i=10$~60, and holding cost, $h_i=0$~15, leads to an increase in the selling price. A manufacturer requires to avoid losses and cover the costs incurred due to the higher wholesale price and holding cost, so a manufacturer sells the product at a higher selling price. Third, Fig. 5 illustrates that an increase in the wholesale price w_i and holding cost h_i results in lower profits because the manufacturer has to bear the higher costs. This analysis supports the research questions regarding the impact of various key variables that consider selling price and inventory on the manufacturer decisions.

In light of the analysis above, this study addresses the gaps in existing studies. Therefore, several managerial insights are generated for decision-makers or managers in a real system. Unlike [18, 20], where consumer perception and intention are the main considerations for companies in marketing remanufactured products, this result indicates that determining the optimal pricing and ordering interval decisions allows firms to improve the marketing of remanufactured products. This is made possible by wholesale prices and low storage costs, which can reduce manufacturer costs. Moreover, this paper emphasizes competitors' decisions which will also affect the firm's optimal decisions. Thus, managers and decision-makers should consider competition when developing a pricing strategy, which further enhances their competitive position in the market. Furthermore, our study also has some theoretical and practical implications. For theoretical implications, it contributes to operation research, decision analysis, and supply chain management literature. Meanwhile, for the practical implications, it is imperative for a manufacturer to determine the optimal selling price and order interval to gain a competitive advantage when making pricing and order decisions.

However, there are several limitations of this study. First, this study only examined the optimal pricing and order queue decision under duopoly competition. Thus, investigating other factors and integrating this study with other theories, such as behavioral economics, is worth exploring the more complex decisions in supply chains. Second, the investigated supply chain members were limited and assumed to have perfect information. Future studies could expand the analysis to include more complex supply chain structures with more than only two firms and consider the impact of imperfect information. Third, this research discussed products sold in one period and limitations in empirical data availability can make understanding the effect of pricing and order interval decisions on supply chain performance challenging. Hence, applying more than one period and utilizing empirical data can validate and obtain a more comprehensive understanding of these findings. Involving those concerns will be an interesting direction to develop this research.

7. Conclusions

1. This study examined duopoly competition between the manufacturer and remanufacturer in a circular supply chain. The customer demand is influenced not only by its own decisions, but also by competitors' decisions. By developing a Nash equilibrium model, the game theory problem solved and generated the optimal decision for the pricing and order interval to maximize the profit. It began by formulating a profit function that considered selling prices and order intervals. Afterward, optimal order intervals were obtained by first differentiating the profit function to the order interval variable and solving it equals to 0. Meanwhile, optimal prices were obtained by substituting the optimal order interval into the profit function. Finally, the optimal profit for either

a manufacturer or a remanufacturer was obtained by substituting all optimal decision variables into the profit function.

2. The numerical analysis results indicated that the optimal price for the manufacturer product is higher than the remanufactured product, $p_1=67>p_2=65$. However, the optimal order interval of the remanufactured product is longer than the other, $T_2=5.2<T_1=4.9$. Therefore, the optimal profits gained by the manufacturer become higher than the remanufacturer, $\pi_1=1443.96>\pi_2=1435.22$. This analysis demonstrates the real case situation that the wholesale price w_i and the holding cost h_i for new products are higher than those for remanufactured products. Hence, the optimal ordering interval T_i for remanufactured products is longer and the manufacturer earns higher profits.

3. The sensitivity analysis explored the impact of both variables to the order interval, price, and profit. The results indicated that an increase in price, $p_i=45$~85, and order interval, $T_i=5.2$~6, cause a decrease in the profit. Afterward, this analysis showed the effect of duopoly competition through changes in decision variables on the manufacturers' profit. The results demonstrated that the increase in the order interval, $T_i=1$~5, and price, $p_i=45$~85, from the competitor strategically increases the manufacturer's profit. Furthermore, this study investigates the impact of changes in key variables on the manufacturer's decision to supply its products from the supplier as its inventory, i.e. wholesale price and holding costs. Increasing the wholesale price, $w_i=35$~70, and holding cost, $h_i=0$~15, will decrease the order interval, increase the selling price, and ultimately reduce profit. Therefore, this study confirms that these factors contribute to the circular supply chain development.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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