Game Theory Application for Circular Economy Model in Furniture Industry

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Abstract. This research proposes a business model for the furniture industry to address the circular economy concept. The circular economy aims to keep resources in use for as long as possible and recover product and material at the end of the life cycle. Game theory is used in this research. The conceptual model proposes rent option, so the end-user is possible to use the furniture in the desired time. Using the rent option to the product could be taken back from the end-user and could be sold or rent it again to another user. The concept of game theory is to formulate and suspect the situations of interaction between players involved, and also decisions taken. Therefore, game theory is used to determine an optimal strategy among players. Player strategies are taken when it has reached the Nash Equilibrium. The proposed model consists of 4 parties, such as the furniture industry, remanufacturer, distributor, and end-user. The payoff is determined for every player to observe each player’s profit in addressing CE. Based on the result, there is one strategy that reached the Nash equilibrium. We also picked out 3 of 162 possible plan that gives the best advantages for all players. Each strategy contains players’ prices decision, and for the end-user decision is the length of rent.

1. Introduction

The furniture industry is an industry that processes raw materials or semi-finished materials from wood, rattan, and other natural raw materials into finished products. The furniture industry is one of the industries that make essential contributions to the economic development in Indonesia. According to the Ministry of Industry of the Republic of Indonesia, in 2018, the Indonesian furniture industry is experiencing revival and has the potential to continue to grow and develop. In 2018, the furniture industry recorded an export value of up to USD 1.4 billion. Therefore, the government is confident to make the furniture industry one of the mainstays in developing the Indonesian economy. The furniture industry will process raw materials into finished and semi-finished products. Wood processing activities consist of product design, sawmill, wood drying, component manufacturing according to specified specifications, component processing, the component assembly according to design, finishing process, and packaging. Indonesian furniture products will be exported to several countries and also become domestic consumption. In general, the furniture production process consists of supplying raw materials, processing raw materials, marketing products, the product being used by consumers, and dispose of at the end of its life cycle (extract - produce - use - disposal). The furniture industry is very dependent on forest products to get its raw materials.
One issue that is currently being discussed in many industries is the global environmental problem. The current industrial production process is still carried out traditionally or called a linear economy. The linear economy has a production flow starting from the extraction stage or extraction of raw materials from nature (extract), the production stage (produce), the step of product use by the user (use), and finally the disposal stage or the final stage of the product (disposal). A linear economy that is carried out continuously will have a terrible impact on the environment [1]. The effect that will occur is that one day the natural resources in the world will eventually run out due to continuous current extraction. Therefore, to overcome these problems, one way that can be done is to change the production flow to the opposite of the linear economy, namely the circular economy (CE). CE has been implemented by developing some technologies like green production by optimizing the production process [2], [3], green supply chain management by minimizing the waste and emission [4], sustainable manufacturing [5], production, scheduling, and distribution optimization [6], [7], part recondition development [8], etc. Unlike the linear economy, the business model in CE, the process of resource circulation, is not only completed by one stakeholder/company [9]. In other words, the situation at CE is established between the stakeholders involved. One of the CE principles is the efficient use of resources. However, this does not mean that CE will be more economical than a linear process. For that reason, game theory is one approach that can precisely and mathematically treat this interdependent situation. Game theory can provide a mathematical background for modelling systems and producing solutions in competitive or conflict situations [10].

In Indonesia, there is no policy regarding waste management measures from the furniture industry. So it will adversely affect the environment, social and economy of the company itself. The number of resources used as the primary raw material for the furniture industry will eventually be used up due to continuous extraction. Therefore, it is recommended for the Indonesian furniture industry to start shifting towards the circular business model. Based on the explained conditions, this research was conducted to create a business model for the furniture industry that addressed the concept of the circular economy in the furniture industry. Game theory approach is used in the making of the business model. The game theory approach can provide a mathematical picture to model circular systems in the furniture industry and produce solutions in competitive or conflict situations. This approach will show the extent to which each player involved will benefit from the symbiosis that occurs between players. The model created can later become a guide for the furniture industry in Indonesia to start implementing a circular economy.

2. Material and method
2.1 Circular economy

According to Ellen MacArthur Foundation [6] states that a circular economy is an industrial system that is restorative or regenerative. The circular economy changes the concept of 'end-of-life' with the concept of recovery, which aims to eliminate waste. The essence of the circular economy is eliminating waste. Products designed for later can be done. The circular economy has the aim to use resources taken as long as possible, reuse, reassembly, or remanufacture [11]. A comparison between models in a linear economy with a circular economy. In a linear economy, production activities move in a linear flow consisting of "take-make-distribute-consume-dispose". Where, in the circular economy model, production activities include "take-make-distribute-consume-return". When the product has reached the final stage, the product will not be disposed of but will be returned to the first stage.

2.2 Game theory

The game or game in game theory is defined as several players who interact according to agreed rules. The rules referred to the in-game method are a strategy. The concept of game theory is to formulate, compile, analyze, and finally understand various strategic scenarios. In general, game theory investigates conflict situations, interactions between players, and decisions made by each player.

The elements of the game theory include, first, payoff, a utility obtained by the player. The player's utility can be in the form of money (profits) and implied feelings from the results of the game, such as
embarrassment or self-esteem for the game. In economics, the concept of utility shows the level of satisfaction of economic agents for the consumption of goods or services. Utilities are preferences or value for decision-makers by considering risk factors in the form of numbers that represent the actual pay-off value based on the decision chosen. The second pay off matrix, a table in the form of a rectangle with its elements which is the amount of payoff following the strategy used by both parties. The general form of the matrix for two-person zero-sum games:

2.3 Nash equilibrium

Nash equilibrium was introduced by John Nash in 1950 and became fundamental in game theory. This concept arises because of the uncertainty in a strategic situation. Nash equilibrium is a solution concept of a game that involves two or more players, where each player is assumed to know the balance strategies of other players, and no player can benefit by changing only his strategy [12]. It can be concluded that Nash equilibrium is a set of strategy owned by each player, which is the best response for both. Nash equilibrium theory was used as solution approach to many problems, for example, in competitive insurance problem [13], [14], tax and public investment competition [15], data envelopment analysis [16], tariffs in a multi-country trade problem [17], air pollutant removing problem [18], Energy and Reserve Market [19] and lottery Blotto game [20].

In this study, the Nash equilibrium calculation uses the method created in [21]. Nash's calculations are modelled in a non-cooperative finite game. The method created tries to find the best balance in the sense that all players have optimized their strategies without adjusting the decisions of other players in the game.

3. Circular economy business model

The circular economy can be seen in figure 1. Products in this flow are furniture. To produce furniture, the furniture industry could buy new parts from suppliers or remanufacturing parts from remanufacturer. The furniture produced by industry will be sold to the distributor. In this model, the furniture industry determines decisions in the form of the product selling price. Distributor will offer products that it purchased from the industry to end-users. The decision that will be determined by the distributor is the rental price of the product. In this circular model, the end-user choice is only to rent the product. Therefore, using the rent option circular economy will be addressed. End users will determine the rental period at a cost determined by the distributor. After the specified period, the product will be collected again by the distributor who will then be taken by remanufacturer to be repaired or reprocessed. The role of remanufacturer to improve the products that have been rented to process damaged products into parts that are needed by the industry in making other products.

![Figure 1. The CE model used in this study](image-url)
In this model, each player has a simple decision variable to simplify the calculation. Each player has one decision. The furniture industry will decide the product price, remanufacturer will decide the remanufactured part price, the distributor will decide the rental price, and end-user will determine the rental period. To define profit, each player has a different payoff function. The payoff formulation for each player is based on [9] with changes that adjust conditions in the existing furniture industry. The following subsections will define the payoff function of each player.

3.1. Furniture industry

The payoff of this player is determined by income and expenditure for company production. Revenues are obtained from the sale of products to distributors, while expenses include the purchase of new and remanufactured parts as well as production costs. Player’s payoff function is as follows:

\[ \pi_p = (p \times Q_s) - (p_n \times S_n) - (p_r \times S_r) - (c_p \times Q_s) \]  

(1)

Where \( \pi_p \) is industry’s payoff, \( p \) is the price of the product and \( Q_s \) is the number of products sold to the distributor, \( p_n \) and \( p_r \) shows the selling price of a new part and remanufactured part, \( S_n \) and \( S_r \) indicates the number of new parts and remanufactured parts purchased, \( c_p \) shows the production cost.

3.2. Remanufacturer

Remanufacturer’s payoff is determined by the revenue obtained from the sale of remanufactured parts to the furniture industry, while player’s expenses consist of the cost of purchasing used furniture from the distributor and the cost of remanufacturing product. Player’s payoff function is as follows:

\[ \pi_r = (p_r \times S_r) - (v_r \times Q_r) - (c_r \times S_r) \]  

(2)

Where \( \pi_r \) is remanufacturer’s payoff, \( p_r \) shows the selling price of remanufactured parts, \( S_r \) indicates the number of remanufactured parts, \( v_r \) is the cost of purchasing old furniture from the distributor. \( Q_r \) shows the number of old furniture purchased from a distributor, \( c_r \) shows remanufacturing cost.

3.3. Distributor

The payoff of this player is determined by the income derived from the results of product leases to end-user and sales of used furniture to remanufacturing, while distributor expenditures are the cost of purchasing products to the furniture industry. Player’s payoff function is as follows:

\[ \pi_s = (p_s + c_s) \times T \times Q_s + (v_r \times Q_r) - (p \times Q_s) \]  

(3)

where \( \pi_s \) is distributor’s payoff, \( p \) is price of the product while \( p_s \) is product rental price to end user, \( T \) shows desired rental period (month), and \( Q_s \) shows number of products sold, \( v_r \) is the cost of purchasing old furniture from the distributor, and \( Q_r \) shows the number of old furniture purchased from the distributor, \( c_s \) is maintenance cost while products being rent and it is paid out by end user.

3.4. End user

End user payoff is determined by the size of the WTP and the price of the product to be purchased. Willingness-to-pay (WTP) is the highest willingness paid by end-users in renting products. This study will simulate the value of \( w \) (willingness-to-pay), which aims to see whether the rental conditions on the CE model are fulfilled and find out the benefits of the end-user. Player’s payoff function is as follows:

\[ \pi_e(w, T) = (w - p_s)T \]  

(4)
where $\pi_e$ is end user’s payoff, $w$ is end user willingness to pay to rent the product, $p_s$ shows product rental price and $T$ shows the desired rental period (month).

4. Result and discussion

4.1 Parameters and decision variables

In this research, all players have their parameters and decision variables. The parameters used to consist of several values adjusted to the conditions in the circular model that are made. The parameters used can be seen in Table 1. Meanwhile, the decision variables are a strategy that will be determined by each player. The decision variables of each player can be seen in Table 2.

Table 1. Parameters used in the study

| Player             | Parameter                        | Value           |
|--------------------|----------------------------------|-----------------|
| Furniture Industry | New parts, $S_n$                 | 10 unit         |
|                    | Remanufactured parts, $S_r$     | 10 unit         |
|                    | Purchased product from industry, $Q_s$ | 10 unit     |
| Remanufacturer     | New parts price, $p_n$          | IDR 300,000/unit |
|                    | Production cost, $c_p$          | IDR 700,000/unit |
| Distributor        | Collecting product price, $v_r$ | IDR 80,000/unit |
|                    | Remanufacturing cost, $c_r$     | IDR 100,000/unit |
|                    | Purchased product by remanufacturer, $Q_r$ | 10 unit |
|                    | Maintenance cost, $c_s$         | IDR 70,000/unit/month |

Table 2. Decision variables used in this study

| Player        | Decision Variables | Value       |
|---------------|--------------------|-------------|
| Furniture Industry | Product price ($p$) | IDR 1,300,000/unit |
|                |                    | IDR 1,400,000/unit |
|                |                    | IDR 1,500,000/unit |
|                |                    | IDR 250,000/unit |
| Remanufacturer | Remanufactured part price ($p_r$) | IDR 300,000/unit |
|                |                    | IDR 60,000/month |
| Distributor    | Rent cost ($p_s$)  | IDR 80,000/month |
|                |                    | IDR 100,000/month |
| End User       | Rent period, $T$   | 6 months,   |
|                |                    | 9 months,   |
|                |                    | or 12 months |

4.2 Discussion

This research models a non-cooperative game consisting of 4 players, namely the furniture industry, remanufacturer, distributor, and end-user. The result of this research is a strategy determined by each player at the Nash equilibrium point. There is one strategy that reaches Nash's balance point. Besides, the calculation results also obtained 162 combination strategies, but only three strategies were selected as alternative strategies.

Calculations are performed using MATLAB® software using the Nash point calculation method created by Chatterjee [21]. The output generated from the MATLAB® software is a probability matrix. The probability matrix is a matrix of the result in the search for the Nash equilibrium point.
The result is a 9 x 4 matrix. Which mean this matrix consists of 9 rows that indicate the probability value for each strategy. The result is shown in table 3.

| Furniture Industry | Remanufacturer | Distributor | End-User |
|--------------------|----------------|-------------|----------|
| 0,0000             | 0,0000         | 0,0000      | 0,0040   |
| 0,0000             | 1,0000         | 0,0000      | 0,0000   |
| 1,0000             | 0,0000         | 1,0000      | 0,0000   |
| 0                  | 0              | 0           | 0,4293   |
| 0                  | 0              | 0           | 0,0022   |
| 0                  | 0              | 0           | 0,0000   |
| 0                  | 0              | 0           | 0,5644   |
| 0                  | 0              | 0           | 0,0000   |

Matrix in table 3 shows the probability value of all strategies of each player when reaching the Nash point. The probability value does not indicate the strategy taken by the player. Therefore, probability values are converted into units of price. We used the following formula to turn probability into price:

\[ Value = \sum (\text{probability} \times \text{player’s strategy}) \]  

(5)

For example, based on the matrix, the furniture industry has a probability value for strategy 1 is 0.0000; strategy 2 is 0.0000; and strategy 3 is 1.0000. Therefore, calculations to determine the player’s strategy is 

\[ Value = (0.0000 \times 1,300,000) + (0.0000 \times 1,400,000) + (1.0000 \times 1,500,000) = 1,500,000 \]

| Table 4. Nash equilibrium |
|---------------------------|
| \( \bar{p} \) | \( p_r \) | \( p_s \) | \( W \) | \( T \) (month) |
| 1,500,000 | 300,000 | 100,000 | 100,000 | 10,668 |

| Table 5. Alternative strategies |
|---------------------------------|
| No. Strategy | \( \bar{p} \) | \( p_r \) | \( p_s \) | \( w \) | \( T \) |
| 1 | 1300000 | 250000 | 80000 | 100000 | 12 |
| 2 | 1400000 | 250000 | 80000 | 100000 | 12 |
| 3 | 1400000 | 300000 | 80000 | 100000 | 12 |

| Table 6. Player’s profit |
|--------------------------|
| No. Strategy | Furniture Industry | Remanufacturer | Distributor | End User |
| 1 | 500000 | 700000 | 1800000 | 2400000 |
| 2 | 1500000 | 700000 | 800000 | 2400000 |
| 3 | 1000000 | 1200000 | 800000 | 2400000 |

Thus, it was found that in Nash point the furniture industry set a product price of 1,500,000. From the results of the matrix conversion, each player’s strategy is obtained at the Nash equilibrium are as
shown in table 4. Furthermore, based on calculations on the software, the payoff result with this strategy, the profit gained by the furniture industry player is 2,000,000, remanufacturer is 1,200,000, distributor is 221,800, and end user is 0.

There are 3 strategies chosen as alternative strategies. The strategy chosen is a strategy where every player gets a positive profit. Out of 162 combinations, only 3 strategy combinations will benefit all players. Table 5 shows the 3 alternative strategies obtained from the calculation of a combination of strategies. By using the 3 alternative combinations of strategies above, the profit each player gets with each strategy is shown in table 6.

5. Conclusions

The business model is created by applying the concept of a circular economy consisting of 4 players, namely the furniture industry, remanufacturing, distributors, and end users. In this study, furniture industry acts as a main player. Remanufacturing and distributors are modelled as a subsidiary of the furniture industry that acts as a supporter of the furniture industry’s business activities. We made a rent option for end user to use the product so that the desired circular model can be achieved. The overall research can be summarised as follows:

Based on the results, we obtained 1 strategy that meets Nash’s balance point and 3 selected strategy combinations from 162 resulting strategy combinations. Each strategy consists of the decisions of the furniture industry, remanufacturing, distributors in setting prices and end users in determining the duration of the lease. From the 4 strategies obtained, the optimal strategy in this game condition is chosen from a combination of strategies where the furniture industry uses strategy 2, remanufacturing uses strategy 2, Distributor uses strategy 2, and end-users use strategy 3. However, this research has some limitations. Each player chooses the strategy only based on one decision variable that is price. Decision variables have only a small range of values to simplify calculations. Parameters of sales quantity, number of new and remanufactured parts purchases, and costs related to production and operational activities of each player are assumed to be fixed values.

For further research, we may have to do some developments such as considering other factors such as product quantity, production costs, operational costs, and others to determine each player strategy. It is better if the range of values can be enlarged to improve the calculations and possibilities in the strategies obtained. Quantity of sales and purchases can be used as a decision variable so that it can be considered a game in determining the decision. Nonetheless, we will continue developing our work further by improving our model and variables and parameters used for improving our calculations.

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