BAREKENG: Journal of Mathematics and Its Applications
June 2023 Volume 17 Issue 2 Page 1139-1148
P-ISSN: 1978-7227 E-ISSN: 2615-3017
https://doi.org/10.30598/barekengvol17iss2pp1139-1148

MATHEMATICAL MODEL OF RICE COMMODITY SUPPLY CHAIN IN INDONESIA

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ABSTRACT

Article History:

Received: 28th February 2023
Revised: 12th May 2023
Accepted: 17th May 2023

Keywords:

Rice;
Supply chain;
Maximum profit;
Proportion of demand

Food is the main need for every individual that must always be fulfilled. For Indonesia, food is identified with rice because this type of food is a commodity consumed by the Indonesian population. Therefore, the rice crisis can interrupt economic resilience and national stability. National rice consumption from year to year will continue to increase in line with Indonesia's population. Although Indonesia is the third-largest country in the world in producing the most, Indonesia still depends on rice imports. This was done by the government to maintain the national rice supply. The rice supply chain in Indonesia has not been optimum, as indicated by the relatively small profits of producers. In this research, we construct the maximum profit model of direct and indirect media sales of rice for producers, distributors, and retailers. And then, we determine the optimum solution of the model and analysis of the factors in the rice supply chain that affect it. The results showed that changes in the proportion of demand greatly affect the resulting optimal profit.

How to cite this article:

D. A. Usdianto and R. Setiyowati ., "MATHEMATICAL MODEL OF RICE COMMODITY SUPPLY CHAIN IN INDONESIA," *BAREKENG: J. Math. & App.*, vol. 17, iss. 2, pp. 1139-1148, June, 2023.

Journal homepage: *https://ojs3.unpatti.ac.id/index.php/barekeng/*
Journal e-mail: *barekeng.math@yahoo.com; barekeng.journal@mail.unpatti.ac.id*

Research Article • Open Access

1. INTRODUCTION

Food is a major need for every individual, which must always be met. Food availability has always been the government's concern in meeting food security. As for Indonesia, food is identified with rice because this particular type of food is a commodity consumed by the majority of Indonesia's population. As such, the rice supply crisis could endanger economic stability and national stability.

National rice consumption from year to year will continue to increase in line with the increase in Indonesia's population. Although Indonesia is the third largest country in the world in producing the most rice, Indonesia itself still depends on rice imports. This is done by the government to sustain national rice stock supplies. Mahbubi's research [1] describes the importance of assessing a sustainable rice supply chain system in efforts to ensure national food security. A supply chain consists of all parties involved directly or indirectly in fulfilling customer demand. The supply chain includes not only manufacturers and suppliers but also transporters, warehouses, retailers, and even the customers themselves. The supply chain includes all functions involved in receiving and filling customer requests [2].

These problems can be studied from a mathematical point of view for expected decision-making. According to Winston [3] a scientific approach to decision-making usually involves the use of one or more mathematical models. A mathematical model is a mathematical method of representation of an actual situation that can be used to produce better decisions or simply to understand the truth. The conceptual model of the decision-making process implies that the final decision is made through three main models, namely the model structure, the impact model, and the evaluation model [4]. Bala et al. [5] present a dynamic model of the rice supply chain system from farmers to consumers for efficient supply chain management in Bangladesh. Mathematical models are in the form of equations to describe the supply and demand for supply at a certain time. The research focuses on ensuring the availability of rice to consumers and the analysis of the sensitivity of the parameters. In the research of Surjasa et al. [6] analyzed the rice supply chain in Indonesia and a supplier selection model to identify and study the important components of the entire supply chain to maintain a stable supply and price of rice. In this study, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) model was used to drink out the costs and maximize profits.

In this research, the model structure is taken from Badan Pusat Statistik (BPS) data [7] which is processed by involving producers, distributors, and retailers. This research focuses on constructing models related to supply chains in Indonesia. Such a model is also built from producers selling their products through two media, namely those directly to consumers and indirectly through distributors and retailers. The constructed model structure aims to maximize profits.

2. RESEARCH METHODS

This research is conducted with a literature study method. In this section, we divide it into two sub-sections, namely the literature review that underlies the research in this paper and the research methodology.

2.1 Literature Review

In 2008, Yong's research [8] explained the mismatch between supply, demand and resources faced by the rice supply chain in Malaysia. The study considers the size of domestic production and existing imports from various types of constraints and explains the need for an efficient supply chain improvement. This research is still limited to the basics and challenges of the rice supply chain in the future.

According to Aji [9], supply chain improvement is intended to increase profit competitiveness. In 2013, Mahbubi [1] studied the importance of the rice supply chain for sustainable food security in Indonesia which resulted in a dynamic model. The model formulation is structured by using a flow chart and mathematical formulation. This dynamic model, in order to see the supply chain system and food security, is not included in optimizing the profits of business actors. Research by South et al. [10] shows that the rice supply chain in Indonesia is not yet optimal, as indicated by the relatively small profits of farmers. Farmers as the main actors in the rice supply chain play an important role in meeting consumer demand. Sharma [11] in his research explained that farmers distribute rice directly to consumers to reduce middleman costs and increase income. Indirect distribution is carried out due to low demand or unfulfilled large demand or other reasons. Indirect distribution is carried out through collectors, retailers, and consumers [10].

In 2016 Bala et al. [5] developed a dynamic model of the rice supply chain system from farmers to consumers to address supply chain management scenarios and design policy options for efficient and sustainable supply chain management in Bangladesh. To ensure the availability of rice for the public, the impact of changes in productivity from seasonal rice production, lead time, and average demand variability on supply chain performance is assessed, and different management policies are also analyzed. The stability of rice supply and price can be achieved if rice supplies are always available and the price of rice is affordable to consumers, while the optimum profit is achieved for the actors involved in the rice supply chain [9].

The development of supply chain management models in rice production to improve food endurance and security in the Demak Regency was researched by Kurniawati *et.al.*[12] in 2020. Collaborative strategy for rice supply chain was researched by Guritno *et.al.*[13] using a case study on Demak and Sukoharjo regency, Central Java, Indonesia in 2021. In the same year, rice supply management was also researched by Fristin *et.al.*[14] to ensure self-sufficiency and food security. Furthermore, Wuryantoro *et.al.*[15] analyzed the supply chain and added value of rice in West Lombok Regency. In 2022, Prasetyo *et. al.*[16] will review the model and implementation of rice supply chain management. Based on the studies mentioned, this research was conducted.

2.2 Research Methodology

The rice supply chain model was obtained from the BPS [7], which was then simplified, developed, then analyzed. The steps taken in this study are studying previous research on the rice commodity supply chain model; determining the model assumptions to be developed; constructing a supply chain profit model by determining the demand function, total revenue, and total costs for each actor; proving that the model has the optimal solution for the centralized system; determining the optimal solution for the centralized system; finding suitable parameters for numerical simulations; finally, analyze the sensitivity of parameters to the advantages of the centralized system.

3. RESULTS AND DISCUSSION

Writing the results and discussion can be separated into different subs or can also be combined into one sub. The summary of results can be presented in the form of graphs and figures. The results and discussion sections must be free from multiple interpretations. The discussion must answer research problems, support and defend answers with results, compare with relevant research results, state the study's limitations, and find novelty.

3.1. The Model Framework

The structure of a simplified rice supply chain in Indonesia is presented in Figure 1.

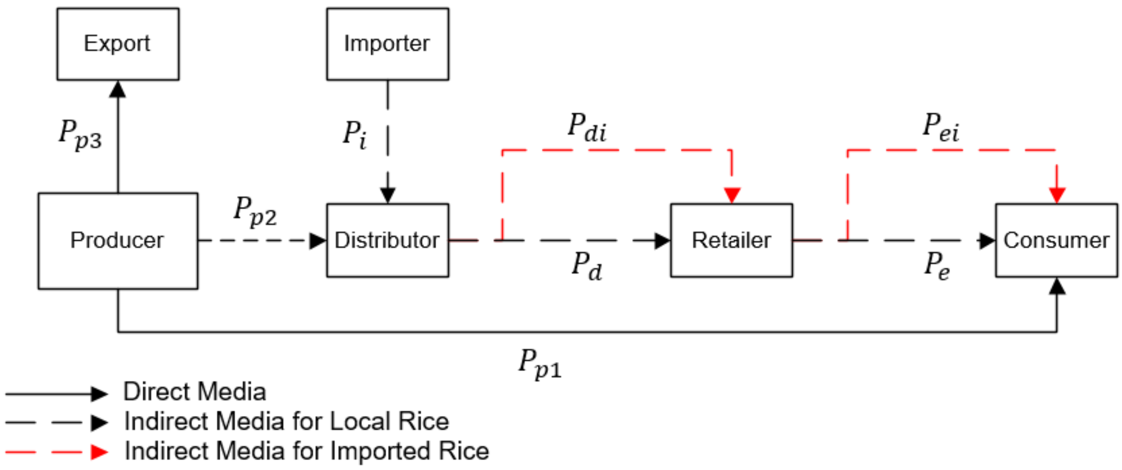

Figure 1. Structure of a simplified rice supply chain in Indonesia

Based on Figure 1, the supply chain model for rice commodities in Indonesia is presented below, involving producers, distributors, and retailers. It is assumed that all actors in the supply chain sell standard rice. Producers sell domestic rice through direct and indirect media and sell rice abroad through export activities.

Distributors and retailers receive rice supplies from producers and imported rice. The decision to determine the optimum price uses a centralized system. The notation used in the model is presented in **Table 1**.

Table 1. Notations and Descriptions used in the model

Notation	Description
Parameter	
a	basic demand for domestic market
b	basic demand for foreign market
θ	demand proportion of demand in direct and indirect media
λ	proportion of demand to retail traders
β_1	price elasticity of rice in domestic direct media
β_2	price elasticity rice in foreign direct media
β_3	price elasticity of imported rice in indirect media
β_4	price elasticity of local rice in indirect media
β_5	price elasticity of rice from importer in indirect media
L_p	producer leads time to export
L_d	distributor lead time due to import activity
ρ_{p1}	sensitivity lead time for producer on direct media
ρ_{p2}	sensitivity of producer lead time for export
ρ_e	sensitivity of lead time for local rice retailer to indirect media
ρ_{ei}	sensitivity of lead time for imported-rice retailer to indirect media
c_1	cross price sensitivity of producer to direct media
c_2	cross price sensitivity of local rice retailer to indirect media
c_3	cross-price sensitivity of imported rice retailer to indirect media
c_p	rice production costs by producer
P_{p2}	selling price of rice from producer in indirect media
P_i	imported rice price from importers
P_d	selling price local rice from the distributor
P_{di}	the selling price of rice imported from the distributor
α_1	elasticity of Rupiah exchange rate against USD (export)
α_2	elasticity of Rupiah exchange rate against USD (import)
K	Rupiah exchange rate against Dollar
Decisions Variables	
P_{p1}	selling price of rice from the producer to domestic direct media
P_{p3}	selling price of rice from producers in foreign direct media
P_e	selling price of local rice from retailer
P_{ei}	selling price of imported rice from retailer

The following assumptions are used in the study

1. The amount of available rice produced is equal to the amount of consumer demand, so there is no shortage of rice.
2. There is only one producer, one distributor and one retailer.
3. The rice production costs by producer are equal to Rp5.200,00/kg based on the average Indonesia rice production costs.
4. Price of rice P_{p1}, P_{p2}, dan P_{p3} always greater than rice productions costs c_p.
5. The values of $P_{p2} < P_d < P_e$ and $P_i < P_{di} < P_{ei}$.

6. The values of $\max\{c_1, c_2, c_3\} < \min\{\beta_1, \beta_2, \beta_3, \beta_4\}$.
7. All parameter values are positive.

3.2. Demand Function

The number of initial units of demand made by producers of direct media for the country is θa. The initial unit of demand for producers for domestic consumers decreases as the selling price of rice changes according to the elasticity parameter of the selling price in domestic direct media, namely $\beta_1 P_{p1}$. Furthermore, changes in domestic consumer preferences in buying rice from producers through the media are directly influenced by the price of rice from retail traders, so that the unit demand for producer increases in line with the price sensitivity parameters of local rice and imported rice, respectively $c_2 P_e$ and $c_3 P_{ei}$. The longer the consumers get imported rice because there is a lead time that is done by the distributor in the indirect media, which results in an increase in producer demand along with the sensitivity of the waiting time, namely $\rho_{p1} L_d$. Thus, the function of producer demand for domestic direct media is

$$D_{ld} = \theta a - \beta_1 P_{p1} + c_2 P_e + c_3 P_{ei} + \rho_{p1} L_d. \tag{1}$$

Producers also sell rice to overseas consumers through export activities. Initial demand unit from producers for export activities is b. The unit of demand will decrease along with the increase in the selling price of rice, which changes according to the parameter of the selling price elasticity in direct media for foreign consumers, namely $\beta_2\ P_{p3}$. The existence of lead time for service and delivery of producer for export activities also reduces the unit demand and $\rho_{p2} L_p$. The existence of the rupiah against the US dollar affects the reduction of demand for units of $\alpha_1 K$. Thus, the demand function for direct media producers for foreign consumers is

$$D_{ll} = b - \beta_2 P_{p3} - \rho_{p2} L_p - \alpha_1 K. \tag{2}$$

The demand function for direct media is the sum of **Equation (1)** and **Equation (2),** namely:

$$D_L = \theta a + b - \beta_1 P_{p1} - \beta_2 P_{p3} + c_2 P_e + c_3 P_{ei} + \rho_{p1} L_d - \rho_{p2} L_p - \alpha_1 K. \tag{3}$$

The initial unit of demand on the indirect medium is $(1-\theta)a$. In indirect media, the initial proportion for local rice is λ. The unit of initial demand for local rice in the media indirectly decreases in line with the increase in the selling price of rice which changes according to the parameter of selling price elasticity at retail traders for local rice by $\beta_4 P_e$. The existence of consumer preference in buying local rice at retailers results in additional demand units due to rising producer prices and imported rice prices by $c_1 P_{p1}$ and $c_3 P_{ei}$ and $c_3 P_{ei}$. In addition, there is a lead time for delivery due to import activities that have an effect on the addition of local rice demand units of $\rho_e L_d$. Thus, the demand function on the indirect media for local rice is

$$D_{tlo} = \lambda(1-\theta)a - \beta_4 P_e + c_1 P_{p1} + c_3 P_{ei} + \rho_e L_d. \tag{4}$$

The proportion of units of initial demand for imported rice is $1-\alpha$. The unit of demand will decrease in line with the increase in the selling price of rice which changes according to the elasticity parameter of the selling price of rice from importers and the selling price of imported rice for domestic consumers, which are respectively $\beta_5 P_i$ and $\beta_3 P_{ei,}$. In addition, the unit of demand will also increase. Demand for imported rice will increase by $c_1 P_{p1}$ and $c_2 P_e$ in line with rising producer prices and local rice prices. The existence of lead time due to export activities will also reduce the demand for imported rice in the indirect media by $\rho_{ei} L_{d.}$. The rupiah exchange rate against the US dollar also has an effect on reducing the demand unit by $\alpha_2 K$. For that, the function of imported rice demand in indirect media is

$$D_{tli} = (1-\lambda)(1-\theta)a - \beta_3 P_{ei} - \beta_5 P_i + c_1 P_{p1} + c_2 P_e - \rho_{ei} L_d - \alpha_2 K. \tag{5}$$

Thus, the function of the media indirect demand is sum of **Equation (4)** and **Equation (5)**:

$$D_{TL} = a - \theta a - \beta_4 P_E - \beta_3 P_{ei} - \beta_5 P_i + 2c_1 P_{p1} + c_2 P_e + c_3 P_{ei} + \rho_e L_d - \rho_{ei} L_d - \alpha_2 K. \tag{6}$$

The total demand function for the rice supply chain is sum of **Equation (3)** and **Equation (6)** as follows:

$$D_T = a + b - P_{p1}\beta_1 - P_{p3}\beta_2 - P_{ei}\beta_3 - P_e\beta_4 - P_i\beta_5 + 2c_2P_e + 2c_3P_{ei} + 2c_1P_{p1} + L_d\rho_e - L_d\rho_{ei} + L_d\rho_{p1} - L_p\rho_{p2} - K\alpha_1 - K\alpha_2. \quad (7)$$

3.3. Profit Function

Producers sell rice through direct and indirect media so the producer profit function is obtained from the sum of profits in the direct and indirect media. The costs incurred by producers are the production costs of c_p multiplied by consumer demand for direct and indirect media for local rice. Revenues earned distributors are derived from the sale of imported rice at a price P_{di} multiplied by the number of requests for imported rice media indirect and sale of local rice at a price P_d multiplied by request of indirect-media local rice. Distributor incur costs by purchasing rice from producer at a price of P_{p2}. Apart from that, distributor also pay a fee of P_i to obtain imported rice. Then, retailers earn income from selling imported rice at a price of P_{ei} which is multiplied by the demand for imported rice in indirect media. In addition, retail traders also earn income by selling local rice at the price of P_e which is multiplied by the local demand for rice in direct media. Retail traders will pay the same amount as the purchase of rice from the distributor. So that, the optimal profit function is obtained

$$\Pi_P = P_{p1}D_{ld} + P_{p3}D_{ll} + \left(P_{p2} - c_p\right)D_{tlo} - c_pD_L \quad (8)$$

$$\Pi_D = (P_{di} - P_i)D_{tli} + (P_d - P_{p2})D_{tlo} \quad (9)$$

$$\Pi_R = (P_{ei} - P_{di})D_{tli} + (P_e - P_d)D_{tlo} \quad (10)$$

3.4. Supply Chain Centralized

The centralized model in the rice supply chain is a profit function model without the constraints obtained by adding up the profits of producer, distributor, and retailer with price decision variables P_{p1}, P_{p3}, P_{ei} and P_e. In this model, suppose $P_{p2} = \eta_1 P_{p1}, P_d = \eta_2 P_e$, dan $P_{di} = \eta_3 P_i$. So, the profit function of the centralized model is sum of **Equation (8)**, **Equation (9)**, and **Equation (10)** written as

$$\Pi_C\left(P_{p1}, P_{p3}, P_{ei}, P_e\right) = P_{p1}D_{ld} + P_{p3}D_{ll} + \left(P_e - c_p\right)D_{tlo} + (P_{ei} - P_i)D_{tli} - c_pD_L. \quad (11)$$

From the profit function (Π_C) of the system, a Hessian matrix can be constructed to prove that the system profit function is a straightly concave or has a single maximum solution.

$$\boldsymbol{H}(\Pi_C) = \begin{pmatrix} -2\beta_1 & 0 & c_1 + c_2 & c_1 + c_3 \\ 0 & -2\beta_2 & 0 & 0 \\ c_1 + c_2 & 0 & -2\beta_4 & c_2 + c_3 \\ c_1 + c_3 & 0 & c_2 + c_3 & -2\beta_3 \end{pmatrix} \quad (12)$$

The principal minor determinants of the Hessian matrix in **Equation (12)** are

$$|H_{11}| = -2\beta_1$$
$$|H_{22}| = 4\beta_1\beta_2$$
$$|H_{33}| = -2\beta_2(-(c_1 + c_2)^2 + 4\beta_1\beta_4)$$
$$|H_{44}| = -2\beta_2\left((c_2 + c_3)X + (c_1 + c_3)Y - 2\beta_3(-(c_1 + c_2)^2 + 4\beta_1\beta_4)\right)$$

with $X = (c_1 + c_2)(c_1 + c_3) + 2(c_2 + c_3)\beta_1$ and $Y = (c_1 + c_2)(c_2 + c_3) + 2(c_1 + c_3)\beta_4$.

Based on the 6th and 7th assumption is obtained $|H_{11}| < 0, |H_{22}| > 0, |H_{33}| < 0$, and $|H_{44}| > 0$. So, it can be concluded that $\Pi_C\left(P_{p1}, P_{p3}, P_{ei}, P_e\right)$ is straightly concave function. It's proof that the system profit function is a straightly concave so that it is guaranteed that the function has a single maximum solution. The model solution is obtained by solving the partial derivative of the profit function $\Pi_C\left(P_{p1}, P_{p3}, P_{ei}, P_e\right)$ equal zero, the optimum solution is obtained

$$P_{p1}^{*} = \frac{1}{2A}(a\theta c_3^2 - a\lambda c_3^2 + a\theta\lambda c_3^2 + c_3^2 c_p\beta_1 - 2ac_3\beta_4 + 2a\theta c_3\beta_4 + 2a\lambda c_3\beta_4 - 2a\theta\lambda c_3\beta_4 + 3c_3^2 c_p\beta_4 + 2Kc_3\alpha_2\beta_4 - 4a\theta\beta_3\beta_4 - 2c_3P_i\beta_3\beta_4 - 4c_p\beta_1\beta_3\beta_4 + 2c_3P_i\beta_4\beta_5 - c_3^2 L_d\rho_e + 2c_3L_d\beta_4\rho_{\mathrm{ei}} + c_1(c_3^2(c_p - P_i) + c_3(a(-1+\theta) + K\alpha_2 + 3c_p\beta_4 + P_i(-\beta_3+\beta_5) + L_d(-\rho_e + \rho_{\mathrm{ei}})) + c_2(a(-1+\theta) + c_3(c_p - P_i) + K\alpha_2 + c_p(2\beta_3 - \beta_4) + P_i(\beta_3+\beta_5) + L_d(-\rho_e+\rho_{\mathrm{ei}})) + 2(\beta_3(a(-1+\theta)\lambda + (c_p+P_i)\beta_4 - L_d\rho_e) + \beta_4(-a(-1 +\theta)(-1+\lambda) + K\alpha_2 + P_i\beta_5 + L_d\rho_{\mathrm{ei}}))) + L_d(c_3^2 - 4\beta_3\beta_4)\rho_{\mathrm{p1}} + c_2^2(a(-1-\theta(-2+\lambda)+\lambda) + c_3(3c_p + P_i) + K\alpha_2 + c_p(\beta_1 + 2\beta_3) + P_i(\beta_3+\beta_5) + L_d(\rho_{\mathrm{ei}} + \rho_{\mathrm{p1}})) + c_2(c_3^2(3c_p + P_i) + 2\beta_3(a(-1+\theta)\lambda - c_p\beta_4 - L_d\rho_e) + c_3(a(-1+3\theta) + K\alpha_2 + c_p(2\beta_1 - \beta_4) + P_i(-\beta_3 + \beta_5) + L_d(-\rho_e + \rho_{\mathrm{ei}} + 2\rho_{\mathrm{p1}}))))$$

$$P_{\mathrm{p3}}^{*} = \frac{b - K\alpha_1 + c_p\beta_2 - L_p\rho_{\mathrm{p2}}}{2\beta_2}$$

$$P_{ei}^{*} = \frac{1}{B}(-(-(-(c_1+c_2)(c_1+c_3) - 2(c_2+c_3)\beta_1)(2\beta_1(a(-1+\theta)\lambda + c_2(c_p+P_i) - c_p\beta_4 - L_d\rho_e) + (c_1+c_2)(-a\theta + c_1(c_p+P_i) - c_p\beta_1 - L_d\rho_{\mathrm{p1}})) + (-(c_1+c_2)^2 + 4\beta_1\beta_4)(2\beta_1(-a(-1+\theta)(-1+\lambda) + 2c_3c_p + K\alpha_2 + P_i(-\beta_3+\beta_5) + L_d\rho_{\mathrm{ei}}) + (c_1+c_3)(-a\theta + c_1(c_p+P_i) - c_p\beta_1 - L_d\rho_{\mathrm{p1}}))))$$

$$P_e^{*} = \frac{1}{B}\frac{1}{-(c_1+c_2)^2 + 4\beta_1\beta_4}(2\beta_1(a\lambda - a\theta\lambda - c_2(c_p+P_i) + c_p\beta_4 + L_d\rho_e) + (c_1+c_2)(a\theta - c_1(c_p + P_i) + c_p\beta_1 + L_d\rho_{\mathrm{p1}}) + ((-(c_1+c_2)(c_1+c_3) - 2(c_2+c_3)\beta_1)(-(-(c_1+c_2)(c_1+c_3) - 2(c_2+c_3)\beta_1)(2\beta_1(a(-1+\theta)\lambda + c_2(c_p+P_i) - c_p\beta_4 - L_d\rho_e) + (c_1+c_2)(-a\theta + c_1(c_p+P_i) - c_p\beta_1 - L_d\rho_{\mathrm{p1}})) + (-(c_1+c_2)^2 + 4\beta_1\beta_4)(2\beta_1(-a(-1+\theta)(-1+\lambda) + 2c_3c_p + K\alpha_2 + P_i(-\beta_3+\beta_5) + L_d\rho_{\mathrm{ei}}) + (c_1+c_3)(-a\theta + c_1(c_p+P_i) - c_p\beta_1 - L_d\rho_{\mathrm{p1}}))))$$

with

$$A = c_3^2\beta_1 + c_2c_3(c_3 + 2\beta_1) + c_2^2(c_3+\beta_1+\beta_3) + (c_3^2 - 4\beta_1\beta_3)\beta_4 + c_1^2(c_2+c_3+\beta_3+\beta_4) + c_1(c_2^2 + 2c_2(c_3+\beta_3) + c_3(c_3 + 2\beta_4)))$$

and

$$B = (-\left((c_1+c_2)(c_1+c_3) + 2(c_2+c_3)\beta_1\right)^2 + (-(c_1+c_3)^2 + 4\beta_1\beta_3)(-(c_1+c_2)^2 + 4\beta_1\beta_4.$$

3.5. Numerical Experiment

The solution obtained is then carried out with a numerical simulation approach with a centralized system. The parameter values used in this study are described in **Table 2**.

Table 2. Parameter Values

Parameter	Value	Parameter	Value
a	30.000 kg	c_1	0.05 kg/Rp
b	4.000 kg	c_2	0.08 kg/Rp
θ	0.1	c_3	0.07 kg/Rp
λ	0.53	K	14.000,00
α_1	0.01 kg/Rp	ρ_{p1}	80 kg / day
α_2	0.02 kg/Rp	ρ_{p2}	200 kg / day
β_1	0.49 kg /Rp	ρ_e	120 kg / day
β_2	0.12 kg /Rp	ρ_{ei}	200 kg / day
β_3	1.2 kg /Rp	c_p	Rp5.200,00 / kg
β_4	1.6 kg /Rp	P_i	Rp6.200,00 / kg
β_5	0.2 kg /Rp	η_1	0.96

Parameter	Value	Parameter	Value
L_p	14 days	η_2	0.99
L_d	14 days	η_3	1.14

Based on the numerical simulations, the optimum solutions of the rice commodity supply chain model are obtained as follows

Table 3. Parameter Values

P_{p1}^*	P_{p2}^*	P_{p3}^*	P_d^*	P_{di}^*	P_e^*	P_{ei}^*
Rp8,161.62	Rp7,892.84	Rp7,016.67	Rp7,900.72	Rp7,111.77	Rp7,980.52	Rp7,191.03
Π_c^*	Π_p^* (Rp)	Π_d^* (Rp)	Π_e^* (Rp)			
16,406,500.00	15,263,900.00	750,390.00	392,202.00			

The sensitivity analysis in this study uses the effect of changing proportions on direct and indirect (θ) media. The parameter value $\theta = (0.0.1]$ is taken because when $\theta > 0.1$ causes the price of $P_{p2} > P_d > P_e$ so that it does not meet the 5th assumption. The effect of changes in parameter value θ at the interval $(0.0.1]$ on the profits of each supply chain actor is presented in Figure 2.

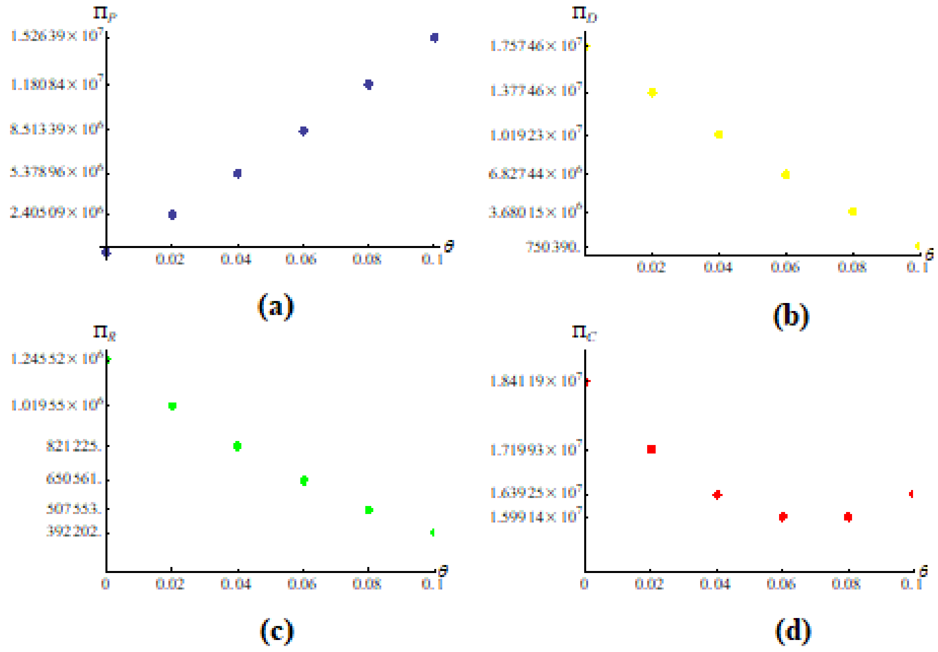

Figure 2. The Curve of θ Change to (a) Producer, (b) Distributor, (c) Retailer, and (d) System Profits

4. CONCLUSIONS

This research examines the rice supply chain in Indonesia obtained from BPS, which is then simplified by involving the main actors of producers, distributors, and retailers. Producers sell rice to domestic consumers through direct and indirect media and sell rice abroad through export activities. Distributors and retailers receive rice supplies from producers and imported rice. The mathematical model is constructed to obtain the maximum total profits by using a centralized system. Based on the numerical simulation results, changes in the parameters of proportions on the direct and indirect media greatly affect the optimal benefits obtained.

ACKNOWLEDGMENT

We are very grateful to University of Sebelas Maret, Surakarta.

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