

**STRATEGIC MANAGEMENT OF PALM OIL PRICE
DYNAMICS USING A GAME-THEORETICAL APPROACH**
(Pengurusan Strategik Dinamik Harga Minyak Kelapa Sawit Menggunakan Pendekatan
Teori Permainan)

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ABSTRACT

As the most widely traded vegetable oil in the world, the primary objective of palm oil stakeholders is to maximise returns, which are driven by price and demand. Price fluctuations are a natural and necessary aspect of a competitive market; however, its unpredictability can significantly diminish returns. Price theory suggests that the existence of a close substitute, such as soybean oil, can substantially impact the dynamics of the palm oil market due to their similar end-product applications. As a result, their prices have grown increasingly competitive as demand shifts in response to their relative pricing. This paper proposes a game-theoretical approach to managing the dynamics of palm oil prices, with a particular emphasis on market interactions between palm oil and soybean oil. The model uses supply as a decision variable, allowing palm oil stakeholders to optimise returns by balancing pricing and demand. In addition to reducing price fluctuations to enhance returns, the methodology can also help to improve sustainability by preventing oversupply, and avert escalating prices that may jeopardise global food security.

Keywords: game theory; palm oil; price theory

ABSTRAK

Sebagai minyak sayuran yang paling banyak didagangkan di dunia, matlamat utama pihak berkepentingan minyak sawit adalah untuk memaksimumkan pulangan, yang didorong oleh harga dan permintaan. Turun naik harga adalah aspek semula jadi dan perlu dalam pasaran kompetitif; walau bagaimanapun, ketidakpastiannya boleh mengurangkan pulangan dengan ketara. Teori harga mencadangkan bahawa kewujudan pengganti rapat, seperti minyak kacang soya, boleh memberi kesan yang ketara kepada dinamik pasaran minyak sawit disebabkan oleh aplikasi produk akhir yang serupa. Akibatnya, harga mereka telah menjadi semakin kompetitif apabila permintaan beralih sebagai tindak balas kepada harga relatif mereka. Kertas kerja ini mencadangkan pendekatan teori permainan untuk mengurus dinamik harga minyak sawit, dengan penekanan khusus kepada interaksi pasaran antara minyak sawit dan minyak kacang soya. Model ini menggunakan bekalan sebagai pembolehubah keputusan, yang membolehkan pihak berkepentingan minyak sawit mengoptimumkan pulangan dengan mengimbangi harga dan permintaan. Selain mengurangkan turun naik harga untuk meningkatkan pulangan, metodologi ini juga boleh membantu meningkatkan kemampanan dengan mencegah lebihan bekalan dan mengelakkan kenaikan harga yang boleh menjejaskan keselamatan makanan global.

Kata kunci: teori permainan; minyak sawit; teori harga

1. Introduction

As a major producer, the palm oil industry plays an important role in Malaysia's economy. In 2021, the production of 18 million metric tonnes (MT) of palm oil generated RM108.52 billion in revenue, accounting for approximately 3.7% of the country's Gross Domestic Product (GDP) (MPOB 2022). Palm oil exports have helped millions of people escape poverty by providing income opportunities and funding infrastructure development, such as roads and schools. Volatility is a recurring issue for the palm oil industry, with Hidayat *et al.* (2015) indicating that price fluctuations reduce its capacity to generate optimal returns, thereby endangering Malaysia's market and social economies (Haron & Ayojimi 2015). Khalid *et al.* (2018) suggest that palm oil price fluctuations follow the law of supply and demand, where a faster increase in supply than in demand results in a decrease in prices according to Rahman *et al.* (2013).

The palm oil industry currently relies on price forecasting to maximise returns by securing the highest prices. This strategy capitalises on price fluctuation, perpetuating a detrimental cycle for palm oil that reduces its demand. Price forecasting can lead to oversupply, which occurs when producers increase supply in anticipation of rising prices in order to maximise profit. At the same time, they may boost supply in expectation of a price decline to offset projected lower returns. Both scenarios result in indiscriminate supply increase, causing palm oil prices to persistently decline and volatility to rise. This has long-term consequences for the sustainability of palm oil.

Forecasts based solely on one-dimensional data often ignore the influence of competition on vegetable oil prices (Duncker 1977; Owen *et al.* 1997). According to Zhou *et al.* (2023), vegetable oil prices show significant interconnections over time, resulting in interrelated demand. As cooking oil substitutes, soybean oil prices exhibit a long-term relationship and respond to changes in palm oil prices (Zaidi *et al.* 2022). The price increase of one cooking oil influences the consumption patterns of the other, as consumers switch between the two products in response to price variations (Mayada & Juwita 2023). Hence, disregarding palm oil substitutes renders price forecasting inefficient, and understanding their impact is essential for optimising returns.

Abdullah (2013) identifies soybean oil as a close substitute for palm oil, citing their similar properties and interchangeability across various applications. Besides food production, biofuel is another significant shared application that influences the price dynamics of palm oil and soybean oil (Carter & Smith 2021). The positive cross-price elasticity suggests that rising palm oil prices increase demand for soybean oil, and vice versa. The price of each product influences not only its own demand, but also that of the competing product (Mohammadi *et al.* 2015). The price equilibrium for the forthcoming cycle is established as producers adjust supply to match demand, as illustrated in Figure 1.

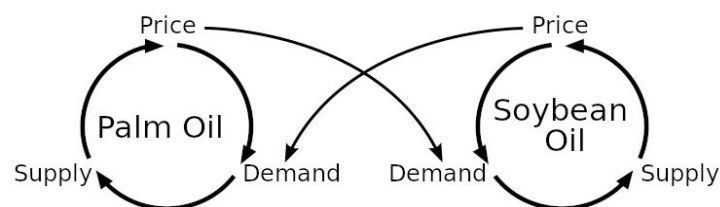


Figure 1: The price of one product influences the demand for both as consumers tend to switch to the product with the lower price

Previous research found a significant positive correlation between palm oil and soybean oil prices (Chuangchid *et al.* 2013; Bhattar 2024). As Fousekis (2024) suggests, their prices are likely to move in tandem, with each gradually influencing the other (Rahman *et al.* 2007). A game-theoretical model is proposed to influence pricing through supply regulation, as their substitutability extends beyond consumption to include production (Smith & Jones 2015; Doe & Lee 2020). It allows prices to respond to evolving market conditions, offering substantial benefits for analysing decision optimisation among competing entities and developing a cohesive system (Liu *et al.* 2020; Huang & Li 2022).

Game theory has been applied across multiple disciplines, including economics, political science, psychology, sociology, and computer science. In economics, it is used to analyse competitive behaviours such as pricing strategies, action designs, and oligopolistic competition (Paseda 2021; Amit 2024). It has also been utilised in market microstructure to investigate how trading mechanisms affect price formation and efficiency (Paseda 2025). Even governments have employed game theory to develop policies that maximise results in areas like public goods provision, taxation, and regulation (Paseda 2025).

Choi *et al.* (2020) employed game theory to analyse the concepts of sharing economy and circular supply chains in the context of production research. Setyowati *et al.* (2021) utilise game theory in their decision-making process to determine which commodities farmers should cultivate in horticultural farming. Producers play an important role in shaping strategic supply decisions, which are influenced by a range of economic, environmental, and policy factors. Their actions are essential for fulfilling demand and attaining optimal pricing (Bhattar 2024). Ultimately, forecasting is viewed as a price-taking approach as it adheres to prevailing market prices, whereas a game-theoretical model is regarded as a price-making strategy that allows palm oil stakeholders to influence pricing.

2. The Game Model

The stochastic game was first introduced by Shapley (1953) to model competitive interactions between adversaries referred to as players, wherein the environment adjusts according to their actions. The interactions result in a final payoff determined by their collective actions within the existing environment, termed a state (Ziliotto 2018). The game then moves to a new random state. As a repeated game played in a sequence of stages with probabilistic transitions, players will utilise their respective payoffs to identify optimal strategies.

In a game-theoretical model, the players are considered rational, utilising strategies exclusively for their own benefit (Hilbe *et al.* 2018). Nevertheless, players must adopt a long-term perspective of how their actions affect both their opponents' responses and the ensuing state. Unlike static games that account for a single interaction, stochastic games represent real-world scenarios, enabling the development of various dynamic model games, such as those proposed by Sorin (2003) and Mertens *et al.* (2015).

Definition: A stochastic game is a tuple (S, N, A, P, R) where:

- (1) N is a finite set of n players
- (2) $A = A_1 \times \dots \times A_n$ where A_i is a finite actions available to player i
- (3) S is a finite set of states
- (4) $P : S \times A \times S \mapsto [0,1]$ is the transition probability function; $P(s, a, s')$ is the probability of transitioning from state s to state s' after action a
- (5) $R = r_1, \dots, r_n$ where $r_i : S \times A \mapsto \mathbb{R}$, $i \in N$ is a real-valued payoff function for player i

The mathematical theory of stochastic games has been extensively documented in various literatures, with applications spanning computer science (Miltersen & Sorensen 2007), economics (Jovanovic & Rosenthal 1988), telecommunication networks (Zhang & Guo 2012), operations research (Altman & Hordijk 1995), and resource extraction (Neyman & Sorin 2003). Consequently, in order to represent the market interactions of palm oil and soybean oil as a stochastic game inside a well-established economic framework, it is essential to demonstrate adherence to characteristics (1) - (5) as outlined in the model definition.

3. Palm-Soybean Stochastic Game

The two-player game with $N = 2$, henceforth referred to as the palm-soybean stochastic game, fulfils the first characteristic of a stochastic game. Each player utilises supply as a decision variable, with action space $A_i = \{I, D\}$ where $i = (\text{palm oil, soybean oil})$. The limited number of actions accessible to players represent a fundamental aspect of a finite game. This is the second characteristic of a stochastic game, with the actions defined as follows:

- (1) I denotes the action of increasing supply to the global market
- (2) D denotes the actions of decreasing supply to the global market

The interactions between palm oil and soybean oil at each stage of the game can be represented in extensive form, as illustrated in Figure 2. The first branch denotes actions by palm oil, while actions by soybean oil are represented by the subsequent branches. The state of the stage is derived from the combined actions of both players, defined by the finite state space $S = \{(I, I), (I, D), (D, I), (D, D)\}$, as outlined in the definition of stochastic game. While the game in extensive form demonstrates sequential moves; the actions undertaken by the players in the palm-soybean stochastic game can also transpire simultaneously.

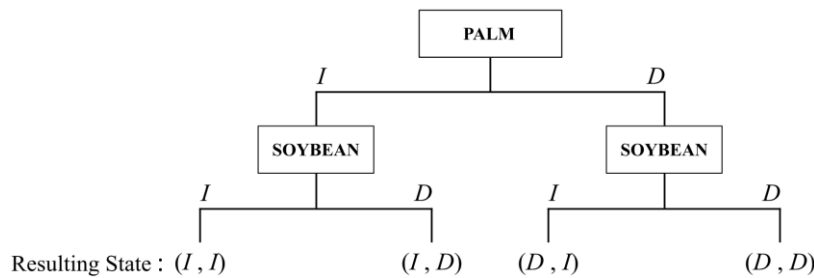


Figure 2: A single stage of the palm-soybean stochastic game in extensive form

The palm-soybean stochastic game is a data-driven model that utilises empirical data to analyse and simulate the strategic interactions between palm oil and soybean oil, with its structure based on observational and computational methodologies. The model formulation process uses two categories of time series data spanning from the first quarter of 1998 to the second quarter of 2022, with supply as the decision variable and price as the outcome variable. Supply data for palm oil and soybean oil is measured in 1000 Metric Tonnes (1000 MT), whereas pricing data is expressed in United States Dollar per Metric Tonne (USD/MT). A sample of the time series data for supply and price is shown in Table 1.

Table 1: Sample of time series data for modelling the palm-soybean stochastic game

Period	Palm Oil Supply	Soybean Oil Supply	Palm Oil Price	Soybean Oil Price
1998Q1	3480	5419	650.33	637.00
1998Q2	4070	6228	675.33	654.00
1998Q3	5009	6005	679.33	606.33
1998Q4	4523	6336	603.24	537.63
:	:	:	:	:
2021Q3	19650	15220	1128.73	1433.68
2021Q4	19200	15170	1307.06	1445.89
2022Q1	17680	13770	1548.04	1674.06
2022Q2	19940	15810	1699.83	1955.20

Source: Oil World (2022) and Federal Reserve Bank of St. Louis (2022)

The actions of increasing or decreasing supply relate to the volume supplied to the global market, based on the quantity variation between the current and the preceding stages. To simulate these actions, the difference in supply volume between consecutive quarters is calculated using $(y_t - y_{t-1})$, as illustrated in Table 2. The positive and negative values indicate the actions taken by the player during that quarter. Positive values signify an increase in supply, whilst negative values represent a decrease. An additional column has been added to represent the state of the game stages based on the combined actions of the players in each quarter. In subsequent quarters, the state is progressively updated with each new iteration of actions undertaken by the players.

Table 2: Supply data is differenced to simulate past actions and derive previous states

Period	Palm Oil Supply	Soybean Oil Supply	State
1998Q2	590	809	(I,I)
1998Q3	939	-223	(I,D)
1998Q4	-486	331	(D,I)
1999Q1	-665	-779	(D,D)
:	:	:	:
2021Q3	-220	-700	(D,D)
2021Q4	-450	-50	(D,D)
2022Q1	-1520	-1400	(D,D)
2022Q2	2260	2040	(I,I)

Source: Oil World (2022)

The state column in the table also serves as a method of illustrating the game's progression from one state in a particular quarter to the subsequent state in the following quarter, driven by the players' actions and any random events. For example, the game reportedly transitions from state (I, I) in the second quarter of 1998 to state (I, D) in the third quarter of 1998, representing a step towards the construction of the transition probability function for the palm-soybean stochastic game.

4. Transition Probability Function

The transition probability function defines the likelihood of moving from one state to another, and it is the fourth characteristic outlined in the stochastic game definition. Using the frequentist approach, the probability of transitioning from state (I, I) to state (I, D) is calculated by dividing the frequency of transition $(I, I) \rightarrow (I, D)$ in the past by the total number of observations in the data. Transitions that have not occurred are denoted as zero and omitted from the state transition diagram in Figure 3.

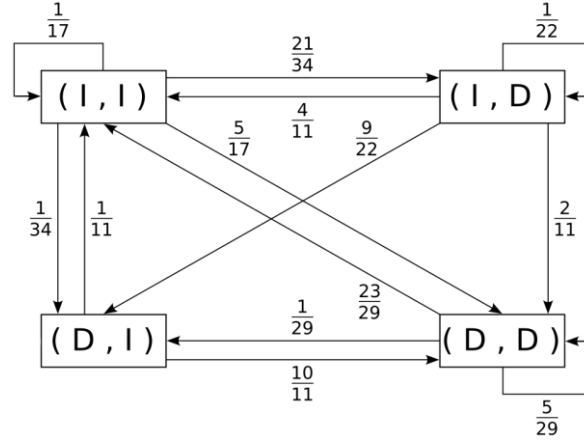


Figure 3: State transition diagram illustrating the probabilities of moving from one state to another based on past occurrences

The state transition diagram demonstrates irreducibility, defined as the existence of a pathway of one or more steps connecting any two states. This is an important property for analysing the long-term behaviour of the system, namely the existence and uniqueness of a stationary distribution. The diagram also illustrates aperiodicity, indicating that it does not become trapped in a cycle of returning to a condition of state at fixed, repeating time intervals. This trait ensures convergence to a singular, stable steady-state distribution over time, regardless of the starting state.

The transition probabilities illustrated in Figure 3 can be expressed in a matrix format known as the transition probability matrix P . In this matrix, the rows represent the current state, whereas the columns denote the subsequent state. The matrix elements P_{ij} denote the probability of transitioning from the i^{th} state to the j^{th} state, with every $P_{ij} \geq 0$ for all i and j . In the probability matrix P , the element P_{11} signifies the transition $(I, I) \rightarrow (I, I)$, whereas P_{34} denotes the transition of $(D, I) \rightarrow (D, D)$.

$$P = \begin{pmatrix} \frac{1}{17} & \frac{21}{34} & \frac{1}{34} & \frac{5}{17} \\ \frac{4}{11} & \frac{1}{22} & \frac{9}{22} & \frac{2}{11} \\ \frac{1}{29} & 0 & \frac{1}{29} & \frac{5}{29} \\ \frac{23}{29} & 0 & \frac{10}{11} & \frac{5}{29} \end{pmatrix}$$

$$= \begin{pmatrix} 0.05882353 & 0.61764706 & 0.02941176 & 0.2941176 \\ 0.36363636 & 0.04545455 & 0.40909091 & 0.1818182 \\ 0.09090909 & 0.00000000 & 0.00000000 & 0.9090909 \\ 0.79310345 & 0.00000000 & 0.03448276 & 0.1724138 \end{pmatrix}$$

The Markovian property of a stochastic game asserts that a future state is independent of its preceding states. This concept can be demonstrated through the n -step transitions, which shows the likelihood of moving from one state to another in exactly n steps. The implication is that, as an infinitely repeating game, the palm-soybean stochastic game must demonstrate stable transition probabilities to ensure that the relative frequency of each transition converges

to its true probability through repeated iterations of the game. The n -step probability transition matrix is calculated by exponentiating the one-step transition matrix P to the power of n as follows:

$$P^n = P \times P^{n-1} \quad (1)$$

The irreducibility and aperiodicity of the palm-soybean stochastic game indicate its ability to converge to a unique and stationary distribution. A stationary distribution is a probability distribution that remains constant over time, demonstrating a state of equilibrium. The convergence of the transition probability matrix to a limit under these conditions of the Markov Chain can be quantitatively demonstrated as follows:

$$\begin{aligned} P^2 &= P \times P \\ &= \begin{pmatrix} 0.4639987 & 0.06440705 & 0.26454589 & 0.2070484 \\ 0.2193100 & 0.22666505 & 0.03555982 & 0.5184651 \\ 0.7263507 & 0.05614973 & 0.03402176 & 0.1834778 \\ 0.1865299 & 0.48985801 & 0.02927188 & 0.2943402 \end{pmatrix} \\ &\quad \vdots \\ P^{19} &= \begin{pmatrix} 0.3536650 & 0.2295777 & 0.1143504 & 0.3024068 \\ 0.3545905 & 0.2288198 & 0.1147791 & 0.3018106 \\ 0.3536226 & 0.2296138 & 0.1143314 & 0.3024322 \\ 0.3546396 & 0.2287783 & 0.1148034 & 0.3017786 \end{pmatrix} \\ P^{20} &= \begin{pmatrix} 0.3545220 & 0.2288755 & 0.1147479 & 0.3018545 \\ 0.3538670 & 0.2294127 & 0.1144445 & 0.3022759 \\ 0.3545510 & 0.2288510 & 0.1147623 & 0.3018357 \\ 0.3538316 & 0.2294411 & 0.1144279 & 0.3022994 \end{pmatrix} \end{aligned}$$

The n -step transition illustrated above exemplifies how the palm-soybean game converges to a stationary matrix with uniform rows that encompass the limiting distribution over time. Stationary distributions are important in stochastic games because they represent the system's long-term, stable equilibrium behaviour as well as the optimal strategies of the players. In the palm-soybean game, this represents the probability of remaining in a specific state following an extensive number of transitions.

5. Payoff

Payoff refers to the reward received by each player at the conclusion of a stage in a game, as dictated by the strategies selected by the players. In the context of a repeated game, the payoff for the palm-soybean stochastic game is expressed as a limiting average reward. It is derived from the outcomes of preceding states with real-valued results represented as $R = \{r_1, r_2\}$. At the k -stage of a game, denoted by $r_i^{(k)}$ for each player i , the limit, when it exists, is referred to as average reward. The limiting average reward is an important concept used to assess the long-term outcomes of games in which players' actions influence future payoffs. For an infinite sequence of payoffs $r_i^{(1)}, r_i^{(2)}, \dots$ for player i , the average reward is calculated as follows:

$$\frac{\sum_{j=1}^k r_i^{(j)}}{k} \quad (2)$$

In the palm-soybean stochastic game, the average reward serves as a fundamental objective for achieving long-term, sustainable performance in environments with continuous and potentially infinite interactions. It also defines the final characteristics of a stochastic game, fulfilled by the palm-soybean stochastic game.

To compute the average reward for the palm-soybean stochastic game, the differenced data from Table 2 is first grouped by state to identify their relevant periods. Using the identified periods, the price columns for both palm oil and soybean oil from the original dataset in Table 1 are filtered, and the average price values for each product are calculated. Table 3 shows an example where price data are filtered according to the state (D , I). The eleven rows of data produced reflect the past occurrences of the state (D , I), and total price values from each column are subsequently divided by the number of rows. The computed values represent the possible payoff for both players if palm oil reduces supply and soybean oil increases supply in the forthcoming cycle.

Table 3: Price data filtered according to state (D , I) to calculate the average prices

Period	Palm Oil Price	Soybean Oil Price
1998Q4	603.24	537.63
1999Q4	368.33	384.00
2002Q4	438.33	559.67
2003Q4	499.33	629.00
2004Q4	429.00	559.33
2005Q4	438.33	558.67
2006Q4	570.54	662.83
2010Q4	1108.00	1242.00
2011Q4	1024.67	1213.67
2014Q4	715.33	828.33
2016Q1	668.92	756.29
Average prices :	624.00	721.04

Source: Federal Reserve Bank of St. Louis (2022)

The average price values are systematically calculated for the three remaining states, and the results are tabulated in a payoff matrix with each state broken down to the separate actions by palm oil and soybean oil. The payoff matrix shown in Figure 4 illustrates the potential outcomes for each player in the upcoming quarter, based on the combined actions by palm oil and soybean oil. The players will utilise their respective possible price payoffs to evaluate their supply decisions for the subsequent stage. As the game progresses to the next stage, new data is incorporated into the dataset and the process is repeated for an updated payoff matrix.

		Soybean Oil	
Palm Oil	Actions	Increase, I	Decrease, D
	Increase, I	(709.18 , 832.21)	(639.90 , 783.78)
	Decrease, D	(624.00 , 721.04)	(764.30 , 876.58)

Figure 4: Payoff matrix showing the projected prices for the upcoming quarter resulting from all possible combinations of actions by both players

The payoff matrix reveals the presence of two Nash equilibriums. A Nash equilibrium is established when each player's strategy is the optimal response to the strategy selected by the competitor, such that no player can improve their outcome by unilaterally changing their strategy. The first Nash equilibrium arises when both players increase their supply, while the second occurs when both reduce their supply. To determine the better strategy between the two Nash equilibriums, the price discount between the payoffs for palm oil and soybean oil is used. In addition to pursuing higher prices, minimising the price differential is essential for maintaining demand. Consequently, the optimal outcome is defined by the highest prices accompanied by the smallest price discount, as depicted in Table 4, which presents the payoff values and their difference.

Table 4: Price discount between palm oil and soybean oil at both Nash equilibriums

Actions	Palm Oil Price	Soybean Oil Price	Soybean Oil Price – Palm Oil Price
(Increase, Increase)	709.18	832.21	123.03
(Decrease, Decrease)	764.30	876.58	112.28

It is advantageous for palm oil to maintain a lower price relative to the peak price of soybean oil while minimising their price discount. This ensures that demand for palm oil against soybean oil is sustained, leading to higher returns. Given that soybean oil prices in both Nash equilibriums surpass palm oil prices, the ideal strategy for soybean oil is to select the highest price, while a minor price discount helps to keep the product competitive. Table 4 indicates the strategy of reducing supply by both players is preferable, as it not only yields the highest prices but also produces a narrower positive price discount between palm oil and soybean oil. Hence, the integration of Nash equilibrium with price discounts offers players a more comprehensive approach to decision-making, by effectively balancing price and demand within the context of the palm-soybean stochastic game.

6. Discussion

The primary objective of managing palm oil price dynamics is to reduce price volatility and improve returns. A game-theoretical model offers palm oil stakeholders a measure of control over market prices by strategically regulating supply in relation to demand under changing market conditions. This is significant for palm oil producing countries like Malaysia and Indonesia, where disparities in production capacity render game theory an effective resource allocation tool (Mughwai 2020). However, establishing a cohesive management system presents certain challenges as producing countries often act in self-interest, adopting conflicting policies that have an impact on the final outcomes.

Indonesia imposed a comprehensive ban on palm oil exports in April 2022, even as prices reached an unprecedented peak (Office of Assistant to Deputy Cabinet Secretary for State Documents & Translation 2022). This initiative was aimed at curbing profiteering and ensure the availability of palm oil for domestic consumption. In May 2022, Malaysia proposed lowering palm oil export tariffs from 8% to 4-6% to increase market share and stimulate demand, in response to Indonesia's export ban (Reuters 2022). Conflicting unilateral actions like these have an impact on palm oil market dynamics and jeopardise the entire palm oil industry. Therefore, a singular entity is necessary to formulate coherent decisions and develop effective strategies for the industry. The palm-soybean stochastic game presupposes the existence of such an entity responsible for making decisions on behalf of palm oil.

The establishment of the Council of Palm Oil Producing Countries (CPOPC) in 2015 represents a strategic initiative designed to coordinate decision-making to benefit the palm oil

industry (Antara 2015). Formed as an intergovernmental organisation, its function is to standardise sustainability practices, coordinate production efforts, and advocate for the palm oil industry. The distribution of data to improve industry oversight allows CPOPC to function as a cohesive decision-making body, making it an effective representative of palm oil in the palm-soybean stochastic game. The actions of increasing or decreasing supply are presumed to be implemented through legislative enactment, regulatory establishment, or program implementation as initially intended for CPOPC at its inception.

The volatility of the global vegetable oil market imposes certain limitations on the functionality of the palm-soybean stochastic game. The quarterly game period distinguishes the model from traditional game theory concepts by allowing players to adjust earlier decisions in response to changing economic conditions. The longer interval may also result in involuntary supply shortages due to weather, environmental factors, disease outbreaks and political conditions. As a result, the capacity for supply change, voluntary or otherwise, has the potential to disrupt payoff stability, resulting in outcomes that differ from the players' expectations.

Another limitation is the accuracy of the data used in the palm-soybean stochastic game for analysis, simulation of previous player actions, and payoff calculations. Economic data collection and publication typically requires 30 to 65 days due to multiple data streams, and this lag has a significant impact on its timeliness and accuracy. Given that the values are in the millions of metric tonnes, rounding of supply statistics further reduces its accuracy. A rounding adjustment of even a single metric tonne can swing the decision between supply increasing or decreasing strategies, especially when neither quantitative significance.

Futures trading that leverages on the volatility of palm oil prices introduces an additional limitation to the palm-soybean stochastic game. Futures prices reflect the anticipated selling price of palm oil in the future, relying on price fluctuations to make a profit, with the buyer receiving the product at a later time. The concept reduces players' control in the palm-soybean game due to a lack of awareness regarding the product supply entering the market. Speculation ultimately affects prices, compromising the accuracy of the payoff matrix and affecting players decisions. The articulation of these limitations does not indicate the frailty of the palm-soybean stochastic game; rather, it serves to avert misinterpretations of the results and delineates the model's representational capacities.

Game theory has previously been utilised in the palm oil industry, notably by Lee *et al.* (2017), who adapted it to address the haze pollution issue faced by Indonesia. Rizwan (2014) uses the Prisoner's Dilemma framework to advocate for formalising collaboration between Malaysia and Indonesia, while Tang *et al.* (2015) employ game theory to analyse and develop better strategies for the palm oil biomass sector. The cooperative game theory model facilitates optimal profit and investment allocation between the palm oil refinery and biomass co-generation system (Tan *et al.* 2021).

Andiappan *et al.* (2022) used game theory to determine strategies for optimising the use of existing plantations, suggesting that expansion may be warranted to meet the rising global demand for vegetable oil while remaining within sustainable limits. Warnes *et al.* (2025) proposed a game-theoretical model in which heterogeneous farmers establish intra-family coalitions for forest clearing, rewarding the community when economic gains from such activities are absent in the region. The aforementioned studies illustrate the viability of applying game theory across various facets of the palm oil industry; nonetheless, its application in the management of palm oil pricing remains unexplored.

7. Conclusion

The study shows that market interactions between palm oil and soybean oil fulfil all the defined attributes of a stochastic game, especially when framed as a price determination mechanism. Stochastic games are generally characterised by computational complexity; however, the palm-soybean stochastic game presents a relatively simple structure, attributed to the utilisation of data-driven methodologies. The palm-soybean stochastic game demonstrated how palm oil stakeholders can utilise supply to potentially reduce price volatility, optimise returns, and improve sustainability.

Future research can enhance the palm-soybean stochastic game model by incorporating quantitative metrics into the actions accorded to each player. This will provide players with better control over the volume of product supplied to the market relative to the expected pricing. To preserve the model as a finite game, as stipulated by the definition of a stochastic game, actions to increase or decrease supply can be implemented in set percentages.

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