Palm oil supply and demand characteristics and behavior: A system dynamics approach

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Abstract

Like other commodities, palm oil is characterized by common commodity cycles in the market. However, in this study, we argue that the palm oil market has distinctive traits compared to other commodity markets with regard to the cobweb theorem by elaborating on the characteristics of the Malaysian palm oil market and its basic underlying behavior. In an attempt to understand the behavior of the industry, researchers had been changing the paradigm of modelling the palm oil market by using the operationally-based modelling approach (like system dynamics - SD-) rather than the observationally-based modelling approach (like econometrics). Thus, we propose a basic SD model of the palm oil market based on the Malaysian palm oil industry and tested its capability to replicate the real situation in the palm oil market. Five placeholder variables are included in the model to represent the exogenous factors influencing the key variables. Findings from the simulation-based run show that the palm oil market produces a fluctuating pattern of its key variables ceteris paribus, as suggested in cobweb theorem. For future works, further disaggregation of the key variables and exogenous factors is possible, thus adding model complexity in order to achieve specific objectives. This study contributes by setting up the fundamental structure of the market model for palm oil and other similar commodities.

Introduction

Palm oil is one of the most-traded vegetable oils in the global market, along with soybean, rapeseed and sunflower oil. Among its substitutes, palm oil stands out as the most economically-viable vegetable oil in terms of yield per hectare (Tan et al., 2009). Palm oil has been used as an input in various sectors including food and cosmetics as well as being processed into biodiesel to be blended with petro-diesel as an alternative renewable fuel. In the global market, Indonesia and Malaysia contribute the biggest combined production, and account for approximately 86 percent of world production (Malaysian Palm Oil Board (MPOB), 2016; United States Department of Agriculture, 2015). Furthermore, the palm oil industry also contributes to socio-economic development with the aim of alleviating poverty, even though the situation of workers in the sector remains deplorable, particularly their employment status and income (Sinaga, 2013).

A typical commodity market, like palm oil, faces fluctuations in its key variables, like price in particular. As suggested by the cobweb theorem, the causes of price fluctuation in a commodity market are mainly attributed to its supply and demand. In addition, other stochastics exogenous factors also affect key variables and ultimately cause the price to fluctuate (Glöser & Hartwig, 2015).

The operations research community has been using system dynamics (SD) in modelling commodity markets. In SD, the incorporation of delays and feedback effects of a stock and flow model allows a comprehensive analysis of dynamic market behavior (Sterman, 2000). The generic SD commodity model, proposed by Meadows (1970), has been applied on the livestock market based on the cobweb theorem. The author proposed a dynamic cobweb theorem that installs the dynamics of capacity-building delays of raw materials as the main cause for cyclical price behavior.

Despite sharing common traits with other commodity markets, the palm oil market has distinctive criteria in terms of its supply chain and rule factor of endogenous as well as exogenous variables. For this reason, we attempted to develop a basic palm oil market model based on the generic commodity market model in SD in this study. We also explain the different traits in the palm oil market model compared to other commodity markets. At the end of the study, we developed an SD model representing the fundamental dynamics in the palm oil market. The application of SD in modelling the palm oil industry has helped to highlight the relationship between variables as well as feedback processes in the industry, which sometimes may be overlooked. This holistic view is critical for designing good policies and clearly identifying the important roles played by all elements in the industry (including the people, the market, etc.) in order to achieve sustainability. Moreover, SD demands a high level of community engagement in the modelling process and promotes operational thinking among citizens to design good policies for sustainable agriculture. For this reason, the application of SD accentuates the critical role of citizen science and citizen contribution to the industry dynamic.

To facilitate the understanding of palm oil market behavior, researchers had been changing the paradigm of modelling the palm oil market from using the operationally-based modelling approach (like system dynamics) to the observationally-based modelling approach (like econometrics). This transition can be seen from the studies by Yahaya et al. (2006), Abdulla et al. (2014), Shri-Dewi et al. (2015), and Mohammadi et al. (2016). Operationally-based modelling emphasizes feedback processes following the actual operation happening in a system, rather than the correlational relationships measured by the strength of coefficient values, which is lauded by observationally-based modelling (Olaya, 2015). As such, this study proposes a basic SD model of the palm oil market that is capable of depicting the basic feedback processes and behavior of the palm oil market. The findings of this study contribute to this field by highlighting the characteristics of the palm oil market and its differences compared to other commodity markets, as well as the role played by variables like supply, demand and prices in influencing the behavior of the industry. The goal of this research is to provide a sufficiently good reference for future research in modelling the palm oil market. Furthermore, with some modifications, the proposed model can also serve as a reference in terms of its structure and dynamic behavior for other agricultural commodities, such as cocoa, coconut and rice.

Generic Commodity Market System Dynamics Model

In microeconomic theory, cobweb theorem explains market fluctuations based on the appearance of the supply and demand combinations by showing the shape of a cobweb (Harlow, 1960; Larson 1964; Holt & Craig, 2006). In cobweb theorem, there are three main supply and demand functions with different fluctuations: namely continuous, divergent and convergent (Pashigian, 2008). The supply side exhibits a discontinuous adjustment, while the demand side shows instantaneous reaction to changes in price (Ezekiel, 1938).

Meadows (1970) demonstrated the application of cobweb theorem in a dynamic environment in the livestock market. In dynamic environments, delays in the negative feedbacks controlling inventory, capacity acquisition or other resources are the underlying causes of cyclical movements in many commodity markets. The basic feedback structure of production cycles proposed by Meadows (1970) is illustrated using the Causal Loop Diagram (CLD), shown in Figure 1.

However, commodity markets are also influenced by stochastic exogenous factors like economic crisis, unexpected supply disruptions or other market shocks, which make the market fluctuations less periodical and harder to predict (Gloser & Hartwig, 2015). This is true in the palm oil market, in which supply and demand are influenced by exogenous factor like adverse weather, palm oil tax, soybean prices and even crude oil prices (Shri Dewi et al., 2011; Arshad & Hameed, 2012; Rahman et al., 2013; Abdulla et al., 2014). Thus, in the palm oil market, one can expect a fluctuating pattern perturbed by these exogenous factors, as illustrated by the actual data of the Malaysian palm oil industry in Figure 2.

Most of palm oil market models developed in previous studies were based on the generic commodity cycle model presented with an added degree of detail and some modification based on the model purpose regardless of the industry region. Examples of this are the palm oil SD models in Indonesia (Suryani, 2015) and in Ma-
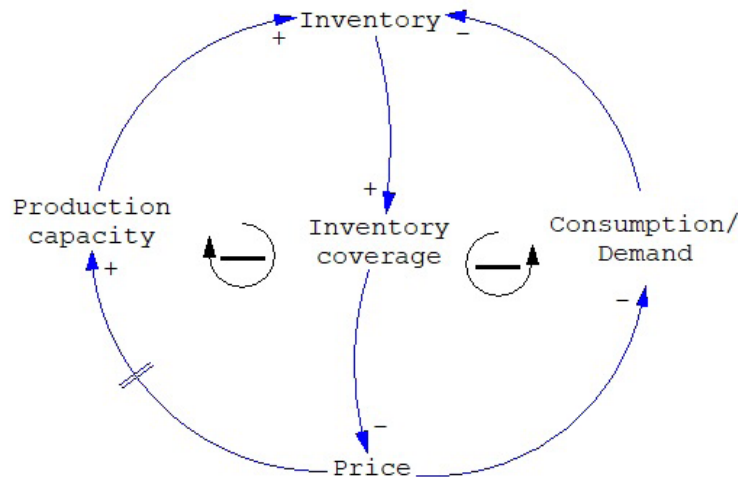
Figure 1: Feedback loop for typical commodity cycles (adapted from Meadows, 1970)

Figure 2: Malaysian palm oil historical data on crude palm oil (CPO) supply, consumption and price (Source: MPOB, 2016)

laysia (Yahaya et al., 2006; Abdulla et al., 2014; Mohammadi, et al. 2015; Shri Dewi et al., 2015). The important question here is how the modeler can effectively model the palm oil industry using SD, while also following the cobweb theorem, considering that the industry itself has its own distinctive characteristics. Thus, this article seeks to answer this question by developing a basic SD model which incorporates the fundamental structure and behavior of the palm oil market (based on the Malaysian palm oil industry, considering its reputation as one of the largest palm oil producers in the world market) involving its supply, demand and price setting mechanism. The model represents the basic dynamics of the palm oil market and can be modified to fit the specific objectives of any modelling project for the palm oil industry in the future.

Malaysian Palm Oil Market Model Characteristics

Before developing the palm oil market model, it is imperative to understand the underlying dynamic behavior in the palm oil market to ensure that the developed model is correct both in structural and behavioral aspects. This section explains the basic characteristics and behavior of the palm oil market based on the Malaysian palm oil industry, as it is the second largest palm oil producer in the world market after Indonesia. This will form a basis for the underlying rules in modelling a generic and robust palm oil market SD model. The developed model, though simple and small in its scope, is assumed to be capable of representing the general behavior of the palm oil market. The basic palm oil market model developed in the next section may be enhanced to include addi-

tional details depending on the needs of future studies. It is convenient to divide the palm oil market into three main sections: namely production, demand and price setting. Production begins with the oil palm plantations and consists of three phases: namely the immature, mature and ageing phases. Each phase involves different delays which cause uneven patterns in palm oil production. Young seedlings take approximately three years to become mature. In the mature period, oil palm is capable of producing at the maximum yield level for approximately 20 years (Wahid & Simeh, 2010). After 20 years, oil palm has passed its peak production and the yield can decrease by 15 percent (Wahid & Simeh, 2010). Hence, total yield comes from the mature and ageing areas. The oil production process involves the extraction of a certain percentage of extractable oil from the oil palm fruit. The extracted oil is called crude palm oil (CPO) and is recommended for prompt further processing as its Free Fatty Acid (FFA) content will increase if it is stored for a long time, thus deteriorating its quality (Kanagaratnam et al., 2013; Rani et al., 2015).

CPO is distributed for export, local supply for processing to produce processed palm oil (PPO), and as a feedstock for palm-based biodiesel production. The total demand is thus composed of CPO demand from overseas as well as for local processing. Based on microeconomic theory, CPO demand is influenced by its price. However, it is assumed that CPO demand is less sensitive in the short-term due to the fact that most CPO trading is based on long-term future contract prices to reduce the impact from price fluctuation.

Finally, the CPO price setting section, as its name suggests, commands the mechanisms behind setting the price. In a common commodity market, the price setting is largely dictated by the difference between its supply and its demand. Based on microeconomic theory, the price will increase when the demand exceeds supply and vice-versa.

In a generic commodity market model, the long-term expected commodity price determines the expansion of the production capacity (Sterman, 2000). This may be applied when the system contains a short-term capacity expansion capability (for instance, the livestock market in Meadows,1970; or the metal market in Gloser & Hartwig, 2015). For an agricultural commodity like the palm oil market, however, modification has to be made for the link between long-term price and production capacity. In the Malaysian palm oil market in particular, the expansion of oil palm plantation area involves a time delay and several constraints. The time delay includes the delay between planting the seeds and harvesting fruits from mature oil palm trees. Furthermore, oil palm plan-

tation expansion requires suitable land to be converted into plantation area. Malaysia, for instance, is currently facing a scarcity of potential land for oil palm plantation expansion. Although some land is available in the regions of Sabah and Sarawak, it is constrained by issues related to land ownership and suitability (PEMANDU, 2014). Therefore, it is unrealistic to model Malaysian oil palm plantation area expansion based on the long-term CPO prices due to this limitation. Unlike in other commodity markets, oil palm plantations in Malaysia can be assumed to be stagnant, with a very low percentage of expansion or growth.

Another important aspect in considering the linkage between palm oil production capacity and long-term growth is the capability of reducing the production capacity. A typical commodity market may be capable of reducing its production capacity based on the profit derived from its price level (for instance, in the livestock market). However, in the palm oil market, reducing the capacity may not be as swift as in other commodity markets due to the nature of the industry. As an agricultural commodity industry, the production of palm oil requires the supply of oil palm fruits from oil palm plantations. During the low palm oil price period, it is economically infeasible and nonsensical for planters to chop down the trees just to respond to low profit gain. Rather, the planters will continue their business activity, supplying fresh fruit bunches (FFB) and reaping whatever revenue they can while waiting for the price to recover. Planters will behaviorally make profit their utmost priority aside from other uncertainty in the market judging from the amount of input and time they have invested in planting oil palm trees.

This is also true from the perspective of CPO processors. The processors will not stop producing CPO and let the supplied FFB rot unprocessed. In a nutshell, it can be assumed that the price and profit have a low influence on the change in capacity acquisition in the palm oil industry, contrary to other commodity markets. CPO will continue being produced, and therefore market demand is largely responsible for determining the ratio between supply and demand. The main causes for the shrinkage of production capacity is through aggressive measures like closing the plantation area or through the replanting of ageing trees, which creates a time gap of approximately three years of suppressed FFB supply before the young plants becomes mature and therefore capable of producing maximum yield. Hence, it is inappropriate from a behavioral perspective to link profit derived from CPO prices with dynamic change in the plantation area, even in the long term in the context of the Malaysian palm oil industry.
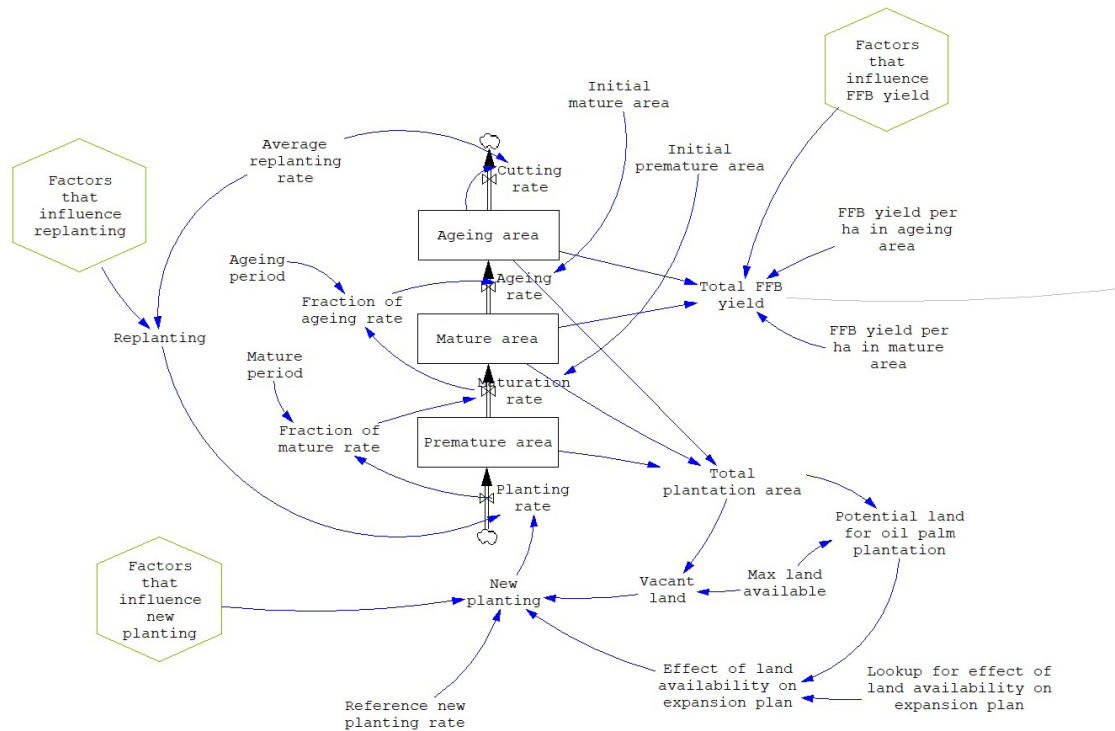
Figure 3: Causal loop diagram of the Malaysian palm oil market. (Authors' Illustration)
CPO = crude palm oil; FFB = fresh fruit bunch

The aforementioned characteristics and underlying dynamics of the palm oil market can be captured using a Causal Loop Diagram (CLD). A CLD is drawn to capture the qualitative model at the beginning of the modelling process. It helps in projecting the cause and effect relationships and feedbacks among variables, particularly for the purpose of capturing the mental model of a problem in a non-technical fashion (Sterman, 2000). Variables are linked by arrows with the appropriate polarity based on their relationship and showing the direction of influence. Positive polarity exhibits a direct influence, while negative polarity exhibits an inverse influence. This helps in forming the feedback processes in the model, which are categorized into positive and negative loops. Positive loops reinforce the variables in the loops, while negative loops balance the output from the loops (Stermand, 2000; Morecroft, 2007).

Figure 3 shows the CLD of the Malaysian palm oil industry, projecting the fundamental interrelationships and feedback processes. It has three negative loops belonging to the plantation sector, whereby each incremental increase in plantation area increases the next area and at the same time reduces the previous area. Collectively, the replanting rate connects the inter-phase process, which closes the plantation sector loop, constituting a positive feedback. Another negative loop is construed by the relationship between CPO supply, demand and prices based on microeconomic theory. This negative loop exhibits the balancing mechanism of the loop. For instance, with excessive supply (high CPO supply minus demand), the CPO price will become low. Low CPO prices will increase demand through more purchase of CPO. However, high purchase of CPO will at some point reduce CPO supply over its demand, thus increasing the CPO prices over time. High CPO prices will then suppress demand and the loop continues. This behavior of the price setting mechanism is expected to produce fluctua-

tions, as suggested by the cobweb theorem.

Malaysian Palm Oil Supply and Demand Model

Despite its usefulness, the CLD only acts as a tool for preliminary analysis of the studied system and can never be taken as a complete imitation of the real system. The limitations of the CLD include the non-distinguishable nature of the variable types and lack of details in the feedback loops of the system (Sterman, 2000). Referring to the CLD in the previous section, we developed a stock and flow diagram (SFD) to capture the basic dynamics in the palm oil supply and demand in Malaysia. Unlike CLD, SFD quantifies the relationship between variables in the form of stocks and flows, thus permitting more detailed analysis of the studied system. Structurally, SFD is much more effective in depicting the real system compared to CLD. The main components that build an SFD are stock, flow, auxiliary and link. Stock refers to the state of the system at a particular time and is also known as the accumulation or level. Flow variables determine the value of the stock, whereby net flow will increase or decrease the value of the stock. Auxiliary is the other variable in the system which specifies the decision rules carrying information between system components. The variables are connected by links in the form of arrows to define the connection and control between the variables in the system.

In this study, the SFD consists of the oil palm plantation sector, the CPO supply and demand section, and the CPO price setting mechanism. In general, the developed model is aggregated to capture the basic palm oil supply and demand dynamics in the Malaysian palm oil industry. There are placeholder variables in the hexagonal box as a suggestion of possible additional exogenous factors influencing the corresponding key variables. These factors could be added with various levels of disaggregation depending on the modelling objective. Via these

Figure 4: Stock and flow diagram for the oil palm plantation sub-model (Authors' Illustration)

placeholder variables, exogenous factors like substitutes' prices, export taxes and adverse weather can be incorporated into the model as the factors influencing the behavior of key variables (e.g. CPO supply, demand, and prices) in a more logical, operationally-oriented manner. This approach is contrary to observationally-based modelling, whereby the aforementioned factors would be directly related to the key variables and the strength of the correlational relationships would be measured based on the values of the respective coefficients.

The oil palm plantation sector in Figure 4 captures the various phases of the plantation area: namely premature, mature and ageing. The rate of each phase is modelled using a delay to depict the true dynamics of oil palm planting. For instance, 100 hectares of newly planted premature area is expected to become 100 hectares of mature area after 3 years, and 100 hectares of ageing area after 20 years. Equations 1-5 list the key functions in the oil palm plantation sector sub-model. There are three placeholder variables in the model: factors that in-

fluence new planting, factors that influence replanting, and factors that influence FFB yield. Equation 1 shows the planting rate, which is composed of new planting and replanting. Equations 2 and 3 are the maturation and ageing rates, which are determined by the fraction of each rate. For the maturation rate, the fraction is calculated based on the planting rate and the delay for the new planted area to become mature, defined by a maturation period as in Equation 4. The ageing rate is calculated in a similar function based on the maturation rate and the delay for the mature area to become ageing, defined by the ageing period as in Equation 5.

Total FFB yield in the oil palm plantation sector sub-model serves as the connection with the CPO price setting sub-model, as shown in Figure 5. CPO production is obtained by multiplying the total FFB yield with the oil extraction rate. CPO demand is aggregated for simplification purposes in this study. The CPO price setting mechanism is based on its supply and demand ratio. In the same loop, CPO price influences the purchase of

$$Planting\ rate=New\ planting+Replanting \tag{1}$$

$$Maturation\ rate=Fraction\ of\ mature\ rate \tag{2}$$

$$Ageing\ rate=Fraction\ of\ ageing\ rate \tag{3}$$

$$Fraction\ of\ maturation\ rate=f(Planting\ rate,Mature\ period) \tag{4}$$

$$Fraction\ of\ ageing\ rate=f(Maturation\ rate,Ageing\ period) \tag{5}$$
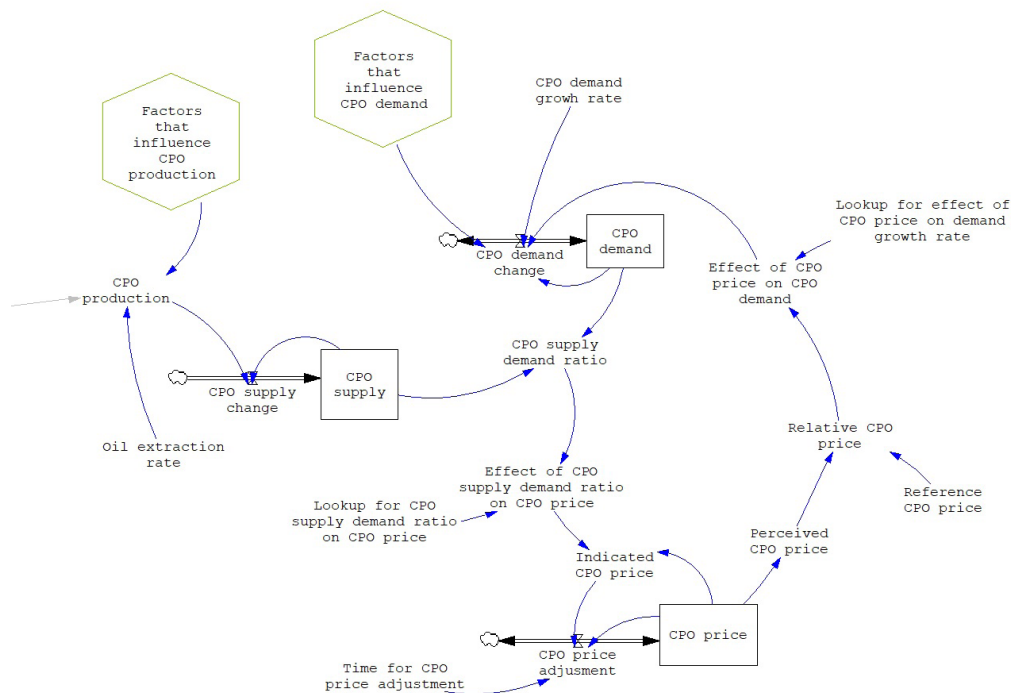
Figure 5: Stock and flow diagram for CPO price setting sub-model (Authors' Illustration)

CPO, thus determining the demand. We modelled the decision to purchase CPO behavior based on a CPO price moving average to represent the non-sensitivity of purchasers to short-term price fluctuations.

Equations 6 to 16 list the key equations in the CPO price setting sub-model. Equation 6 shows the CPO supply formulated in a stock form. The accumulation of the stock is dependent on the CPO supply change (increase or decrease) and the initial CPO supply. The stock form is also used to formulate CPO demand and price in Equa-

tion 7 and Equation 8, respectively. The CPO demand stock is accumulated through the demand change and initial demand. In a similar fashion, CPO price stock is accumulated via price adjustment and the initial price. CPO supply change is calculated by multiplying the total FFB yield with the oil extraction rate (the percentage of oil extractable from a tonne of FFB) as in Equation 9. The CPO demand change, on the other hand, is dependent on the demand growth rate, which is also influenced by the effect of CPO price on demand, as in Equation 10. The effect of CPO price on demand is based on the rel-

$$CPO\ supply = \int CPO\ supply\ change + CPO\ supply_0\ dt \tag{6}$$

$$CPO\ demand = \int CPO\ demand\ change + CPOdemand_0 dt \tag{7}$$

$$CPO\ price = \int CPO\ price\ adjustment + CPO\ price_0 dt \tag{8}$$

$$CPO\ supply\ change = Total\ FFB\ yield \times Oil\ extraction\ rate \tag{9}$$

$$CPO\ demand\ change = Effect\ of\ CPO\ price\ on\ CPO\ demand \times CPO\ demand\ growth\ rate \tag{10}$$

$$Effect\ of\ CPO\ price\ on\ CPO\ demand = f(Relative\ CPO\ price) \tag{11}$$

$$Relative\ CPO\ price = (Perceived\ CPO\ price)/(Reference\ CPO\ price) \tag{12}$$

$$CPO\ price\ adjustment = (Indicated\ CPO\ price - CPO\ price)\ /\ Time\ for\ CPO\ price\ adjustment) \tag{13}$$

$$Indicated\ CPO\ price = Effect\ of\ CPO\ supply\ and\ demand\ on\ CPO\ price \times CPO\ price \tag{14}$$

$$Effect\ of\ CPO\ supply\ demand\ on\ CPO\ price = f\ (Supply\ demand\ ratio) \tag{15}$$

$$CPO\ supply\ demand\ ratio = (CPO\ supply)/(CPO\ demand) \tag{16}$$
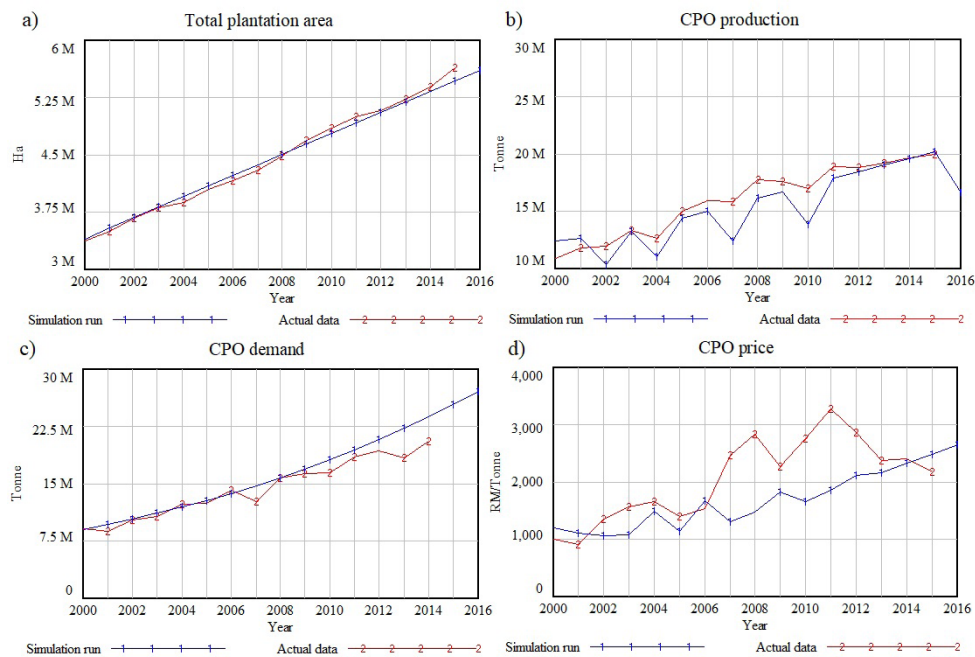
Figure 6: Simulation run comparison with actual data: (a) Total plantation area; (b) crude palm oil (CPO) production; (c) CPO demand; and (d) CPO price. (RM: Malaysian Ringgit)

ative CPO price, as in Equation 11, which is equal to the ratio between perceived CPO price in the market and the reference CPO price, as in Equation 12. In other words, if the perceived CPO price is higher than the reference CPO price (which means the buyers are willing to pay more than the reference price), the ratio will be higher, thus the CPO demand will increase, and vice versa.

The CPO price adjustment in Equation 13 is calculated by dividing the difference between the indicated price and the CPO price with the time needed for the price to be adjusted. This equation incorporates the role of time delay in setting the CPO price in the market. A shorter-term delay means the price is more sensitive to the change, while a longer-term delay means the price is less susceptible to the market sentiment. The indicated CPO price incorporates the effect of CPO supply and demand on the CPO price, as in Equation 14. The effect of CPO supply and demand is based on the supply demand ratio in Equation 15, which is calculated by dividing the CPO supply with CPO demand, as in Equation 16. This equation indicates that as the ratio of CPO supply to demand increases (oversupply), the CPO price will decrease, and vice versa.

In this sub-model, there are two placeholder variables: factors that influence CPO production and factors that influence CPO demand. These placeholder variables can be replaced with exogenous factors (e.g. substitutes' prices, export taxes, adverse weather, etc.) to depict their

influences on CPO supply and demand behavior, which leads to the fluctuation in CPO prices. In addition, further details can be added into the model by further disaggregating CPO supply and demand, for instance, by incorporating CPO import and separating CPO demand based on distribution channels such as PPO production, biodiesel production, and exports.

Model Validation and Base Run Simulation

The model has been validated using actual data from the years 2000-2015. Figure 6 shows the comparison of the simulation run and actual data of the key variables, namely the total plantation area, CPO production, CPO demand and CPO price. Statistical error analysis using Root Mean Square Percent Error (RMSPE) and Theil's inequality coefficients has been done for validation purposes (Sterman, 1984). The RMSPE provides a normalized measure of the magnitude of the error. Theil's inequality coefficients on the other hand consist of UM, US, and UC, which reflect the fraction of the mean-square-error due to bias, unequal variance, and unequal covariance, respectively (Sterman, 1984). The results of the statistical error analysis are compiled in Table 1. All variables produced sufficiently small RMSPE values, denoting the close relationship between simulation run data and the actual data. Furthermore, the low Theil's inequality coefficient produced by all variables denotes a satisfying fit of the modelled data to the actual data. A better fit may

Tabel 1: Statistical error analysis of key variables

Variable	RMSPE (%)	Theil's Inequality Coefficients		
		U^M	U^S	U^C
Total plantation area	1.35	0.02	0.57	0.40
CPO production	9.94	0.29	0.00	0.71
CPO demand	9.22	0.40	0.29	0.31
CPO price	27.78	0.38	0.12	0.51

Tabel 2: Parameters used in simulation base run

Variables	Parameter	Unit
Ageing period	20	Years
Average replanting rate	60,000	Hectare/Years
CPO demand growth rate	1	Dimensionless
Factors that influence CPO demand	1	Dimensionless
Factors that influence CPO production	1	Dimensionless
Factors that influence FFB yield	1	Dimensionless
Factors that influence new planting	1	Dimensionless
Factors that influence replanting	1	Dimensionless
FFB yield per ha in ageing area	15	Tonne/Hectare
FFB yield per ha in mature area	22	Tonne/Hectare
Initial ageing area	1,000,000	Hectare
Initial CPO demand	9,000,000	Tonne
Initial CPO price	1,200	Malaysian Ringgit/Tonne
Initial CPO supply	10,800,000	Tonne
Initial mature area	2,000,000	Hectare
Initial premature area	400,000	Hectare
Mature period	3	Years
Oil extraction rate	21	Percent

be obtained with the incorporation of exogenous influence variables represented by the placeholder variables, as shown in SFD in the previous section.

The base run of the model is executed using the parameters shown in Table 2. The parameter values are based on Malaysian palm oil industry data obtained from various sources The running period of the base run simulation was extended until the year 2100 to allow observation of its behavior in the long term. Figure 7 shows the simulation base run for CPO supply, demand and price. As the CPO supply is fairly stagnant, the source of price fluctuation comes from its demand. There is some delay of CPO demand response to CPO price change to depict the low sensitivity of demand change to the CPO price fluctuation. As argued in the previous section, there is no significant influence of the CPO price on the size of the production capacity of Malaysian palm oil due to limita-
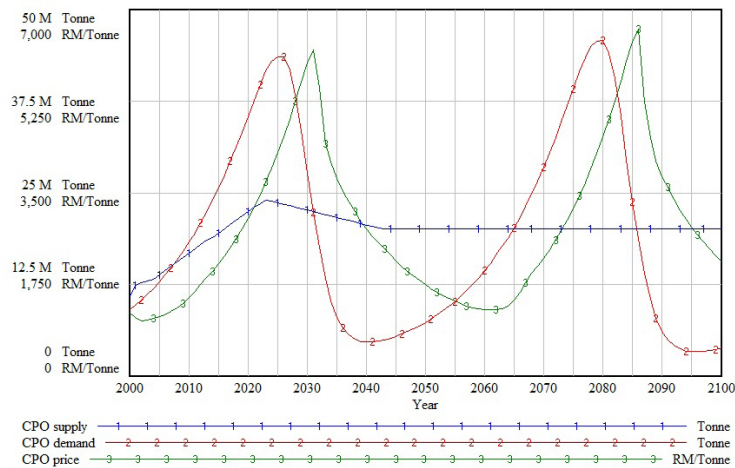
Figure 7: CPO supply, demand and price for simulation base run (RM: Malaysian Ringgit)
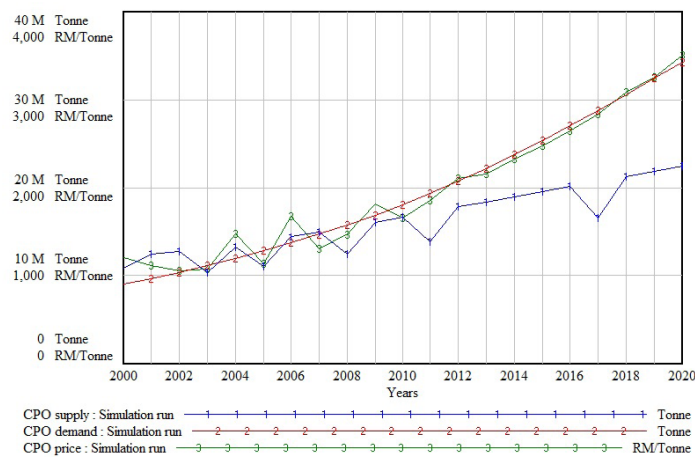

Figure 8: CPO supply, demand, and price with CPO production uncertainty due to exogenous factors (RM: Malaysian Ringgit)

tions to expansion. This explains the relatively constant production in the simulation base run. The fluctuation in CPO price is thus highly attributed to the demand change ceteris paribus.

In the real world, CPO production actually plays an important role in the price setting mechanism, but the source of CPO production fluctuation is largely attributed to exogenous factors (e.g. adverse weather and labor availability). To simulate this, we conducted another simulation in which CPO supply was pre-set with uncertainty elements. As illustrated in Figure 8, uncertain CPO supply is also a huge determinant of CPO price fluctuation ceteris paribus.

This study attempts to develop a basic model of the palm oil market based on the Malaysian context. The obtained simulation base run model of CPO supply, demand and price is based on the assumption that there are no exogenous factors influencing the key variables.

In the real world, on the other hand, various exogenous factors may influence key variables, as demonstrated in Figure 8. Thus, in future works, a model expansion may be possible by exploring the effects of exogenous factors. Table 3 compiles a non-exhaustive list of exogenous factors to be considered in the model. The inclusion of these factors may result in more variance in the simulation outcome and dynamic behavior. Nevertheless, the palm oil market model developed in this study has been shown to be capable of representing the basic behavior of Malaysian supply, demand and price for palm oil.

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Tabel 3: Possible exogenous factors influencing key variables in the palm oil market

Placeholder variables	Possible exogenous factors
Factors that influence CPO demand	Substitutes' prices, crude oil price, taxes and levies
Factors that influence CPO production	Production costs, labor availability
Factors that influence FFB yield	Adverse weather, labor availability
Factors that influence new planting	Seedling price, fertilizer price, labor availability, land area change
Factors that influence replanting	Seedlings price, fertilizer price, government incentives, labor availability, land area change

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Conclusions

In this study, an SD model of the palm oil market has been developed to capture the basic underlying dynamic behavior of the Malaysian palm oil industry. Validation of the simulation base run data with actual data has proven the capability of the model to describe the fundamental structure of the Malaysian palm oil industry. The basic model assumed that the oil palm plantation area is currently stagnant based on the current Malaysian palm oil industry situation, which is characterized by limited expansion opportunity. Based on the simulation base run, the palm oil market shows a typical commodity fluctuation pattern, as suggested in the classic cobweb theorem. However, contrary to other commodity markets, the production capacity is stagnant (due to the behavior of producers and planters) and has little response to CPO price (in terms of capacity shrinkage and expansion), but high dependency on exogenous factors. In addition, CPO price has been found to be highly affected by demand ceteris paribus. However, in reality, CPO supply (largely dictated by CPO production) plays an important role in determining CPO prices, even though the base run suggested the capacity is stagnant, because the fluctuation of CPO supply may come from exogenous factors (e.g. adverse weather and labor shortages). To demonstrate this, uncertainty of CPO supply was tested in another simulation run which resulted in fluctuation of CPO prices, indicating CPO supply can play a huge role in determining the prices ceteris paribus.

The findings of this study are expected to contribute to this field by demonstrating the structure and behavior of the palm oil market in terms of the dynamics of its supply, demand and price setting mechanism. For future projects, five placeholder variables representing the exogenous factors influencing the corresponding key variables have been included in the model for further exploration and model expandability. This could include factors that influence CPO demand, CPO production, FFB yield, new planting, and replanting. Any possible exogenous factors could be incorporated via these placeholder variables based on the modelling scope and objectives in the future works. Furthermore, with some modification, the model could also be a good reference for modelling other agricultural commodities like cocoa, coconut and rice.

Acknowledgments

Conflict of Interests

The authors hereby declare that there are no conflicts of interests.

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