Oil Palm Industry Economic Journal Vol. 21 (2) September 2021 p. 1 – 21
DOI: https://doi.org/10.21894/opiej.2021.05

Interest Rate and Supply Response of Oil Palm Producers in Indonesia

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Article history:
Received date: 24 May 2021
Accepted: 12 July 2021
Available online: 30 September 2021

ABSTRACT

Supply response analysis of agricultural products remains feasible in agricultural economics because of its relevance for producers and policymakers. This study estimates the extended Nerlovian model of supply response for the Indonesian oil palm producers, namely state-owned, private-owned, and smallholders. It mainly focuses on the impact of interest rate variation that reflects the cost of borrowing by producers for replanting purpose. The data covers annual observations between 1970 and 2017. The autoregressive distributed lag (ARDL) procedure and its non-linear form (NARDL) suggest a long-run relation of Indonesia's palm oil supply response function, except for smallholders. In the long-run, a negative expected interest rate increases palm oil supply, especially for the state-owned and private-owned producers. Oil palm producers are responsive to other supply response variables viz. relative prices, and government expenditure in the short-run. Similar findings observe if expected money supply replaces expected interest rate, to capture monetary policy. Monetary policy by Bank Indonesia (Central Bank of Indonesia) has an important implication to the palm oil sector.

Keywords: asymmetric, Indonesia, interest rates, palm oil producers, supply response function.

INTRODUCTION

The objective of this study is to examine the responses of Indonesia's oil palm producers, namely state-owned, private, and smallholders to the expected interest rate. Palm oil sector is a core sector to Indonesia's economy and development. According to BPS-Statistics Indonesia (2018), 47% of the total plantation area (12.8 million hectares) of oil palm are in Sumatra, 37.0% in Kalimantan, 3.6% in Sulawesi, and the rest such as Papua (2.0%) and Java (0.1%). Indonesia remains as the world's largest producer of palm oil (Sawe, 2018). Oil palm is the main agricultural exports for Indonesia with about 10% of total exports (Russell, 2018) contributing to foreign exchange revenue, and reduces poverty (World Bank, 2011). *Figure 1* offers a stylised fact of an increasing trend of Indonesia's total palm oil produced over the period 1970 to 2017, from about 216 827 tonnes in 1970 to 35 million tonnes in 2017. It is partially due to the Indonesia's government in regulating finance schemes for oil palm plantation development initiated since 1970s (Pramudya *et al.*, 2017). Another determining factor is the government's push to switch from coconut oil to palm oil. Pramudya *et al.* (2018) observes that the

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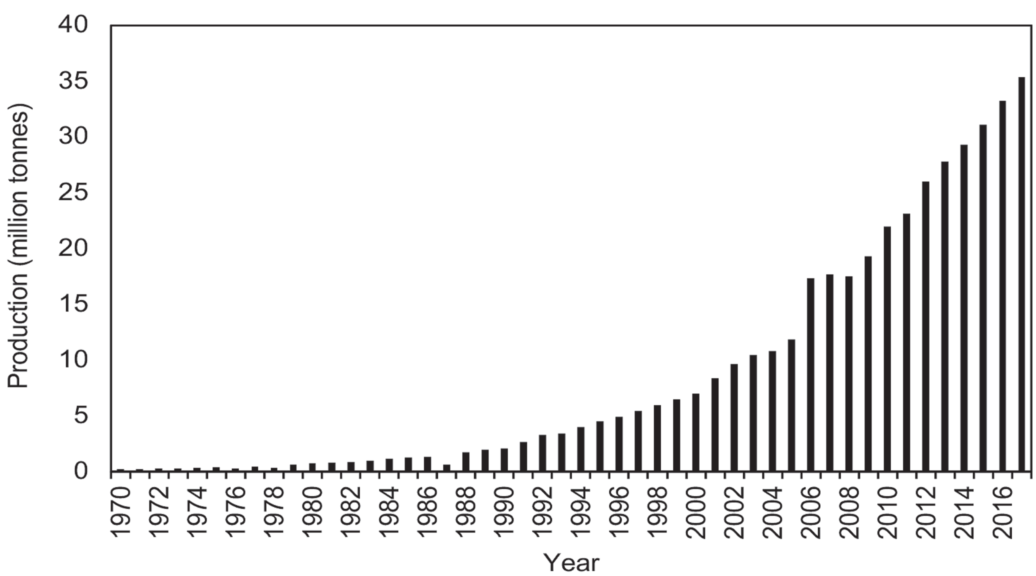
weakly enforced regulations by state to control palm oil expansion resulting in the widespread of illegal plantations. A trough of Indonesia's palm oil output recorded in 1987, then by a substantial increase in 2006. According to Andoko and Zmudczynska (2019), the Law No. 39 of 2014 is the basic concept for oil palm plantations in Indonesia that farms for crude palm oil, play an essential role and have great potential in national economic development. Other factors are the promotion of the use of palm oil for biodiesel by the European countries, high prices of palm oil, favourable weather, availability of land in Borneo and other previously non-developed areas, recent years of high seed sales, record energy prices, and high vegetable oil prices (USDA, 2007). *Figure 2* depicts both private-owned producers (and 'companies' as data source) and smallholders have substantially increased their plantation area over the period 1970 to 2017. National Labour Party (*Partai Buruh Nasional, PBN*), the state-owned plantations took the lead in the early years, and smallholders started around 1979. The planting area of state-owned plantations remained relatively unchanged.

An agricultural supply response function from Nerlove (1958) relates the supply of a commodity to expected prices and non-price factors. A feasible non-price factor interest rate is not widely tested in agricultural supply response function, except for Mohammad and Tang (2005). An interest rate that reflects the cost of borrowing to the respective palm oil producers may affect their replanting decision. This study helps to understand the responsiveness of the Indonesian oil palm producers in their planting decision against interest rate changes. Haryadi and Kusumowardhani (2017) confirms that oil palm farmers need borrowing to finance their works for replanting and chopping down old palms, land clearing and preparation, and purchasing certified seeds, as well as operational expenses. Borrowings for replanting is needed when the palm trees have reached about 25 years of age. The Indonesian Palm Oil Association (*Gabungan Pengusaha Kelapa Sawit Indonesia,* GAPKI) delivers that high lending rate in Indonesia (*i.e.* above 10%) has discouraged palm oil producers' ongoing efforts to increase their supplies (Suwastoyo, 2018). Smallholder producers are generally faced difficulty to access financing facility from formal financial institutions (Bronkhorst *et al.*, 2017; Sahara *et al.*, 2017).

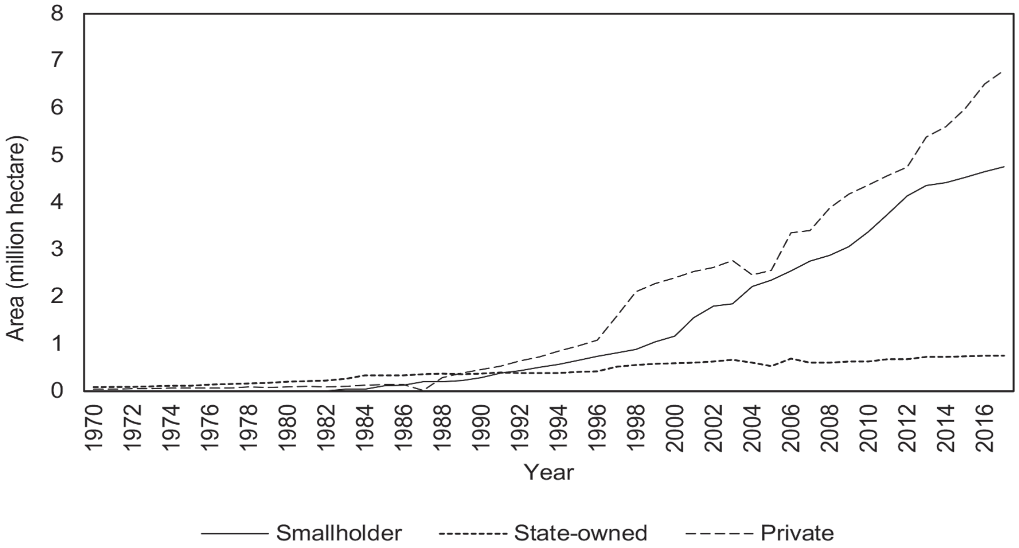
Figure 3 illustrates that the nominal interest rates by Bank Indonesia (Central Bank of Indonesia) were declining gradually for the period 1970 to 2017. The average interest rate was about 13%, while the highest was 39% in 1998 given the Asian Financial Crisis (1997 to 1998). The lowest interest rates of about 6% observed from 1978 to 1983, as well as 2012. *Figure 4* shows a negative correlation between the aggregate palm oil supply and nominal interest rate initiating this study.

This study considers the literature gap in agricultural supply response analysis available for Indonesia, viz. Sukiyono (1995) and Marpaung *et al*. (2017). Their Nerlove model omits the impact of interest rate variation. Mohammad and Tang (2005) considers this literature gap that the Malaysian palm oil producers



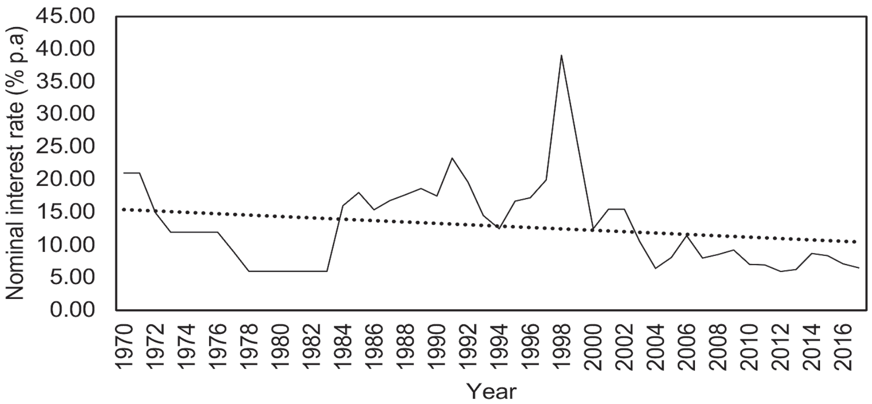
Source: Tree crop estate statistics of Indonesia, Indonesian Ministry of Agriculture.

Figure 1. Aggregate palm oil produced (in million tonnes) in Indonesia, from 1970 to 2017.



Source: Tree crop estate statistics of Indonesia, Indonesian Ministry of Agriculture.

Figure 2. Palm oil plantation area by producers (in million hectare) in Indonesia, from 1970 to 2017.



Source: IFS (International Financial Statistics); IMF (International Monetary Fund), 3-months deposit rate.

Figure 3. Nominal interest rate (% p.a) for Indonesia, from 1970 to 2017.

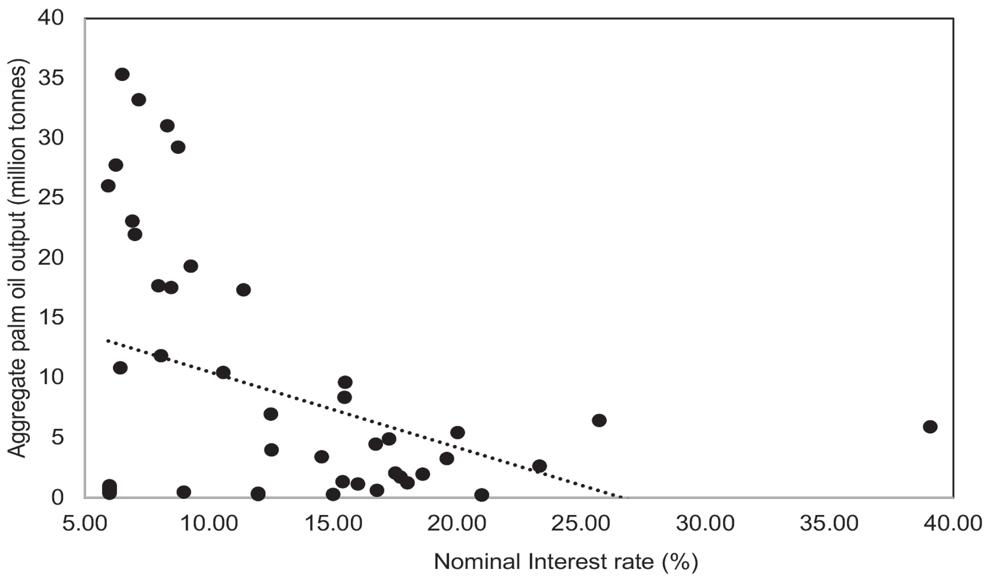


Figure 4. Correlation between palm oil supply and nominal interest rate for Indonesia, from 1970 to 2017.

respond negatively to [nominal] interest rate on oil palm planting (investment) decisions. This study follows their framework for the Indonesian data by three forms of producer's state-owned, private-owned, and smallholder. From a policy perspective, this study offers Bank Indonesia on interest rate [monetary] policy that does influence the responses of both state and private owned producers in their palm oil replanting decision.

The paper is structured as follows. First section reviews the selected studies on agricultural supply response's function including palm oil supply response in Indonesia and presents its conceptual framework. Second refreshes the Nerlove model that extended by Mohammad and Tang (2005), the variables and their stationarity. The testing methods are both linear and non-linear autoregressive distributed lag (ARDL and NARDL) procedures to estimate their long and short-runs supply response equations. Third is the empirical results, and finally, concludes this study.

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

A bulk of survey articles focuses on supply responses of agricultural commodities (Askari and Cummings, 1977; Henneberry and Tweeten, 1991; Kohli, 1996; Ogbu and Gbetibouo, 1990; Rao, 1989; Thiele, 2000). Among them, Askari and Cummings (1977) surveys the available studies between 1871 and 1972, and tabled their short and long-runs elasticities by crop and by region. They deliver that the estimates are incomparable given different definitions of price variables and supply, the periods under study, and the data accuracy. Rao (1989) considers the studies on agricultural supply response to prices in developing countries, in which their estimates (elasticities) depend on the methodology employed, and the country specific factors those relate to technology, economic structure, and macro constraints. Ogbu and Gbetibouo (1990) reviews the studies on Sub-Saharan African countries (Cameroon, Kenya, Malawi, Nigeria, Senegal and Tanzania). They observe that the methodology employed is insufficient and irrelevant explanatory variables. Henneberry and Tweeten (1991) reviews agricultural supply response in both developed and developing countries. Methodology, sample period, definition of price variable, and type of data determine the elasticities. Kohli (1996) reviews the testing methods such as Nerlovian model, multinomial logit model, time series-cross section models, profit function model, and frontier profit function. The study finds the Nerlovian model permits flexibiilty in developing dynamic specifications, but it is restricted by the assumption of both quantity of inputs and prices are exogenous. Thiele (2000) discusses different approaches employed in agricultural supply response analysis, but none of the approaches is likely to be reliable since the cross-country regressions have suffered from unobserved country characteristics, and limitations of time-series estimators.

Among the country-wise studies are Ghatak and Seale (2001); Arnade *et al.* (2002); Leaver (2004); Colman *et al.* (2005); Kumar and Sharma (2006); Ocran and Biekpe (2008); Muchapondwa (2009); Vitale *et al.* (2009); Devadoss and Luckstead (2010); Yu and Fan (2011); Imai *et al.* (2011); Aipi *et al.* (2012); Shahzad *et al.* (2018); Rosas *et al.* (2018) and Khan *et al.* (2019). Devadoss and Luckstead (2010) estimates that the supply response function of apple for new plantings, removals, and yield for the State of Washington. New planting decisions respond to apple profits, cherry profits, weather, and lagged investment. Farmers decision for removals respond to expected short-run revenues of apples and peaches. Price and weather variables are their relevance in determining apple yield. Imai *et al.* (2011) estimates the supply response equations for different agricultural commodities, namely maize, wheat, rice, fruit, vegetable, and oilseeds in response to agricultural (own) prices change in a panel data of 10 selected Asian countries for the period 1966 to 2005. The yield responds positively to the own price, *i.e.* the strongest is oilseeds, but response negatively to the price of oil. Yu and Fan (2011) investigates the rice supply response of the Cambodian farmers and government to rice price using the Cambodia Socio-Economic Surveys (CSES) conducted in 2004 and 2007. Using ARDL procedure, Shahzad *et al.* (2018) estimates the supply response of tobacco growers to price variables (*i.e.* own price and price of wheat crop) and non-price variables (*i.e.* lagged production, total area of tobacco crop and average rainfall) in Khyber Pakhtunkhwa province, Pakistan for the period 1981 to 2014. In the long-run, tobacco growers are responsive positively to tobacco price and tobacco area, while wheat price is in a negative sign, as well as in the short-run including lagged production. Khan *et al.* (2019) examines the supply response of rice in Khyber Pakhtunkhwa for the period 1976 to 2010. The results suggest that both short and long-runs inelastic of rice production in respond to lagged production, rice price and maize price, except for lagged production in the long-run.

There are a few studies available for the Indonesian agricultural products (Rosegrant *et al.*, 1998;

Magfiroh *et al*., 2018) and palm oil as well (Sukiyono, 1995; Marpaung *et al*., 2017). Rosegrant *et al.* (1998) estimates the dynamic supply response model of food crop for Indonesia. They looked at the effects of technology, prices, and investments on output growth for rice, corn, soybean, and cassava for the period 1969 to 1990. The estimation shows a large impact of public investment in agricultural research, extension, and irrigation on long-run output growth. Removing the fertiliser subsidy and reinvestment of the resulting fiscal savings in research, extension and irrigation would produce large benefits. Magfiroh *et al.* (2018) examines the supply response of maize producers with respect to its own domestic and imported prices, substituted crops' prices (rice, soyabean, feed, cassava), and rainfall index for the annual observations between 1986 and 2017. They found that maize acreage expansion is responsive to price of soyabeans, wages of labour, price of urea fertiliser, seed, feed, and imported maize. The domestic maize price is elastic.

For the palm oil, Sukiyono (1995) applied the Nerlovian model and found that domestic price of palm oil, labour wage and technological change are important to the oil palm area planted by state owned and private for the period 1966 to 1993. Government support such as Nucleus Estate and Smallholder (PIR/NES) Project is insignificant. A recent study by Marpaung *et al.* (2017), they employed the Nerlovian model for smallholders, government estates, private estates, and national estates from 1980 to 2016. The price of crude palm oil and Plantation Revitalization policy has influenced the producers' supply decision.

In view of the influence of interest rate variation, Mohammad and Tang (2005) estimates the Nerlovian model for aggregate palm oil supply (output) in Malaysia by considering the impact of interest rate variation (*i.e.* cost of borrowing). They confirm a long-run relation among palm oil production, interest rate, government expenditure on agriculture, and relative price for the period 1967 to 2002. Palm oil supply is responsive to these variables in long and short-runs. Pramudya *et al.* (2017) notes that 'finance' is a policy instrument to govern the expansion and sustainability of agriculture that ignored by previous studies.

Conceptual Framework – Farmers' Borrowing Behaviour

This study applies the Nerlove model of agricultural supply response which has been extended by Mohammad and Tang (2005). They examine the impact of interest rate variation on the Malaysian palm oil supply. Interest rate variation is crucial to the agricultural supply response by influencing farmers' borrowing behaviour. Atieno (1997) relates farmers' borrowing behaviour to farmers' initial resource endowment (farm income, non-farm income and land), interest rate, non-interest credit costs, farming experience and collateral value. Atieno found that interest rate is insignificant because it is relatively low as compared to the opportunity cost of funds. Farmers' borrowing behaviour is positively related by total land owned, collateral value, and non-interest credit costs, but farming experience has a negative sign. Fecke *et al.* (2016) adds that interest rate, gross value added in agriculture, grace periods, and farmers' business expectations are important for loan demand behaviour in agriculture sector. Interest rate has a significant negative effect, while other variables are positive. Swinnen and Gow (1997) observes that high interest rates in Central and Eastern Europe countries is a problem in financing agriculture. Commercial banks have traditionally played an important role in financing agriculture (Betubiza and Leatham, 1995).

Palm oil sector is capital-intensive, finance schemes are crucial in enabling and advancing palm oil production. Therefore, it requires significant investment throughout their entire life cycle from establishment to replanting. Haryadi and Kusumowardhani (2017) notes that most of the credit approved for smallholders in the palm oil sector is for working capital, and insufficient for replanting. Formal institutions (*i.e.* banks) offer a range of credit schemes, but most of the smallholders can only access [*Kredit Usaha Rakyat* (KUR)] for working capital because lack of collateral. The amount of credit obtained from KUR is insufficient for replanting costs. Smallholders consider informal local lending market with higher interest rates given failure to access formal credit. For the informal institutions (*i.e.* local traders), borrowing is often limited in amount, and accessible only to those who sell their fresh fruit bunches to the traders (side-selling) with no interest rate and no specific requirements. The Indonesian independent smallholders consider three categories of borrowings, namely working capital loans, agricultural input financing, and long-term loans for replanting purposes (Singapore Institute of International Affairs, 2018).

There are similarities and differences between smallholders' and commercial-oriented's borrowing behaviours. Smallholders are typically risk averse given the absence of ready access to savings, insurance and credit markets. Nurfatriani *et al.* (2019) observes that smallholder plantations are illegally located in state forestland that crude palm oil fund can potentially use to finance replanting. They found that the replanting program is not smoothly implemented because lack of access to any other fund sources. Farmers' borrowing behaviour in Sindh province of Pakistan is positively associated with gender, household size, educational level, farming experience, farm size, income, and availability of collateral, but not their age (Chandio *et al.,* 2017). The Iranian (small and poor) farmers' borrowing behaviour is associated with higher levels of farm output and income (Yazdani and Gunjal, 1998). For commercial-oriented borrowings, Toumbourou (2018) found that funding from banks is a key factor enabling corporate oil palm expansion that at least 50 million requires to convert 100 square kilometres (39 square miles) of land into an oil palm plantation. According to Myers (1977), corporate borrowing is negatively associated with market value accounted for by real options. Another aspect is the practice of matching maturities of assets and debt liabilities. Betubiza and Leatham (1995) examines the effect of selected demand and supply factors on non-real estate agricultural lending by commercial banks in Texas. The determinants are farm profitability, farm risk, value of farmland and buildings, size of farming community, ownership of farmland, and the level of farm mechanization.

METHODOLOGY

The Nerlove (1958) model has been widely applied for agricultural supply response because of its simplicity via. dynamic supply response analysis and the formulation of price expectation. It involves a one-stage procedure and directly regresses production on prices and other relevant variables (McKay *et al.,* 1999). It entails fewer computational steps to generate supply response coefficients and minimises the specification errors (Kohli, 1996).[1] The Nerlove model, in general consists of the three core equations,

$$Q_t^* = a_0 + a_1 P_t^e + a_2 Z_t + U_t \quad (1)$$

$$P_t^e - P_{t-1}^e = \beta(P_{t-1} - P_{t-1}^e), \text{and} \quad (2)$$

$$Q_t - Q_{t-1} = \delta(Q_t^* - Q_{t-1}) \quad (3)$$

where Q_t^* is the optimal output; P_t^e is expected price; Z_t is non-price factors; Q_t is actual output; P_t actual price; and it is assumed that $0 \le \beta \le 1$, and $0 \le \delta \le 1$ (Henneberry and Tweeten, 1991). This study follows Mohammad and Tang (2005) with the following equation.

$$ln\text{DV}_t = \beta_0 + \beta_1 \text{IR}_t^e + \beta_2 ln\text{RPCO}_t^e + \beta_3 ln\text{RPR}_t^e + \beta_4 ln\text{G}_t^e + \beta_5 TIME + \varepsilon_t \quad (4)$$

where $ln\text{DV}_t$ is natural logarithm of palm oil production at aggregated level, and by three categories of producers, namely state-owned, private-owned, and smallholders. TIME is a linear time trend to capture technological change or producers' preference. The symbol '*e*' stands for '*expected*' based on the naïve or static expectation[2] with a time lag of three years, which is biologically feasible for palm oil gestation period. *Table 1* describes the variables and their datasets.[3] The coefficients β_2, β_3, β_4, and $\beta_5 > 0$, and $\beta_1 < 0$. The data cover available annual observations between 1970 and 2017, except for smallholders' supply, which is available from 1979.

[1] The Nerlove model is suffering from the unit root problem in time series data with spurious regression results (Muhammad *et al.*, 2018). They consider this concern by applying ARDL procedure with the dynamics of the underlying variables. This study follows their approach.

[2] It was widely used in the agricultural supply response literature. The cobweb model which described it in the form $P_t^e = P_{t-1}$, informs that the next period's price would be the same as the last period's price, and it would be rational in the world.

[3] This study uses the 6-month deposit rate (IR) because of its availability for the period 1970 to 2017. The money market rate is available from 1983, while 1986 for the lending rate. For the relative price of palm oil to coconut oil (RPCO), coconut has been phased out in Indonesia's policymaking more than a decade ago for the large-scale producers. However, as reported by Bernadette (2016), Indonesia is the second-biggest coconut exporter after the Philippines. Indonesia has the largest coconut palm-growing areas in the world, followed by the Philippines and India (Alouw and Wulandari, 2020). As of 2018, Indonesia had a total of 3.7 million hectares of coconut plantations with 2.9 million tonnes of production. The relative price of palm oil to rubber (RPR) is an important price variable to be included that the palm oil-rubber nexus is probably more relevant to smallholders. Indonesia is the second-largest producer of rubber (by smallholders, 80%) and exports about 85% of its rubber to the international market (ANPRC, 2016) after Thailand. As in 2018, the rubber plantations cover a total of 3.67 million hectares, which potentially converts to palm oil with the total production of 3.63 million tonnes (Directorate General of Estate Crops, 2018). In the Indonesian context, oil palm and rubber are competitors in terms of land use, especially when considering its land suitability in terms of agro-ecological conditions (Goh *et al.*, 2016). The government spending data on agricultural development is not available for Indonesia. Therefore, this study considers a broadly defined government spending (G) to capture government's support or fiscal policy. UNEP (2016) finds that fiscal support for production has prioritised rapid expansion, but it does not provide a sound basis for supporting the productivity of smallholders. Government Regulation No. 24/2015 and Presidential Regulation No. 61/2015, for examples are one of the fiscal policies issued by the Indonesian government to support sustainability in plantation development (Nurfatriani *et al.,* 2019).

TABLE 1. THE VARIABLES

Variables	Unit of measurement	Sources
Aggregate palm oil supply, *ln*PO_t Disaggregated by: • State-owned producers, *ln*POG_t • Private-owned producers, *ln*POP_t • Smallholders, *ln*POS_t	Output reported in tonnage. The variable was then transformed to natural logarithm, *ln*.	(i) Tree crop estate statistics of Indonesia 2015-2017, Indonesian Ministry of Agriculture. http://ditjenbun.pertanian.go.id/tinymcpuk/gambar/file/statistik/2017/Kelapa-Sawit-2015-2017.pdf
Expected real interest rate, IR^e_t	Based on a proxy of a 6-month deposit rate (%) that subtracted by CPI (consumer price index) inflation rate. The naïve expectation, *e* is with a time lag (gestation) of three years.	(ii) International Financial Statistics (IFS), International Monetary Fund. https://data.imf.org/regular.aspx?key=61545855
Expected real relative price of palm oil to coconut oil, *ln*$RPCO^e_t$	A ratio of palm oil price to coconut oil price. Both prices are initially measured in real US$ per tonne (100=2010).	(iii) World Bank commodity price data (the pink sheet), World Bank. http://www.worldbank.org/en/research/commodity-markets#1
Expected real relative price of palm oil to rubber, *ln*RPR^e_t	A ratio of palm oil price to rubber price (in real US$ per tonne).	Similar source as (iii)
Expected real government expenditure, *ln*G^e_t	In billions of US$, converted from Indonesia Rupiah by period average exchange rate. CPI is price deflator (100=2010).	Similar source as (ii)

Table 2 reports the summary statistics of the respective variables. Generally speaking, the largest contributor (median) of Indonesia's palm oil supply is from the private-owned producers ($lnPOP_t$) then by state-owned producers ($lnPOG_t$) and smallholders ($lnPOS_t$). Meanwhile, the relative price of palm oil to rubber ($lnRPR^e_t$) has larger variation or more volatile than the relative price of palm oil to coconut oil ($lnRPCO^e_t$).

Table 3 reports the stationarity or the degree of integration, *I*(d) of the underlying variables. The Kwiatkowski *et al.* (1992) (Kwiatkowski-Phillips-Schmidt-Shin, KPSS) tests suggest that the underlying variables are non-stationary at levels, *I*(1), except for the real relative price of palm oil to rubber ($lnRPR^e_t$) which is stationary, *I*(0). This observation supports the ARDL procedure (Pesaran *et al.*, 2001) to equation (4) which is applicable irrespective of the regressors are *I*(0) or *I*(1). This avoids the pre-testing issues associated with standard cointegration testing methods (Engle and Granger, 1987; Johansen and Juselius, 1990) those require the underlying variables are *I*(1).

A long-run relation of equation (4), $lnDV_t$ -IR^e_t -$lnRPCO^e_t$ -$lnRPR^e_t$ -lnG^e_t can express in an ARDL version of error-correction specification as Equation (5):

$$\Delta lnDV_t = c + \sum_{i=1}^{n}\beta'_{1i}\Delta\, lnDV_{t-i} + \sum_{i=0}^{n}\beta'_{2i}\,\Delta IR^e_{t-i} + \sum_{i=0}^{n}\beta'_{3i}\Delta\, lnRPCO^e_{t-i} + \sum_{i=0}^{n}\beta'_{4i}\Delta\, lnRPR^e_{t-i} + \sum_{i=0}^{n}\beta'_{5i}\Delta\, lnG^e_{t-i} + \gamma_0 lnDV_{t-1} + \gamma_1 IR^e_{t-1} + \gamma_2 lnRPCO^e_{t-1} + \gamma_3 lnRPR^e_{t-1} + \gamma_4 lnG^e_{t-1} + \gamma_5 TIME + u_t \quad (5)$$

usual *F*-test (bounds test). Given small sample sizes of 39 and 45, the critical values provided by Narayan (2005) are preferable because they were stimulated for the small sample sizes between 30 and 80. If the *F*-statistic falls above the upper bound *I*(1) critical value at a conventional level of significance (1%, 5%, or 10%), the null hypothesis can be rejected, suggesting the variables are cointegrated or a level relation.

The existence of a long-run relation is tested by rejecting the null hypothesis of no level relationship (H_0:$\gamma_0 = \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0$) against the alternative hypothesis of a level relationship (H_1:$\gamma_0 \neq 0, \gamma_1 \neq 0, \gamma_2 \neq 0, \gamma_3 \neq 0, \gamma_4 \neq 0$) by a If the *F*-statistic falls below the lower bound *I*(0) critical value, the null hypothesis cannot be rejected, hence no cointegration can be concluded. However, if the *F*-statistic falls between the lower and upper bound critical

TABLE 2. SUMMARY STATISTICS

	$lnPO_t$	$lnPOG_t$	$lnPOP_t$	$lnPOS_t$	IR^e_t	$lnRPCO^e_t$	$lnRPR^e_t$	lnG^e_t
Mean	14.972	13.761	13.983	13.280	0.017	4.401	17.649	4.292
Median	15.124	14.197	14.207	14.111	0.036	4.429	17.636	4.318
Maximum	17.381	14.732	16.885	16.241	0.167	4.703	18.348	5.319
Minimum	12.286	11.501	9.581	6.633	-0.284	4.080	17.012	2.766
Standard Dev.	1.623	0.889	2.009	2.994	0.094	0.156	0.332	0.654
Jarque-Bera	3.585	7.583	2.508	6.853	11.622	2.131	0.675	0.986
(Probability)	(0.166)	(0.022)	(0.285)	(0.032)	(0.002)	(0.344)	(0.713)	(0.610)
Observations	48	48	48	39	45	45	45	45

TABLE 3. KPSS STATIONARITY TESTS (Kwiatkowski *et al.*, 1992)

Variables	LM statistics	Finding, *I*(d)
$lnPO_t$	0.144*	Non-stationary, *I*(1)
$lnPOG_t$	0.221***	Non-stationary, *I*(1)
$lnPOP_t$	0.099	Non-stationary, *I*(1)[1]
$lnPOS_t$	0.210**	Non-stationary, *I*(1)
IR^e_t	0.135*	Non-stationary, *I*(1)
$lnRPCO^e_t$	0.132*	Non-stationary, *I*(1)
$lnRPR^e_t$	0.082	Stationary, *I*(0)
lnG^e_t	0.135*	Non-stationary, *I*(1)
Kwiatkowski *et al.* (1992)	Asymptotic critical values:	* 10% 0.119 ** 5% 0.146 *** 1% 0.216

Note: The KPSS equations include constant and linear trend. The null hypothesis denotes that the variable is stationary, *I*(0). The Bartlett Kernel is used for the spectral estimation method by using the Newey-West bandwidth. [1] The KPSS equation of this variable is intentionally set to include constant only where its LM statistics (0.887) exceeds its 1% level critical value (0.739) rejecting the null hypothesis that this variable is non-stationary.

values between *I*(0) and *I*(1) bands, no conclusion can be delivered. It requires to reaffirm no *I*(2) variable(s), and not all variables are either *I*(0) or *I*(1). The equation (5) is based on OLS (ordinary least squares) estimator. For example, the long-run coefficient of the expected real interest rate, IR^e_t is $-(\gamma_1/\gamma_0)$ (Pesaran *et al.*, 2001), while its short-run coefficients are β'_{2i} of ΔIR^e_{t-i}. Similar calculation applies for other variables. The expected real relative price of palm oil to coconut oil, $lnRPCO^e_t$, is computed as $-(\gamma_2/\gamma_0)$, while its short-run coefficients are β'_{3i} of $\Delta lnRPCO^e_{t-i}$ with their respective lags. If no cointegration, the short-run coefficients of the underlying variables can be inferenced directly from the estimated error-correction model, ECM.

RESULTS AND DISCUSSION

The empirical findings are sorted and discussed by aggregate palm oil supply, then by state-owned, private-owned, and smallholders. Different types of producers may respond differently to the supply response determinants due to the nature of their behaviour. *Tables 4* to *6* present the empirical results of ARDL bounds testing approach to cointegration, and their estimates of equations (4) and (5).

First and more importantly to highlight that the expected real interest rate (IR^e_t) has a positive sign in the long-run (*Table 5*), which is infeasible, that is the higher the interest rate (*i.e.* the higher the cost of borrowing is expected), the palm oil producers (except for smallholders) require more finances for replanting, and increase their supply. It indicates possible specification error. This study tackles the non-linear component of interest rate variable. Among other possible causes, the Nerlove model is heavily dependent on price variables, while non-price variables less emphasise. It omits other relevant non-price variables. Secondly, the underlying dependent can be either output or area planted. This study uses output as proxy to supply (Mohammad and Tang, 2005). Thirdly, OLS estimator

TABLE 4. ARDL BOUNDS *F*-TEST FOR COINTEGRATION

F (DV_t | IR^e_t, $lnRPCO^e_t$, $lnRPR^e_t$, lnG^e_t)		ARDL(.)	*F*-statistic
$lnPO_t$	Aggregate palm oil supply	ARDL (2, 0, 1, 0, 0)	4.308*
$lnPOG_t$	by state-owned producers	ARDL (1, 3, 1, 0, 0)	8.989***
$lnPOP_t$	by private-owned producers	ARDL (2, 0, 2, 1, 0)	7.708***
$lnPOS_t$	by smallholders	ARDL (2, 0, 3, 2, 2)	3.337
	Critical values bound, *I* (0)	Lower bound,	Upper bound, *I* (1)
	* 10%	2.985	3.918
	** 5%	3.512	4.587
	*** 1%	4.763	6.200

Note: The lag structure of ARDL(.) is determined by Akaike information criterion (AIC) from a maximum lag length of 3 based on rule in Enders (2014), $T^{1/3}$ (where T is the number of observations) that $49^{1/3} = 3.659$. The reported critical values are from Narayan (2005) with *k*=4, and *n* =40 where *k* is the number of independent variables, and *n* is sample size – Case 4: unrestricted constant and restricted trend.

TABLE 5. ARDL LONG-RUN RELATION

	Dependent variable			
Independent Variables:	$lnPO_t$	$lnPOG_t$	$lnPOP_t$	$lnPOS_t$
IR^e_t	0.852 [0.491]	2.847 [0.895]***	3.900 [1.086]***	3.378 [8.506]
$lnRPCO^e_t$	0.973 [0.474]	1.218 [0.502]**	3.783 [1.387]***	-2.580 [9.074]
$lnRPR^e_t$	-0.254 [0.162]	-0.514 [0.207]**	-0.325 [0.305]	-4.561 [3.823]
lnG^e_t	-0.225 [0.088]	-0.217 [0.109]*	-0.485 [0.151]***	-3.380 [2.052]
TIME	0.101 [0.006]	0.026 [0.007]***	0.113 [0.011]***	-0.015 [0.166]

Note: Figures in the square brackets [.] denotes the standard error. ***, ** and * signify statistically significant at 1%, 5% and 10%, respectively.

is conventionally applied, while other estimators are available *i.e.* generalised method of moments, two-stage least squares (structural equations), and so on. Lastly, small sample bias may occur with between 39 and 48 annual observations.

The ARDL procedure imposes linearity (symmetry) assumption that the positive and negative variations of the expected real interest rate have similar effect on palm oil supply, the dependent variable. It is infeasible since the palm oil producers may response differently between positive and negative expected real interest rates (*i.e.* non-linear or asymmetric). This study further employs the non-linear autoregressive distributed lag (NARDL) procedure (Shin *et al.*, 2014) as briefly described in Appendix A. *Tables 7* to *9* present the results. In general, the key findings are relatively consistent to the ARDL procedure, expect for the expected real interest rate. It supports the intuition of non-linearity of interest rate and offers feasible results.

Aggregate Palm Oil Supply

This sub-section offers an initial understanding on how the Indonesian palm oil producers, in general respond to the underlying supply response variables. *Table 4* shows the computed *F*-statistic of aggregate palm oil output, 4.308 exceeds 0.10 upper bound of the critical value band, 3.918, rejecting the null hypothesis of no level relationship. There is a long-run relation (cointegration) among Indonesia's aggregate palm oil supply, expected interest rate (IR^e_t), expected relative prices both palm oil to coconut oil and rubber ($lnRPCO^e_t$ and $lnRPR^e_t$), and expected government expenditure (lnG^e_t). Alternatively, to say that these variables are moving together over time. The estimated long-run relation, equation (4) is reported in *Table 5*. In the long-run, aggregate palm oil supply is responsive to interest rate, relative price of palm oil to coconut oil, and government expenditure, including technology change or producers' preference (TIME). Nevertheless, interest rate and government expenditure are both in opposite signs. The supply response variables are mostly statistically insignificant in the short-run (*Table 6*).

Based on the NARDL procedure, the results are richer with a feasible finding that negative expected real interest rate is statistically significant (at 1% level) with a positive sign in the long-run (*Table 8*). Palm oil producers respond positively to lower (real) cost of borrowing by increasing palm oil supply through borrowing from formal institutions for replanting. Other supply response is statistically significant, while the relative price of palm oil to rubber and government expenditure are in opposite sign. In the short-run, the supply response determinants are mostly statistically significant at 10%, and in correct sign (*Table 9*). Largely, the findings of aggregate palm oil supply may be insufficient due to aggregation bias.

State-owned. The findings of state-owned producers are relatively close to the aggregate palm oil producers. Both the ARDL and NARDL tests (*Tables 4* and *7*) suggest a long-run relation of equation (4). In *Table 5*, the estimated long-run coefficients are statistically significant as similar to the aggregate level including their signs. As noted, a positive coefficient of expected interest rate is infeasible. However, this variable explains well in the short-run with a negative sign the response of state-owned supply of palm oil to the lagged one-and two years expected interest rates (*Table 6*). However, the NARDL results as in *Table 8* informs that negative expected interest rate has positive impact on the state-owned palm oil producers. They respond to the low (real) cost of borrowing by replanting financing that results higher supply.

The state-owned producers are responsive to the relative price of palm oil to coconut oil with estimated coefficient of 2.191. When the relative price of palm oil to coconut oil is expected to increase 10% in future (*i.e.* the next 3 years) either by higher palm oil price, or lower coconut oil, the producers foresee a profit opportunity, and to increase their output by 21%. The supply response of state-owned producers to the relative price of palm oil to rubber is negative, -0.983. If the

TABLE 6. ARDL ERROR-CORRECTION MODEL (ECM) EQUATIONS

	Dependent variable			
Independent Variables:	$\Delta ln PO_t$	$\Delta ln POG_t$	$\Delta ln POP_t$	$\Delta ln POS_t$
Intercept	9.925 [1.796]***	20.110 [2.534]***	2.277 [0.286]***	26.031 [5.180]***
$\Delta ln DV_{t-1}$	-0.259 [0.113]**		-0.470 [0.082]***	-0.339 [0.120]***
ΔIR^e_t		1.003 [0.597]		
ΔIR^e_{t-1}		-1.448 [0.632]**		
ΔIR^e_{t-2}		-1.230 [0.598]**		
$\Delta ln RPCO^e_t$	0.306 [0.125]**	0.695 [0.255]**	1.073 [0.290]***	-1.389 [0.469]***
$\Delta ln RPCO^e_{t-1}$			-1.288 [0.307]***	-0.543 [0.435]
$\Delta ln RPCO^e_{t-2}$				-0.680 [0.482]
$\Delta ln RPR^e_t$			0.220 [0.197]	-0.125 [0.302]
$\Delta ln RPR^e_{t-1}$				1.788 [0.332]***
$\Delta ln G^e_t$				-0.388 [0.203]*
$\Delta ln G^e_{t-1}$				0.812 [0.203]***
ect_{t-1}	-0.711 [0.131]***	-1.126 [0.142]***	-0.860 [0.118]***	-0.215 [0.043]***
Adjusted R^2	0.535	0.607	0.772	0.533
Durbin-Watson	2.247	2.279	2.313	2.020
LM test (*F*-stat.)[1]	1.062 (0.379)	1.637 (0.203)	1.508 (0.233)	1.052 (0.392)
CUSUM (5%)	*stable*	*stable*	*stable*	*stable*
CUSUM of Squares	1987-2005	*stable*	1989-2007	2000-2006

Note: Figure in the square brackets [.] denotes standard error, while *p*-value in the parentheses (.). ***, ** and * signify statistically significant at 1%, 5% and 10%, respectively. [1] Breusch-Godfrey serial correlation LM test null hypothesis of residuals are serially uncorrelated. [2] Ramsey RESET test null hypothesis of correct specification.

TABLE 7. NON-LINEAR ARDL BOUNDS *F*-TEST FOR COINTEGRATION

$F(DV_t \mid IR^{e+}_t, IR^{e-}_t, lnRPCO^e_t, lnRPR^e_t, lnG^e_t)$			NARDL(.)	*F*-statistic
$lnPO_t$	Aggregate palm oil supply		NARDL(1, 3, 3, 3, 3, 2)	6.620***
$lnPOG_t$	by state-owned producers		NARDL(3, 3, 3, 3, 3, 2)	6.630***
$lnPOP_t$	by private-owned producers		NARDL(3, 3, 2, 3, 3, 3)	5.117**
$lnPOS_t$	by smallholders		NARDL(2, 0, 0, 3, 2, 2)	2.979
	Critical values	Lower bound, *I*(0)	Upper bound, *I*(1)	
	* 10%	2.781	3.813	
	** 5%	3.257	4.431	
	*** 1%	4.427	5.837	

Note: The reported critical values are from Narayan (2005) with *k*=5, and *n*=40 where *k* is the number of independent variables, and *n* is sample size – Case 4: unrestricted constant and restricted trend.

TABLE 8. NON-LINEAR ARDL LONG-RUN RELATION

	Dependent Variable			
Independent variables:	$lnPO_t$	$lnPOG_t$	$lnPOP_t$	$lnPOS_t$
IR^{e+}_t	0.070 [0.841]	-0.863 [1.109]	5.412 [5.535]	-3.433 [10.536]
IR^{e-}_t	1.927 [0.445]***	3.529 [0.575]***	5.480 [2.265]**	8.667 [7.557]
$lnRPCO^e_t$	2.071 [0.518]***	2.191 [0.681]***	7.312 [4.248]	-2.092 [7.321]
$lnRPR^e_t$	-0.454 [0.187]**	-0.983 [0.259]***	-0.646 [0.692]	-2.773 [2.912]
lnG^e_t	-0.431 [0.094]***	-0.735 [0.119]***	-0.301 [0.435]	-4.095 [2.021]*
TIME	0.141 [0.022]***	0.123 [0.029]***	0.106 [0.111]	0.334 [0.303]

Note: Figures in the square brackets [.] denotes the standard error. ***, ** and * signify statistically significant at 1%, 5% and 10%, respectively.

price of rubber expects to fall in the next 3 years, the palm oil output by state-owned producers reduces. It is possible to explain that the state-owned producers are lacking of allocation for replanting, while the existing oil palm trees will have a lower yield.[4] The government expenditure has a negative sign, -0.735 that state-owned producers respond to an expansionary fiscal policy that takes place in future with lower their palm oil production. They perceive it as an unfavourable signal that government expenditure does not allocate to agricultural sector (Ministry of Agriculture), or to non-palm oil sectors. The state-owned palm oil producers are positively responded their preference or technological change as implied by the positive coefficient of TIME.

In the short-run, all of the supply response variables are statistically significant, and have their expected signs. For example, both relative prices, and government expenditure have a positive coefficient (*Table 9*). Interestingly, the state-owned producers respond positively to their previous supply in the past two years (t-1 and t-2) with their estimated coefficients of 0.322 and 0.259. It indicates an active (new) replanting by the state-owned producers that newly planted palm oil trees are more productive in the sequence years. It is feasible within the current context of government exhortations to the plantation sector to speed up replanting of old tree stands with higher yielding clones in order to remain competitive (Mohammad and Tang, 2005).

Private-owned. The ARDL results (*Tables 5* and *6*) of private-owned are identical to the state-owned both in the long and short runs, but interest rates are excluded (*i.e.* highly statistically insignificant)

[4] In 2015, only 2.46% of total government expenditure on ministries or agencies allocated by Ministry of Agriculture for the purpose of 'Food Security for Price Stabilisation and Meeting the Needs of People's Food'. The largest allocation, 14.97% is to Ministry of Defence, see Budget in Brief (APBN, 2015).

TABLE 9. NON-LINEAR ARDL ERROR-CORRECTION MODEL (ECM) EQUATIONS

	Dependent Variable			
Independent Variables:	$\Delta lnPO_t$	$\Delta lnPOG_t$	$\Delta lnPOP_t$	$\Delta lnPOS_t$
Intercept	17.678 [2.252]***	46.838 [5.906]***	-4.138 [0.623]***	24.353 [4.635]***
$\Delta lnDV_{t-1}$		0.322 [0.180]*	-0.468 [0.098]***	-0.326 [0.117]**
$\Delta lnDV_{t-2}$		0.259 [0.122]**	-0.163 [0.074]**	
ΔIR^{e+}_t	-2.689 [0.729]***	-6.279 [1.440]***	-3.246 [1.160]**	
ΔIR^{e+}_{t-1}	0.229 [0.632]	-0.770 [1.093]	1.911 [0.880]**	
ΔIR^{e+}_{t-2}	1.969 [0.563]***	5.839 [1.095]***	2.218 [0.690]***	
ΔIR^{e-}_t	1.488 [0.615]**	4.287 [1.370]***	3.139 [0.898]***	
ΔIR^{e-}_{t-1}	-2.524 [0.436]***	-4.188 [0.840]***	-3.275 [0.929]***	
ΔIR^{e-}_{t-2}	-1.677 [0.624]**	-5.090 [1.165]***		
$\Delta lnRPCO^e_t$	0.649 [0.145]***	0.760 [0.256]***	0.988 [0.219]***	-1.531 [0.464]***
$\Delta lnRPCO^e_{t-1}$	-1.042 [0.205]***	-1.455 [0.349]***	-1.734 [0.368]***	-0.595 [0.424]
$\Delta lnRPCO^e_{t-2}$	-0.505 [0.152]***	-0.863 [0.309]**	-0.690 [0.287]**	-0.856 [0.471]*
$\Delta lnRPR^e_t$	-0.214 [0.107]*	-0.888 [0.200]***	0.441 [0.158]**	-0.134 [0.296]
$\Delta lnRPR^e_{t-1}$	0.493 [0.125]***	1.540 [0.317]***	0.297 [0.162]*	1.719 [0.319]***
$\Delta lnRPR^e_{t-2}$	0.182 [0.110]	0.451 [0.216]*	0.344 [0.152]**	
ΔlnG^e_t	-0.201 [0.075]**	-0.554 [0.157]***	-0.152 [0.106]	-0.519 [0.209]**
ΔlnG^e_{t-1}	0.163 [0.072]**	0.443 [0.134]***	-0.242 [0.087]**	0.952 [0.208]***
ΔlnG^e_{t-2}			-0.230 [0.106]**	
ect_{t-1}	-1.274 [0.163]***	-1.868 [0.236]***	-0.573 [0.082]***	-0.268 [0.052]***
Adjusted R^2	0.732	0.816	0.927	0.552
Durbin-Watson	1.738	2.228	1.262	2.006
LM test (*F*-stat.)[1]	0.900 (0.463)	0.494 (0.692)	2.148 (0.140)	1.099 (0.375)
Reset test (*F*-stat.)[2]	1.468 (0.241)	120.013 (0.000)***	16.222 (0.001)***	30.331 (0.000)***
CUSUM (5%)	*stable*	*stable*	*stable*	*stable*
CUSUM of Squares	*stable*	*stable*	*stable*	2000-2007

Note: Figure in the square brackets [.] denotes standard error, while p-value in the parentheses (.). ***, ** and * signify statistically significant at 1%, 5%, and 10%, respectively. [1] Breusch-Godfrey serial correlation LM test null hypothesis of residuals are serially uncorrelated. [2] Ramsey RESET test null hypothesis of correct specification.

from the short-run estimation. Both linear and non-linear ARDL bounds tests confirm a long-run relation of palm oil supply response function as equation (4). The estimated long-run relation by NARDL in *Table 8* shows that private-owned producers only respond to a negative expected interest rate in the long-run. In the short-run (*Table 9*), all the supply response determinants are statistically significant with their expected sign, except for the lagged one and two year government expenditure have negative coefficient of -0.242, and -0.230. The government's support on agriculture sector such as palm oil is mostly 'skewed' to state-owned producers than of private-owned. The current palm oil supply by private-owned producers is negatively associated with supply in the past two years (-0.468 and -0.163) which indicates that the more palm oil supply in the past, the lesser the current supply by the existing oil palm plantations. It also reflects non-active replanting exercises by private-owned producers that partly due to high cost of borrowing (*i.e.* high interest rate).

Smallholders. In contrary to the above findings, the palm oil smallholders respond only to the underlying variables in the short-run. *Tables 4* and *7 shown*, the *F*-statistics of ARDL and NARDL bounds test, 3.337 and 2.979 are below their lower bound critical value at 5%, 3.512% and 3.257%, respectively. That is, the null hypothesis of no level relationship cannot be rejected indicating no long-run relation. By and large, its error-correction term, ect_{t-1} is statistically significant at 1% level, which may inform a cointegration relation (Bahmani-Oskooee and

Brooks, 1999)[5]. However, this statistical inference is vulnerable since the long-run estimates as reported in *Tables 5* and *8* (the last column) are infeasible because they are statistically insignificant at 10% level.

The short-run estimates of NARDL-ECM are reported in *Table 9*. The interest rate variables either $\Delta IR^{e\,+}_{t-i}$ or $\Delta IR^{e\,-}_{t-i}$ are dropped out from estimation process because they are highly statistically insignificant. This situation is eventually held that smallholders are generally unable to receive finance from the formal financial institutions. Rainforest Alliance (2016) outlines the possible reasons behind this phenomenon. Firstly, the amount of credit smallholders demanded is often either too small for banks or too big for micro finance organisations. Secondly, smallholders lack of proper legal documentation as required by the banks (credit history and hard value collateral *i.e.* land ownership certificate). Thirdly, smallholders are being considered as high default risks since they do not hold proper farming management practice.

The relative price of palm oil to coconut oil is unfavourably negative sign, which indicates that smallholders reduce supply when the relative price increases. The opposite should be true. The smallholders are responsive to the changes of lagged one relative price of palm oil to rubber, and government expenditure. These variables are statistically significant, and have expected signs of 1.788 and 0.812. Similar to the finding of private-owned, the lagged one year of output has negative impact (-0.326) on the current palm oil supply, indicating insufficient replanting efforts by smallholders that relates to the high cost of borrowing and financing constraint imposed by formal institutions. Such financial access barriers are also identified by Sahara *et al.* (2017) and Bronkhorst *et al.* (2017).

For comprehensiveness, this study also considers the expansionary monetary policy as an integral part of the analysis given that interest rate(s) is a monetary instrument. As stated in the Federal Reserve System, monetary policy is to make possible a flow of credit and money that will foster orderly economic growth. (Doll, 1958). Doll (1958) add that "… *analysis of the effect of such a [monetary] policy on the agricultural industry must be made in terms of agriculture being an interdependent sector of the total economy*" and, "… *the best monetary policy for the agricultural sector is one that will encourage orderly growth at relatively stable price levels for the general economy*." (Doll, 1958).[6] The empirical results are relatively close to interest rate variation.[7] The ARDL estimates show a positive implication of expected monetary policy (proxied by money supply M2) on palm oil supply in the long-run, except for smallholders. That is the state-owned and private-owned producers respond to an expansionary monetary policy by *Bank Indonesia* with higher supply of palm oil. In the short-run, this finding is only for private-owned producers, while smallholders are positively responded to relative price of palm oil to rubber, and government expenditure (expansionary fiscal policy).

CONCLUSION

Based on the Nerlove model, this study estimates the supply response function for the Indonesian palm oil planters by considering the interest rate variation. This study looks at different categories of palm oil producers, namely state-owned, private-owned, and smallholders. The empirical results are based on the ARDL and NARDL procedures for the available annual data between 1970 and 2017. The Indonesian oil palm producers do respond to the expected interest rate (*i.e.*, cost of borrowing). A negative expected real interest rate increases palm oil supply by state-owned and private-owned producers for financing their replanting in the long-run, and for operating expenditures (*i.e.* cost reduction and improvements in efficiency in the application of fertilisers) in the short-run. However, it is not the case for smallholders.

Other key findings are as follows. Firstly, there is a long-run relation (cointegration) of Indonesia's palm oil supply response function by state-owned producers, and private-owned producers as well as by total output (all producers). Secondly, state-owned producers respond positively to relative price of palm oil to coconut oil, and technological change or planters'

[5] The estimated coefficient of error-correction term, -0.215 measures the speed of adjustment of the *i*-th endogenous variable towards equilibrium (*i.e.* a long-run relation). Generally, it is in a negative sign and less than one. If this coefficient is in between -1 and -2, then lagged error-correction term produced dampened fluctuations about the equilibrium path (Narayan and Smyth, 2006).

[6] Lambert (1986) conducts a literature review on the interrelationships between US monetary and fiscal policies and resulting impacts on the agricultural sector (agribusiness) that both policies change export demand for agricultural products, increase instability of agricultural income, and higher interest rates costs in a capital-intensive agricultural industry. For the cases of India and Pakistan, Wagan *et al.*, (2018) find that tight monetary policy significantly reduces food inflation and agricultural production while increasing the rural unemployment rate.

[7] The computed statistics are excluded here, but available upon request.

preference in the long-run. These variables including relative price of palm oil to rubber, and government expenditure remain relevant to state-owned producers in the short-run. Thirdly, private-owned producers respond only to interest rate variation in the long-run, but they respond positively to another supply response variables in the short-run, except for government expenditure. Lastly, the smallholders respond only in the short-run to relative price of palm oil to rubber, and government expenditure (an expansionary fiscal policy).

This study has a relevant policy implication, particularly *Bank Indonesia* to pursue favourable monetary policy via interest rates. Palm oil producers is responsive to expected negative real interest rates, in the long-run. Negative real interest rates encourage borrowing by palm oil producers to replant old tree or replace coconut and rubber trees with oil palm. It helps to narrow the gap between potential yield and realised yield. *Bank Indonesia* is in an objective of achieving a stable (low) inflation rate which is an 'adjustor' to the real cost of borrowing. Secondly, this study suggests *Bank Indonesia* to further revise the existing financing regulations those related to financing oil palm replanting projects. An important step is for the Indonesian smallholders to be able to invest in the production of sustainable palm oil by having access to the formal credit systems. Perhaps, financing will enhance productivity and promoting sustainable palm oil production by smallholders. The Indonesian state has had different and changing financing roles that are historically contingent and shaped by the evolving economic and political landscape. These roles reflect Indonesia's priorities of achieving economic growth through palm-oil development, furthering social equity, and promoting environmental sustainability. Thirdly, lower price of palm oil discourages replanting as the producers need the cash in the short-run and replacing oil palm with alternative (coconut and rubber), or to reduce their supply due to low profitability in the long-run. To address this concern, an appropriate floor price (minimum price level) of palm oil is necessary including its regulation, implementation, and revision. Lastly, government support is favourable, in particular for smallholders in the short-run. It can be achieved by considering government allocation including subsidies, financing schemes and intervention for sustainability in palm oil sector.

This study acknowledges several limitations. The extended Nerlove model assumes naïve expectation because of its simplicity. It may not be perfect to capture better the producers' expectation. Also, this study choices a 3-month deposit rate as a proxy variable of cost of borrowing given data availability for more observations. Indeed, the return on savings and cost of borrowing are two different rates, in which the deposit rates are mostly lower than the lending rates by financial institutions. Lastly, using highly aggregated data such as total supply by producers (state-owned, private-owned, and smallholders) may result aggregation bias. It does not reflect the micro foundations of palm oil supply response.

For further research, other expectation techniques can be considered as robustness check such as adaptive expectation and rational expectation. Lending rate is more appropriate to measure the cost of borrowing, but it is only available from 1986. It may be available from *Bank Indonesia* or to be constructed by using approximation method for the early data. It is recommended to use highly disaggregated data at producers (firms) level, which may be available from the respective statistical agencies upon request.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks to the Director-General of MPOB for his permission to publish this article.

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APPENDIX A

Non-linear autoregressive distributed lag (NARDL) testing procedure

The non-linear autoregressive distributed lag (NARDL) testing procedure by Shin *et al.*, (2014) is employed to test the existence of an asymmetric long-run relationship of palm oil supply response function, as equation (4). This procedure is similar to ARDL (Pesaran *et al.*, 2001), but non-linearity assumption is imposed. An error-correction version of the NARDL model is as below.

$$\begin{aligned}\Delta ln\mathrm{DV}_t = c &+ \sum_{i=1}^{n} \beta'_{1i}\Delta\, ln\mathrm{DV}_{t-i} + \sum_{i=0}^{n} \beta'^{+}_{2i}\, \Delta\mathrm{IR}^{e+}_{t-i} + \sum_{i=0}^{n} \beta'^{-}_{3i}\, \Delta\mathrm{IR}^{e-}_{t-i} + \sum_{i=0}^{n} \beta'_{4i}\Delta\, ln\mathrm{RPCO}^{e}_{t-i} \\ &+ \sum_{i=0}^{n} \beta'_{5i}\Delta\, ln\mathrm{RPR}^{e}_{t-i} + \sum_{i=0}^{n} \beta'_{6i}\Delta\, ln\mathrm{G}^{e}_{t-i} \\ &+ \gamma_0 ln\mathrm{DV}_{t-1} + \gamma_1^{+}\mathrm{IR}^{e+}_{t-1} + \gamma_2^{-}\mathrm{IR}^{e-}_{t-1} + \gamma_3 ln\mathrm{RPCO}^{e}_{t-1} + \gamma_4 ln\mathrm{RPR}^{e}_{t-1} + \\ &\gamma_5 ln\mathrm{G}^{e}_{t-1} + \gamma_6\mathrm{TIME} + u_t \qquad \text{(A1)}\end{aligned}$$

The interest rate variables, $\mathrm{IR}^{e}_{t}{}^{+}$ and $\mathrm{IR}^{e}_{t}{}^{-}$ are now the partial sum of process positive (+) and negative (-) as superscripted. The null hypothesis to be tested is H_0:$\gamma_0 = \gamma_1^{+} = \gamma_2^{-} = \gamma_3 = \gamma_4 = \gamma_5 = 0$ (no asymmetric level relationship), against the alternative hypothesis H_1:$\gamma_0 \neq 0, \gamma_1^{+} \neq 0, \gamma_2^{-} \neq 0, \gamma_3 \neq 0, \gamma_4 \neq 0, \gamma_5 \neq 0$ (an asymmetric cointegrating relationship). Similar statistical inference of *F*-test as ARDL is applied. The estimated long-run coefficient of expected positive interest rate, $\mathrm{IR}^{e}_{t}{}^{+}$ is calculated by $-(\gamma_1^{+}/\gamma_0)$, while its short-run coefficients are β'^{+}_{2i} (of $\Delta\mathrm{IR}^{e+}_{t-i}$, the variable at first-differenced). Similarly, $-(\gamma_2^{-}/\gamma_0)$ is the long-run coefficient of expected negative interest rate, $\mathrm{IR}^{e}_{t}{}^{-}$, and its short-run coefficients are β'^{-}_{3i}. The interpretation of other supply response variables is in such way.