NON-LINEAR EFFECT OF TEMPERATURE ON OIL PALM YIELD: A NOTE BASED ON PANEL THRESHOLD ANALYSIS

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ABSTRACT

The effect of climate change on agriculture and food production has emerged as one of the major concerns of major global economies, especially given that the global population is projected to reach 10.9 billion people by the end of the 21st century (United Nations, 2019). Crops react differently to climate change and hence it is crucial to understand its effect on specific agricultural plants. Specifically, the impact of climate change on agriculture yield may not be linear. As such, this study investigated the impact of climate factors on oil palm yield using state level data from Malaysia. The results suggested that temperature and oil palm yield have a non-linear inverted U-shaped relationship. In addition, rainfall has a positive impact on oil palm yield.

Keywords: oil palm, yield, climate change, temperature, nonlinear

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1. INTRODUCTION

The National Oceanic and Atmospheric Administration (2020) indicated that the average global temperature has increased at a scale of 0.08 degrees Celsius (°C) per decade since the year of 1880. It is simulated that by 2020, the temperature will be more than 0.5°C warmer than the 1986-2005 baseline. Looking ahead, the temperature in Southeast Asia, where Malaysia is a part of it, is projected to rise between 1.87°C and 3.92°C by the end of the century (Parry et al., 2007). The effects of climate change have been felt in Malaysia with higher occurrences of heatwaves, droughts, and floods. With the rising average temperature and sea level, some coastal areas of the country are expected to be inundated by the sea water in decades to come. Besides, Malaysia stays vulnerable to landslides, haze and water pollution. Siwar et al. (2013) reported the

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increase of mean surface temperature for Malaysia to be between 0.6°C to 1.2°C from 1969 to 2009. The projection by 2050 was an increase between 1.5°C to 2°C.
With the global population projected to reach 10.9 billion people by end of the 21st century (United Nations, 2019), understanding the impacts of climate change on the agriculture sector is critical. Thus, numerous approaches to gauge the effects of climate change on agriculture output have been introduced. For example, studies by Abbas et al. (2020), Barrios et al. (2008), Calzadilla et al. (2013), Chen and Gong (2021), Deschenes and Greenstone (2007), Fisher et al. (2012), Fleischer et al. (2008), and Seo and Mendelsohn (2008) evaluated the impacts of climate change either on the aggregated farm revenue, farmland values, or agriculture output. Back in Malaysia, the food security gap requires immediate attention. Ahmed et al. (2016) cautioned that without immediate adaptation actions, food sustainability cost was at a 30-35% shortage in 2015 and will go up to 40% of shortage from the national target in 2065.

As crops react to climate change differently, understanding the effect of changes in temperature and rainfall on specific agricultural plants is exceptionally important. Thus, numerous studies have been undertaken to gauge the impact of climate change on the production of corn (Baum et al., 2020, Brown & Rosenberg, 1999; Islam et al., 2012), potatoes (Hijmans, 2003; Raymundo et al., 2018; Rosenzweig et al., 1996), rice (Faisal & Parveen, 2004; Lal et al., 1998; Muhammad et al., 2014; Murdiyarso, 2000; Rayamajhee et al., 2021), soybean (Fodor, 2017; Liu & Dai, 2020; Vera-Diaz et al., 2008), and wheat (Faisal & Parveen, 2004; Gul et al., 2019; Lal et al., 1998) among other crops. The change in climate is adversely impacting the yield of rice by between 13% and 80%, and oil palm, rubber and cocoa by 10% to 30% in Malaysia (Siwar et al., 2013).

Oil palm is the most efficient oil-yielding crop. On average, it can yield 3.74 tonnes of palm oil per hectare, producing more oil per hectare than rapeseed, soybean, or sunflower (Sumathi et al., 2008). Furthermore, palm oil export for Malaysia in 2020 was 17.4 million tonnes generating more than US$18 billion export earnings for the country (Malaysia Palm Oil Corporation, 2020). Given the importance of oil palm to the world supply of edible oil, it is crucial to comprehend the impact of climate change on the yield of oil palm. According to Kushairi et al. (2011), oil palm trees are most suitable to grow in temperature between 23°C and 32°C. This suggests a changing relationship between temperature and oil palm yield. When the temperature is low, a hotter weather will enhance yield until a threshold temperature is reached. After that, hotter temperature starts to reduce oil palm yield. This suggests a possible inverted-U shaped relationship between temperature and oil palm yield. Hence, the main objective of this study is to investigate the non-linear relationship between average temperature and oil palm yield.

The are limited studies in Malaysia related to the impact of climate variability on the oil palm yield. The study of Sarkar et al. (2020) found that there were more negative than positive impacts of climate change on the oil palm yield. The study simulated that a 1°C to 4°C increased in average temperature will reduce oil palm yield by 10% to 41%. The objective of the present study is to estimate the influence of changes in climate indicators, especially rainfall and small planter holdings, affecting the oil palm yield.

2. DATA AND MODEL

The main objective of this paper is to examine the non-linear effect of average temperature on oil palm yield. The present paper adopts the crop yield response model, where both climate factors and control variables were incorporated to the model. The specific form of the model is given as follows:

$$Yield_{it} = \alpha_0 + \alpha_1 Mature_{it} + \alpha_2 Price_{it} + \alpha_3 Smallholdings_{it} + \alpha_4 Temperature_{it} + \alpha_5 Temperature^2_{it} + \alpha_6 Rain_{it} + \alpha_7 TimeTrend_{it} + \mu_{it} \quad (1)$$

where Yield is the production of fresh fruit bunch (tonnes per hectare) for state i at year t, Mature is the proportion of matured oil palm trees, Price is the average price of fresh fruit brunch (RM per tonne), Smallholdings is the proportion of cultivated oil palm lands owned by smallholders, Temperature is the average annual air-surface temperature (°C), and Rain is the average rainfall (mm).

As each state in this study has at least one metrological station, the climate variables were basically the average values of all the weather stations in that state. However, one of the states under investigation does not have any metrological station. Hence, the climate factors adopted for that state were the average values from the two nearest metrological stations surrounding that state.

Among the climate factors, rainfall may impact the oil palm yield in two opposite ways. First, rainfall fulfils the biological needs of the oil palm crop because the plant will not flourish if it receives too little water. On the other hand, frequent rainfall will disrupt the harvesting and transportation of fresh fruit bunches. Hence, the impact of rainfalls on oil palm yield is ambiguous.

Oil palm trees thrive in temperature between 23°C and 32°C (Kushairi et al., 2011). This implies that if the average temperature is too low or too hot, the oil palm trees will not grow well. In this respect, when the temperature is low, a hotter weather will improve the oil palm yield until a threshold temperature is reached, after which hotter weather will have a detrimental effect on oil palm yiled. Thus, this study hypothesized that average temperature and oil palm yield have an inverted U-shaped relationship. To estimate the optimum average temperature, the square of average temperature ($Temperature^2$) was also incorporated into the model.

Three control variables were introduced into the model. In practice, when the price of fresh fruit bunch is too low, plantation owners will make decisions of not harvesting their fruits. This will reduce the oil palm yield. Hence, the price of fresh fruit brunch has a positive relationship with the yield. The proportion of matured trees in a particular state will also affect the yield. Typically, it takes at least three years for an oil palm tree to bear fruit. As the tree gets older, the yield will also increase until it reaches and old age (normally 18 year-old). Thus, this research hypothesises that a higher proportion of matured trees will generate a higher yield.

Oil palm plantations in Malaysia are generally owned by either big private estates (including large plantation companies), government or independent smallholders. A particular interest is to investigate if the percentages of plantations owned by smallholders have an impact on the oil palm yield. It is widely believed that since smallholders operate a smaller-sized plantation, they are not able to achieve economies of scale. Thus, a larger proportion of smallholdings in a state will decrease the yield. This study expects that the proportion of plantations owned by small plantation owners will have a negative relationship with oil palm yield.

Finally, a time trend (TimeTrend) was incorporated into the model to capture factors that change over time and were not captured by the explanatory variables such as changes in technology and government policies. The palm oil production technology has improved over the years, hence, this study expects that improvement in the planting technology has a positive impact on oil palm yield. On the other hand, the impact of various government policies on palm oil plantations such as sustainability requirements, windfall tax and replanting schemes is ambiguous. Overall, this study predicts that the sign of time trend can be either positive or negative.

Malaysia comprises of thirteen states. However, the oil palm statistics are only available for twelve states. Furthermore, since the data for majority of the control variable is only available starting from 2003, thus, this paper used annual data from 12 states in Malaysia for the period from 2003 to 2019. The final sample consists of 204 observations.

Although many previous studies have used panel GMM estimation technique to model various Quadratic functions, this paper has employed both Fixed Effect model and Random effect model to capture the non-linear relationship between oil palm yield and temperature. This is because the data set used in this paper has more time periods than cross sectional units (T>N). In addition, the underlying model of Equation 1 is not dynamic (ie. no lagged dependent variable). Moreover, some of the previous studies on Quadratic relationship also used Fixed Effect model and Random Effect model (see for example Canas et al., 2003; Xie & Liu, 2019; Xu et al., 2019). It is worth noting that a long-panel data set is used in this study as the number of periods is larger than the number of cross-sectional units. On this note, equation 1 was estimated using the individual-effects model with AR(1) error as suggested by Cameron and Trivedi (2010), which will lead to more efficient estimates.

The data for oil palm yield, proportion of matured trees, prices of fresh fruit bunch and percentage of smallholders were obtained from the Malaysia Palm Oil Board. On the other hand, the data on metrological indicators were collected from the Department of Statistics, Malaysia.

3. RESULTS AND DISCUSSIONS

In this section, the non-linear effect of average temperature on oil palm yield is examined. First, the summary statistics for all the variables used in this study are presented in Table 1. The annual oil palm yield varied substantially over the years and across different states. The highest annual fresh fruits bunches (FFB) yield recorded was 25.6 tonnes/hectare by Melaka in 2008, while the lowest annual yield documented was 10.12 tonnes/hectare by Penang in 2019, with an average annual yield of 17.95 tonnes/hectare. Turning to the control variables, on average, 88.15 percent of the plantations were planted with matured oil palm trees. It is worth noting that the percentages of palm oil plantations that were matured are very similar across states and years with a standard deviation of 6.22 percent. Another interesting fact is that only a small proportion of plantations were owned by smallholders. More specifically, approximately 18.66 percent of the plantations were owned by smallholders. The price of FFB was very volatile. The lowest price for FFB was in 2005 versus the highest price recorded in 2011.

With regards to the climate variables, the average annual temperatures fluctuated between 26.65°C and 29.25°C with an average of 28.08°C. On the other hand, the volume of annual rainfalls recorded differ substantially. For instance, the lowest average annual rainfalls documented was 1389.8mm in Melaka for 2013, while the wettest state was Sarawak in 2008.

Table 1: Summary Statistics

	Mean	Median	Maximum	Minimum	Standard Deviation
Yield	17.95725	18.48000	25.60000	10.12000	3.22377
Mature	0.88151	0.89458	0.98941	0.66228	0.06228
Price	24.35686	24.29000	36.54000	14.43000	6.14930
Smallholdings	0.18669	0.14231	0.68591	0.01877	0.15396
Temperature	28.08926	28.06875	29.25000	26.65000	0.43184
Rain	2515.38900	2396.65000	4241.62000	1389.80000	568.64350

The results from the panel regressions are reported in Table 2. The estimated signs for all the independent variables are as expected except for Smallholdings and Price. However, these two control variables are not statistically significant even at 10 percent level. More interesting is that all the coefficients estimated using fixed effects and random effects share same signs and similar magnitudes.

Table 2: Results of Crop Yield Respond Model

	Fixed Effects Model	Random Effects Model
Mature	3.04411	14.25751***
	(5.66980)	(4.77013)
Price	-0.01572	-0.00756
	(0.02130)	(0.02194)
Smallholdings	0.75051	1.45531
	(6.60849)	(3.23220)
Temperature	62.74537***	62.49449***
	(21.59000)	(23.07828)
Temperature^2	-1.16144***	-1.15083***
	(0.38467)	(0.41115)
Rain	0.00049*	0.00044
	(0.00027)	(0.00029)
TimeTrend	-0.01298	-0.04134
	(0.05787)	(0.03950)
Constant	-831.50020***	-842.63010***
	(180.99790)	(323.83280)
R^2	0.3428	0.1250
χ^2 Statistics for Hausman Test	-	30.6000***

***Notes**:* ***, ** and * indicate significant at 1 percent, 5 percent and 10 percent respectively. The coefficients of correlations between independent variables (except for temperature and its square term) are between -0.414 and 0.682. The standard errors are in parentheses.

As the consistency and efficiency of the estimators remain ambiguous, the Hausman test was used to verify them. The Chi-square statistics of 30.6000 rejects the null hypothesis of random effect estimators are efficient and consistent. Thus, the results suggest that the data and model are with fixed effect model. To examine the existence of serious multicollinearity, the correlation coefficients for all the independent variables were calculated. Except for the correlation between temperature and its square term, the highest coefficient of correlation is 0.682, which suggest that the results are not seriously affected by multicollinearity.

The results from the fixed effect model suggest that proportion of matured trees plays no role in explaining the yield of oil palm tree as it is not significant even at 10 percent level. In reality, oil palm trees will only bear fruit after three years of planting and the trees become more productive as they grow older. However, the results suggest that a higher proportion of matured oil palm trees will not lead to an increase in yield per hectare.

The percentage of smallholder farmers in Malaysia differ significantly across states. In certain states, oil palm plantations that were owned by smallholders only constituted less than five percent of the total palm oil plantations but in other states more than sixty percent of the palm oil plantations were owned by smallholders. Smallholder farmers are perceived to face efficiency issue as the small plots of land that they cultivated would not allow them to achieve economies of scale. The variable that captured this factor (Smallholdings) is not statistically significant at 10 percent level, thus, the proportion of plantations cultivated by smallholders has no impact on the oil palm yield.

Another control variable is the price of fresh fruit bunch (FFB). It is widely believed that farmers will not harvest the palm oil fruits if the price is too low. Thus, the price of FFB will affect the yield of oil palm. However, this variable is not significant from the estimated results in Table 2. To investigate changes in oil palm yield over time, a time trend was included in the model. This variable captured factors that change over time but unable to be captured by the independent variables such as technological change and regulatory changes. The estimated sign of the time trend is negative but not significant.

Table 2 also presents the non-linear relationship between average temperature and oil palm yield. The estimated results suggest that the temperature indicators have significantly impacted the oil palm yield. The estimated coefficients of temperature and its square term are positive and negative, respectively. This means that the temperature and oil palm yield have a non-linear inversed U-shaped relationship. As temperature increases, the yield will increase up to a point, but after the threshold, a hotter temperature will adversely affect the yield. The threshold for temperature variable, where the yield tends to decline if the temperature exceeds the value is 27.01°C (62.74537÷2.32288). According to Kushairi et al. (2011), oil palm trees grow well in climate between 23°C and 32°C, with a simple average temperature of 27.5°C. Thus, this average temperature is very close to our threshold estimate of 27.01°C.

Turning to the marginal effect of temperature on oil palm yield, initially, when the temperature increases by 1°C, the oil palm yield will also increase by 0.84 (62.74537-2×1.16144×26.65) tonnes/hectare. As the weather gets hotter and pass the threshold value of 27.01°C, a 1°C increases in the average temperature will cause the yield to drop by 5.20 (62.74537-2×1.16144×29.25) tonnes/hectare. It is worth nothing that although there is no comparable existing study on oil palm yield as reported in the form of this study, the study of Sarkar et al. (2020) and several studies on other crops such as rice (Faisal & Parveen, 2004; Lal et al., 1998;

Muhammad et al., 2014; Murdiyarso, 2000; Rayamajhee et al., 2021) and wheat (Faisal & Parveen, 2004; Gul et al., 2019; Lal et al., 1998) have suggested that warmer temperatures are yield-decreasing.

Another climate variable in focus is the amount of rainfall. The results show that rainfall has a positive impact on oil palm yield but only at 10 percent significant level. Typically, oil palm trees will thrive if rainfall occurs between 1,700 mm and 3,000 mm per year (Kushairi et al., 2011). During the sample period, the average rainfall was 2515.38 mm per annum. As such, higher rainfall will increase the oil palm yield.

4. CONCLUSION AND IMPLICATIONS

The main aim of this paper is to examine and estimate the impact of climate factors on the oil palm yield. More specifically, the paper wishes to address the issue of the non-linearity in the relationship between the average temperature and oil palm yield. Using annual data from 2003 to 2019 for 12 states of Malaysia, the estimated results from the fixed effect model suggest that climate variables have impacted the oil palm yield.

In particular, the results indicate that there is a non-linear inverted U-shaped relationship between the average temperature and oil palm yield. This implies that a warmer weather initially will enhance the yield. However, as the climate becomes warmer, the oil palm yield will decline. More specifically, from the estimated marginal effect values suggest that a one-degree Celsius increase in the average surface air temperature will reduce the yield by approximately 5.20 tonnes/hectare.

The study estimated that the threshold temperature is 27.01°C. As the temperature of Malaysia is projected to rise significantly over the decades, this will have an impact on the oil palm yield. Thus, various measures are required to be adopted to counter the adverse impacts of rising temperature. Among them is the introduction of new clones of oil palm trees that are heat tolerant. Another approach is to develop a more efficient way to extract the oil from the fresh fruits bunch (FFB). Hence, a new paradigm shift is needed to tackle the impact of global warming on the palm oil industry.

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