AN EMPIRICAL ANALYSIS OF THE CLIMATE AND PRICE OF COCOA PRODUCTION IN MALAYSIA

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ABSTRACT - *Considering the demand expansion in downstream cocoa grinding, the feasible factors underlying these existing yield gaps are addressed by evaluating changes and relationships in year pattern of climate and price determinants on regional cocoa yield. Furthermore, study also focused on the impact of climate and price on cocoa productivity by employing an Autoregressive Distributed Lag (ARDL) using time series data for a 18-year period (2001-2018) to explore the association among the variables with the evidence of long-run analysis. Our results showed that all climate variables of sunshine evapotranspiration, wind and temperature had negative and significant association with cocoa productivity in long-run analyses except rainfall. The productivity trend was positive with projected increase in total rainfall by 1 mm and an increase in the number of raining days by one led to an increase of 0.4% and 10% in cocoa productivity, respectively. Price had no significant effect on cocoa productivity in the long run. In concise, climate change would transmute the total cocoa production in the coming decades and the year pattern of climate impact on yield was identified. Cocoa trade price is estimated to rise considerably under the more pessimistic scenario. The rise of the commodity price reduce consumer surplus and thus diminish the benefits from climate change with predicted yield effects would otherwise receive. Intuitively, this study helps the policy makers to identify the causes of the yield in the long-run that will benefit the cocoa sector in particular.*

Key words: climate and yield, pattern, climate variability, long-run analysis, surplus and demand

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is a perennial tropical commodity in the world that is characterized by a long life span (≥ 25 years). Cocoa produces pods continuously throughout years to sustain the huge market demand for downstream cocoa industry as the beans are the main ingredient in chocolate manufacture. In a cocoa production system, natural resources such as land, sunshine, water, air and soil conditions are important factors that influence cocoa production. Among these natural resources, climate is considered predominant and could significantly affect the yield of agriculture farms (Murad *et al*., 2010). Cocoa, for instance, is highly sensitive to changes from temperature to rainfall and hours of sunshine due to the effects on evapotranspiration (Oyekale *et al*., 2009).

Cocoa is best cultivated at altitudes of 30 to 300 meters above sea level. For optimum yield, the rainfall requirement is about 1250 to 3000 mm per annum with dry season not exceeding three consecutive months (rainfall not less than 100 mm per month) (Lee *et al*., 2013). Minimum temperature of cocoa cultivation ranges between 19 to 21 °C while maximum temperature falls within 30 to 32 °C. Suitable relative humidity of cocoa cultivation ranges between 85 to 90% with the average sunshine hours within 5.0 to 5.5 hours per day. Successful cultivation of cocoa also requires deep well drained soil with water table below 90 cm from the soil surface, porous structures for better root penetration and good soil texture consisting of 25-40% clay, 35-65% sand and < 30% loam (Lee *et al*., 2013).

Cocoa has been cultivated extensively in Malaysia from 123,855 ha in 1980 to 414,236 ha in 1989 due to the unprecedented high cocoa prices (Lee, 2013). Unfortunately, the cocoa industry faces disconcerting scenarios with a tremendous decline in planted area from 393,465 ha in 1990 to 190,127 in 1995 and as of 2017, the cocoa planted area was reduced to 17,554 ha. Cocoa bean production declined from 250,000 metric tons in 1990 to 1,029 metric tons in 2017. However, the demand outstripped production by 300,000 metric tons and Malaysian cocoa industry with export earnings of beans and cacao products has increased tremendously from less than RM1.0 billion in the year 2000 to RM5.78 billion in 2016 (MCB, 2018). Worldwide, the total cocoa bean production exceeded four thousand metric tons in the 2016/2017 with most of the world's cocoa produced in Africa with 73.1% (3625 thousand metric tons), followed by 16.9% (739 thousand metric tons) from the Americas and 9.9% (379 thousand metric tons) from Asian and Oceanic countries (ICCO, 2018). The world demand for cocoa and chocolate has increased significantly, achieving 200 billion USD in the global confectionery market (Zhang and Motilal, 2016) and over the past few years, cocoa has become popular due to its health benefits and role as a potential functional food such as cocoa butter and powder (Rusconi and Conti, 2010; Bernaert*et al*., 2012). However, cocoa growing countries can barely meet the boosted demand for cocoa beans (ICCO, 2016) and price volatility induces uncertainties among cocoa participants in the market, causing millions of African cocoa farmers highly vulnerable to poverty (Fountain and Hütz-Adams, 2015).

In Malaysia, it is believed that the major gap between the supply of low bean production and high demand of bean grinding is caused by low cocoa productivity (an average of 0.2 ton per hectare in 2017), smallholders' age (66.3% of smallholders are 61 years or older) (Mohd Mustafa *et al*., 2017), incidence of pests and diseases, increasing production costs, labour shortage, world cocoa price and extreme weather changes. The increasing demand of cocoa over the coming decades will probably be realized through expansion of the cocoa cultivation area and increased productivity. Thus, increasing productivity is a necessary step towards reducing pressure on land. A rise in the incidences of heat stress, droughts and floods has negative economic impacts on the productivity. For an instance, a study reported that a rise in temperature by 2 °C causes a reduction of 0.36 ton ha^{-1} on Malaysian rice production which approximately causes economic loss of RM162.53 million per year (Vaghefi *et al*., 2011). In short, climate change causes negative impacts on crop yield which will consequently have economic effects on agricultural prices, demand, production, trade and producer and consumer welfare (Li *et al*., 2011). Therefore, climate change phenomenon is an important issue that should be focused in maintaining productivity of agricultural crops. The objectives of this study were to analyze the year pattern of climatic variables on cocoa production and to project the potential long-term impact of cocoa commodity price and climate variability on cocoa yield in order to estimate the scope to increase cocoa productivity in existing stands.

MATERIALS AND METHODS

Study site

Study was carried out at Cocoa Research and Development Centre Bagan Datuk (N3 53' 42 in latitude, E100 M, 52' 0' in longitude, 9.14 meter in altitude), Perak, Malaysia. Annual rainfall average is 1826.3 mm per year with June and July being the driest months, with respectively 94.0 mm and 107.0 mm (average data from 2001 to 2018), indicating in Perak, rainfall quantities and distribution pattern are not at the limits for cocoa production (Figure 1).

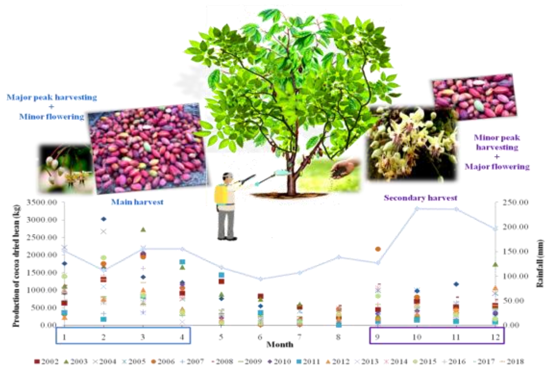


Figure 1: Yield pattern relates to cocoa reproductive stages

Average annual temperature remains relatively constant throughout the year at around 28.1 °C. Cocoa production normally has two harvests per year with the main harvest peak is from January to April while the secondary harvest (lower peak) is from September to December (Figure 1). Soils in Perak are predominantly Siri Selangor with USDA soil taxonomy of Aeric Tropic Fluvaquent and bulk density is 1.54 g cc-1. Farms are relatively small, with an average of 2 ha. Traditional cocoa planting system is followed with gliricidia (Gliricidia sepium) planted as shade tree. Despite gliricidia, cocoa is integrated with other economic crops such as coconut, fruits, timber with cocoa as the main crop.

Field management practice

Field management was done by following the cocoa planting manual (Lee et al., 2013). 1.2 kg tree-1yr-1 of compound fertilizer which contained elements of nitrogen (N), phosphorus (P) and potassium (K) was applied by broadcasting under tree canopy over the field. Fertilization was carried out three times a year, immediately after harvesting season. Liming was applied with calcium hydroxide only one time a year with 800 g tree-1 through broadcasting under tree canopy. For pests control especially cocoa pod borer (CPB) insecticide spray with recommended dosage by the product which contained active ingredient of 50.0% w/w Chlorpyrifos and 5.0% w/w Cypermethrin was carried out. Sprays were carried out at monthly intervals. Heavy pruning was implemented once a year after main harvest to re-shape the tree canopy by getting rid of disease-infected and unproductive stems (Figure 1).

Climatic data

Well-processed of historical climatic variables for cocoa production (total monthly rainfall, total wind, total sunshine, total evapotranspiration, average daily wind, average monthly sunshine, average evapotranspiration, number of raining days and average temperature) during the period from 2001 to 2018 at Cocoa Research and Development Centre Bagan Datuk (N3 53' 42 in latitude, E100 M, 52' 0' in longitude, 9.14 meter in altitude), Perak, Malaysia were collected. Daily weather data was recorded every 30 min using a weather station (Spectrum Watchdog 2700 Weather Station, USA).

Crop data

Historical cocoa yield data covered from 2001 to 2018 with a total of 154.75 ha mature cocoa area. Ripe cocoa pods were harvested weekly and pod breaking was done using a knife. Wet beans were extracted from the pods for further fermentation for five days with single turning at the 48th hour. Fermented beans were then sun-dried at one bean thickness on a drying yard. Dried beans were then measured and weight (kg) was recorded as cocoa yield while productivity was calculated as yield per hectare (kg ha-1).

Analytical framework for year pattern distribution

Multiple mean comparisons were analyzed at 95% significance level by applying Duncan's multiple range test (DMRT) using Statistical Analysis System (SAS Institute, 2002). Results were further computed in graphs to study the pattern of climate distribution from 2001 to 2018.

Correlation

The Pearson's correlation data analysis was performed to measure the strength of the association among the climate variability and cocoa production. The range of coefficient is -1 to +1 and the calculation of the correlation coefficient (r) was performed.

$$r_{xy} = \frac{\sum(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum(x_i - \overline{x})^2 \sum(y_i - \overline{y})^2}}$$

Where, x and y are the variables, $\overline{x}$ (means) for x-variable and $\bar{y}$ (means) for the y-variable. Values r close to 1 implies strong positive linear relationship between x and y; values r close to -1 implies strong negative linear relationship between x and y; values r close to zero implies little or no linear relationship between x and y.

Multiple regressions

Regression model can be calculated by the following equation:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \varepsilon$$

Where Y is the cocoa yield (dependent variable), X_1, X_2,… are independent climate variables of rainfall, wind, sunshine, evapotranspiration and temperature. β_1, β_2…are the model coefficient of the independent variables and ε is the error. R-squared (R^2) is the coefficient of multiple determinations used to verify the goodness-of-fit of the regression model (Bowerman*et al*., 2005).

R^2 = SSR/ SST = 1 – (SSE/ SST)

Where SST is the total sum of squared, SSR is the regression sum of squares and SSE is the error sum of squares.

The variables to get the best fit of model were selected using:

a. Forward selection which starts with an equation containing no predictor variables and only a constant term.

b. Backward elimination creates full equation and successively drops one variable at a time on the basis of their contribution to the reduction of error sum of squares with the smallest *t*-test in the equation.

c. Stepwise regression is created after considering the forward selection and backward elimination. Therefore, model set with $P<0.05$ showing statistical significant result between the variables can be applied.

Long-run estimation technique and diagnostic test

This study applies the Autoregressive Distributed Lag (ARDL) bounds testing approach, which involves unrestricted error correction model for co-integration analysis between cocoa yields, price and climate (Pesaran *et al*., 2001). The choice of this test is based on its advantage, which can be applied irrespective of whether the interest variables are I(0) or I(1). As such, the ARDL [p, q, r] model can be expressed in the following form:

$$\Delta y_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta y_{t-i} + \sum_{j=0}^{q} \beta_2 \Delta Price_{t-j} + \sum_{k=0}^{r} \beta_3 \Delta Climate_{t-k} + \theta_0 y_{t-1} + \theta_1 Price_{t-1}$$

$$+\theta_2 Climate_{t-1} + \theta_3 \mathrm{T} + \varepsilon_t$$

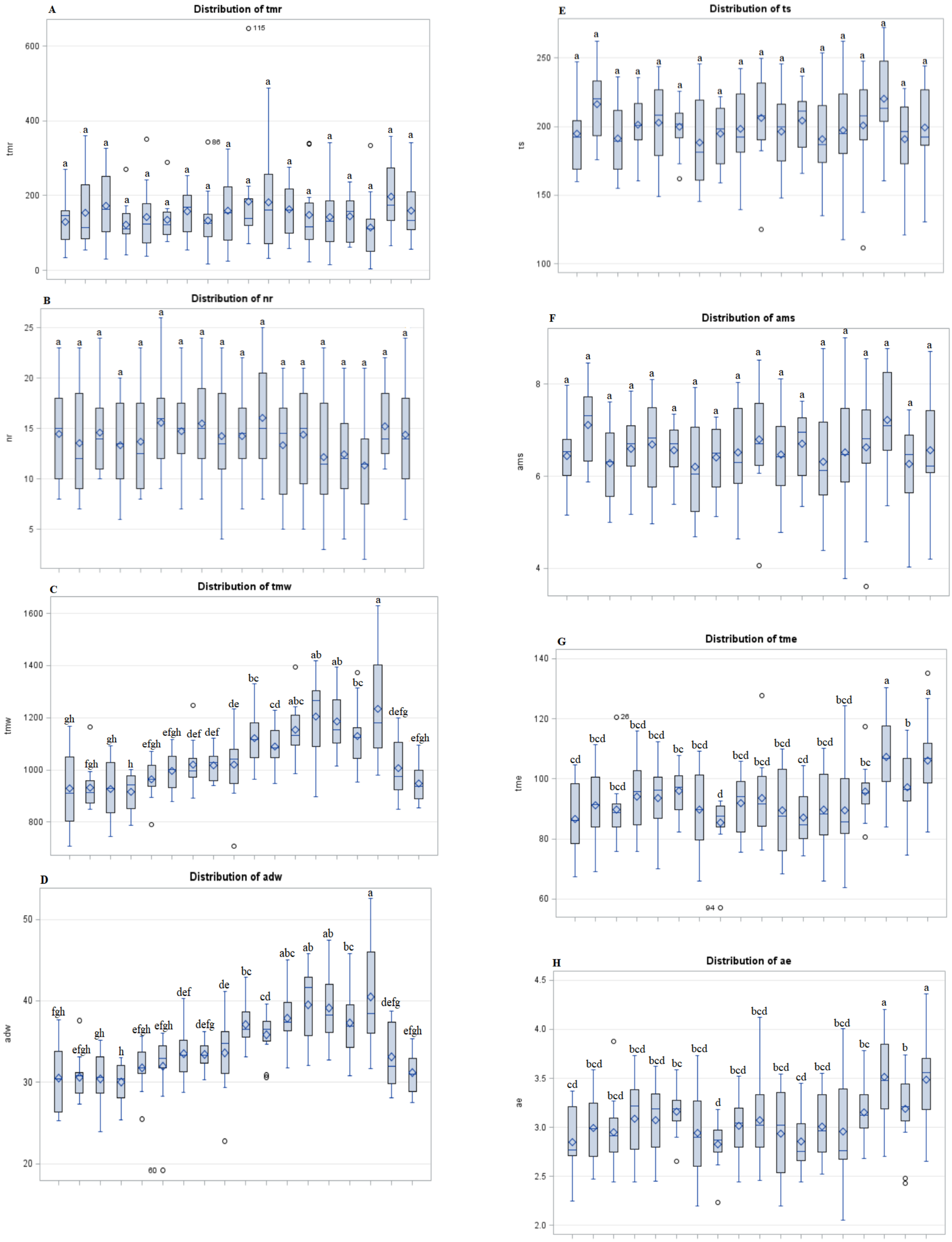
where yt is the cocoa yields, price is the average cocoa price, and climate is measured by a set of proxies, which includes total rainfall (mm), total wind (km), total sunshine (hours), total evapotranspiration (mm), average daily wind (km), average sunshine, average evapotranspiration (mm), number of raining days, average temperature (ºC) and T denotes time trend. p, q and r are the lag length which minimises the Akaike information criterion (AIC) value. The βs represents the error correction dynamic while the θs corresponds to the coefficient on lagged levels terms. To identify the existence of the long-run relationship, an F-test is applied to test the joint significance of coefficients θ0, θ1and θ2, where the null hypothesis is defined by H0:θ0= θ1= θ2 = 0 against its alternative H1: θ 0 ≠ θ 1≠ θ 2 ≠ 0. The computed F-test statistic is mapped with the two asymptotic critical value bounds (Pesaran et al., 2001).

If the computed F-test statistic exceeds the upper bound critical value, the null hypothesis is rejected and concludes that a long-run relationship exists. Conversely, if the computed F-test statistic falls below the lower boundcritical value, the null hypothesis cannot be rejected, indicating no long-run relationship. However, if the computed value lies between the upperand lower bound, conclusive inference cannot be drawn.

RESULTS AND DISCUSSIONS

Year pattern of yield variables in cocoa

Cocoa yield was determined by multiple climate variables of total monthly rainfall, number of raining day, total wind, average daily wind, total sunshine, average monthly sunshine, total monthly evapotranspiration, average monthly evapotranspiration, and average temperature over the fruiting season. Historical yield and climate factors of total monthly rainfall, total sunshine, average monthly sunshine and number of raining days did not show significant difference throughout the year of study (2001-2018) (Figure 2). The rainfall pattern in the regional study of cocoa production was quite constant, with an average of 152.30 mm per month. The driest month normally happened in June and July (<100 mm) and was not more than three consecutive months (Figure 2A). There was no significant difference found in the number of raining days over the entire years (Figure 2B) and the highest number of raining days was recorded in November with an average of 21 days and June achieved significantly the lowest with only nine raining days (data not shown). The total wind in a month was at an average of 1044.31 km throughout the study year. Interestingly, the total monthly wind was low in 2001 to 2006 (average 944.09 km) and increased significantly by 30.7% to 1233.73 km in 2016 which was then reduced 23.2% to 947.91 km in 2018 (Figure 2C). Similar pattern of distribution was observed for average daily wind which was measured at 33.94 km throughout years (Figure 2D) and hit the highest record in March and April while the lowest was recorded in December and January. In contrast, there were no significant differences reported in total sunshine hours in a month and average monthly sunshine from 2001 to 2018. There was an average of 199.61 sunshine hours throughout the years (Figure 2E), and the highest sunshine hour was recorded in 2016 with an average of 7.2 sunshine hours in a day (Figure 2F). Total monthly evapotranspiration also showed an increasing trend from 2001 (86.56 mm) to 106.22 mm in 2018 by 22.7% (Figure 2G). Additionally, average evapotranspiration was recorded at 3.49 mm in 2018, and the lowest was measured in 2008 at 2.83 mm (Figure 2H). Warmer temperature was measured as cocoa-growing period proceeded from 2001 (28.17 °C) to 2018 by 0.1% and the year 2016 had the highest average temperature recorded at 28.86 °C (Figure 2I). Within a year, May had the highest recorded temperature (28.84 °C) while November, December and January had a cooler temperature at an average of 27.7 °C (data not shown).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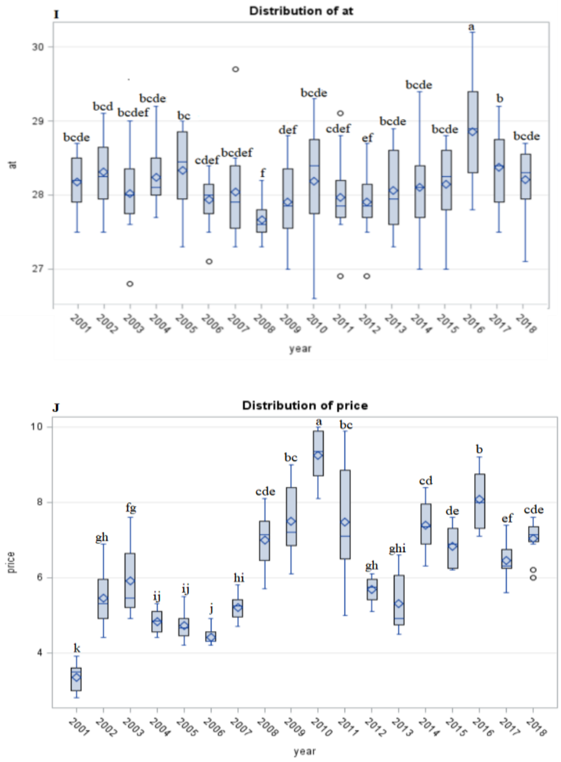

Figure 2: Changes in rainfall (tmr: total monthly rainfall; nr: number of raining day), wind (tmw: total monthly wind; adw: average daily wind), sunshine (ts: total sunshine hour; ams: average monthly sunshine), evapotranspiration (tme: total monthly evapotranspiration; ae: average evapotranspiration), temperature (at: average temperature) and price from 2001 to 2018 in the regional area of Perak, Malaysia.

Commodity price of cocoa showed a better trend with increasing trade price from the lowest in 2001 (RM3.35) and hit the highest trading price in 2010 at RM9.24. Afterwards, the price dropped by 38.5% to RM5.68 in 2012 and increased by 30.3% in 2014. The price kept at a range of RM6.83 in 2015 to RM7.04 in 2018 (Figure 2J). Moreover, there was no significant difference reported at cocoa trading price every month over the years (data not shown).

Cocoa is highly dependent on temperature and despite rainfall, is the main factor determining the cultivation region of cocoa (Daymond and Hadley, 2004). In Ghana, daily maximum temperatures were reported to hit up to 44 °C (Asareet al., 2017). Temperature tends to affect the photosynthesis in cocoa where the photosynthesis rate declined as average monthly temperature increased above 34 °C during dry period (Balasimhaet al., 1991). A linear response of flowering when temperature increased was reported in Bahia, Brazil where optimum flowering in cocoa is at 26.7 °C (Daymond and Hadley, 2011). Increase in temperature demonstrated higher pod respiration rates and may contribute towards greater occurrence of pod losses due to vaporat wilt, thus, yield gaps increased (Daymond and Hadley, 2008). This is due to the active growth of leaf and shoot at higher temperatures which out compete young cocoa pods for assimilates. The high temperature in West Africa has caused detrimental to cocoa productivity (Schroth et al., 2016) as pod and bean size decline when temperature increases (Daymond and Hadley, 2008).

Cocoa yield-climate relationships

The correlation coefficients I between cocoa dried bean production and specific climatic variables over specific harvesting years were displayed in Table 1. The relative yields were significant ($P \leq 0.05$) and correlated negatively with total monthly wind and average daily wind while the other climate factors such as rainfall, temperature, sunshine and evapotranspiration did not show significant correlation with cocoa production from 2001 to 2018 (Table 1). These apparent correlations between cocoa yield and sole climatic variables may not reflect the actual effect. Generally, rainfall and temperature are considered the dominant factors affecting crop production but the distribution of rainfall and temperature in this region did not show significant correlation with cocoa production. However, climate variables showed a significant correlation among each other over the harvesting period. Rainfall (total monthly rainfall and number of raining days) was negatively correlated with temperature, sunshine hour and evapotranspiration. There was no significant correlation showed among total monthly rainfall and wind (Table 1). Analysis also showed that the number of raining was positively correlated with total monthly rainfall but not significant. For evapotranspiration and sunshine, both variables correlated negatively with other climate variables such as temperature and wind except rainfall (number of raining day and total monthly rainfall). As for wind, it did show significant correlation with total monthly rainfall, but it was significant and positively correlated with the rest of climate variables (temperature, wind, sunshine and evapotranspiration) except number of raining day (Table 1).

Backward elimination analysis starts with model 1 with all independent variables after conducting collinearity analysis, and the process of elimination was illustrated in Table 2. First, variable tme (total monthly evapotranspiration) with the highest p-value of 0.9592 was excluded from model 1, and the remaining variables formed model 2. Secondly, tmr (total monthly rainfall) was excluded due to the highest p-value of 0.9574, and the process continued until the sixth step (model 6), where all the p-values of the variables were found to be significant (less than 0.05). These variables (total monthly wind, total sunshine, average monthly sunshine and average evapotranspiration) were classified as the most significant variables and used to forecast the cocoa yield. Thus, model 6 was employed to forecast regional cocoa production compared to model 1 (R^2 = 0.1372, R^2_{adj} = 0.0994) as the difference between R^2_{adj} and R^2 was smaller in model 6 (Table 2).

Y = 752.49 – 0.97 tmw – 17.73 ts + 548.19 ams + 269.16 ae (R^2 = 0.1245, R^2_{adj} = 0.1078)

On the other hand, stepwise regression analysis showed the best equation as:

Y = 827.16 – 3.47 tmw + 74.94 adw +278.06 ae (R^2 = 0.1115, R^2_{adj} = 0.0988)

By comparing both models, model 6 from the backward elimination procedure was the better model fitted to the data than stepwise regression model due to the higher value of R^2. This suggests that the regression model able to account for the effects of total monthly wind, total sunshine, average monthly sunshine and average evapotranspiration on cocoa yield in majority years.

Among these climate variables, rainfall is considered the most important environmental factor influencing cocoa yield as cocoa requires sufficient rainfall to support growth and fruiting of trees (Wood, 1985). Perak is located on the west coast of the Peninsular Malaysia which is also a state with constant rainfall distribution (not less than 1200 mm year-1) and no distinct year patterns attributed. Study showed that prolonged dry periods with rainfall less than 100 mm per month for more than three consecutive months can have substantial negative effects on cocoa yield. Rainfall has been reported to be beneficial to cocoa especially during initial stages of pod bearing (first four months of pod development) and sufficient rainfall during this stage increased pod production by 40% (Hutcheon et al., 1973). Pod development in cocoa typically takes five to six months to ripe after pod emergence.

The requirement of water becomes less influential as the pods reach maturity. This is because cell enlargement happens during early pod development stage can be influenced by factors such as water availability in order to create the turgor pressure as physical force for cell expansion (Dante *et al*., 2014; Fishman *et al*., 2002). A study showed that trees experienced water deficit during early stages of pod development produced more than 50% lower dry bean weight. Cocoa trees suffered from soil moisture deficit during dry periods with limited rainfall at initial stage of pod development still caused a reduction in yield even rainfall was re-introduced during later pod development (Schwendenmann *et al*., 2010). Sufficient rainfall at the early stages of pod development can caused a significant impact on cocoa yield. Thus, farmers may apply appropriate irrigation during early pod development if the total rainfall is less than 100 mm per month to obtain higher yield.In Sulawesi Indonesia, cocoa trees exposed to soil moisture deficit imposed over 13 months can cause a 10% reduction in bean yields (Moser *et al*., 2010). Severe drought scenario during El Niño-Southern Oscillation (ENSO) in 2015-16 has increased tree mortality and caused 89% reduction in potential yield on cocoa grown under agroforestry system in Brazil. The yield reduction still evident nine months after the drought has ended (Gateau-Rey *et al*., 2018). This study implied positive impact of rainfall in the long-run on cocoa productivity and rainfall was found to be correlated negatively with sunshine, evapotranspiration and temperature. The result was further supported by Oyekale *et al*. (2009) where 97.0% of the respondents claimed that rainfall is an important factor for pod growth and development, followed by temperature about 1.0% while other factors such as sunshine and wind claimed for the remaining 2.0%.

Table 1: Correlation among climate variables in cocoa production

	tmr	tmw	Ts	tme	adw	ams	ae	nr	at	yield
tmr		-0.05893 ns	-0.37419 **	-0.20343 *	-0.07938 ns	-0.38163 **	-0.21631 *	0.57263 **	-0.31690 **	-0.02089 ns
tmw			0.31632 **	0.36489 **	0.96995 **	0.28156 **	0.34742 **	-0.19444 *	0.21096 *	-0.20130 *
ts				0.58852 **	0.32950 **	0.98091 **	0.61430 **	-0.57963 **	0.55751 **	0.07702 ns
tme					0.34251 **	0.53753 **	0.97031 **	-0.34759 **	0.50522 **	0.08282 ns
adw						0.33134 **	0.36495 **	-0.21268 *	0.21605 *	-0.15085 *
ams							0.59997 **	-0.58654 **	0.53308 **	0.12004 ns
ae								-0.37323 **	0.50983 **	0.13156 ns
nr									-0.44345 **	-0.00172 ns
at										-0.02162 ns

n.s. Non-significant at P≥0.05; *Significant at P<0.05; **Significant at P<0.01

Table 2: Model summary using Backward Regression Analysis

Variable	Significant level of the independent variables (p-value of the coefficients) in different models					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
tmw	0.4086	0.4072	0.4041	0.0004	0.0003	0.0004
ts	0.2289	0.1525	0.1517	0.0138	0.0143	0.0063
ams	0.1664	0.0953	0.0946	0.0037	0.005	0.0033
ae	0.6393	0.0088	0.0087	0.0078	0.0072	0.0167
tme	0.9592	removed	removed	removed	removed	removed
tmr	0.9574	0.9547	removed	removed	removed	removed
adw	0.8094	0.8126	0.8106	removed	removed	removed
nr	0.4117	0.411	0.3703	0.3592	removed	removed
at	0.2030	0.2018	0.201	0.205	0.1425	removed

Table 3: ADF unit root test results

Variables	**Levels**		**First difference**	**Conclusion**
	Intercept	Intercept and trend	Intercept	
Productivity	-1.9829	-2.1956	-5.9676***	I(1)
Price	-2.4964	-2.4841	-11.8630***	I(1)
Total rainfall	-12.1887***	-12.2168***	-8.1801***	I(0)
Total wind	-1.4095	-0.7255	-9.0013***	I(1)
Total sunshine	-9.0503***	-9.0264***	-8.3432***	I(0)
Total evaporation	-2.1768	-2.3172	-10.7733***	I(1)
Average daily wind	-1.4390	-1.8604	-8.5717***	I(1)
Average monthly sunshine	-3.6395***	-3.6201**	-8.2889***	I(0)
Average evaporation	-2.2534	-2.4214	-10.5948***	I(1)
Number of raining days	-2.6912*	-2.7151	-10.3972***	I(1)
Average temperature	-2.7571*	-2.8704	-9.5636***	I(1)

Note: The optimal lag structure of the ADF test is chosen based on the Akaike Info Criterion (AIC). Asterisk *, **, and *** represent the significance level at 10%, 5% and 1% respectively.

Impact of climate and price variables on cocoa productivity in the long-run

Table 4 provided the results of the long-run estimates using the bound testing procedures. The F-statistic clearly showed that the null hypothesis of $\theta_0 = \theta_1 = \theta_2 = 0$against its alternative $\theta_0 \neq \theta_1 \neq \theta_2 \neq 0$was rejected at 1% significance level in all the models, regardless of the critical values. There were significant long-run relationships between climate and cocoa yields. The signs and magnitudes of the coefficients were dependent on the climate proxies used. An increase in total rainfall by 1 mm and an increase in the number of raining days by one lead to an increase of 0.4% and 10% in cocoa productivity, respectively. The remaining climate proxy returned significantly negative coefficients. An increase of 1 km/hr in total wind results in a 0.2% reduction in cocoa productivity. Average daily wind, on the other hand, indicates a 9.2% decrease in cocoa productivity following an increase of 1 km/hr average daily wind in a month, which translates to a 0.3% decrease in cocoa productivity in a day (0.0922/30days). Thus, confirming the results obtained when using total wind as a climate proxy. Cocoa trees increase exposure to the sun is also harmful to cocoa productivity. An increase in the total sunshine by an hour in a month reduces cocoa productivity by 1.5%. Using average monthly sunshine as a climate proxy, results indicate that an average increase in sun exposure by an hour in a day for 30 days, reduces cocoa productivity by 42.8%, or an average of 1.4% (0.4280/30days) reduction in cocoa production in a day. Increase evapotranspiration is also found to be detrimental to cocoa production. Using total evapotranspiration as a climate proxy, results indicate that an increase of total evaporation by 1 mm, reduces the productivity of cocoa by 1.9%. When using average evapotranspiration as a climate proxy, results indicate that an average increase of 1 mm per day (30 mm for 30 days), reduces cocoa productivity by 71.6%, or an average of 2.3% (0.7161/30days) reduction in a day. Finally, an increase in temperature also reduces cocoa productivity. An increase in the average temperature by 1 °C for a month reduces cocoa productivity by 49.4%. In contrast, cocoa price is insignificant with cocoa yields in the long-run.

Table 4: Long run estimation

Dependence variable: Productivity	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Price	0.0217	0.0408	0.0517	0.0355	0.0470	0.0507	0.0358	0.0363	0.0268
Total rainfall	0.0043***	-	-	-	-	-	-	-	-
Total wind	-	-0.0026***	-	-	-	-	-	-	-
Total sunshine	-	-	-0.0145***	-	-	-	-	-	-
Total vaporative	-	-	-	-0.0187**	-	-	-	-	-
Average daily wind	-	-	-	-	-0.0922***	-	-	-	-
Average monthly sunshine	-	-	-	-	-	-0.4280***	-	-	-
Average vaporative	-	-	-	-	-	-	-0.7161***	-	-
Number of raining days	-	-	-	-	-	-	-	0.0995***	-
Average temperature	-	-	-	-	-	-	-	-	-0.4942***
F-statistic	42.0212	44.9543	47.9346	43.2661	41.1459	48.3189	39.3274	44.9696	38.9198
Half-life	1.24	1.27	1.21	1.35	1.26	1.21	1.34	1.20	1.24

Note: *** indicates 1% level of significance and the F-statistic for each estimated model is compared against the critical value for case 5 reported in Pesaran et al. (2001).

Following the results in Table 3, the restricted Error Correction Model (ECM) was estimated for each of the model (column 1-9) and the coefficient of the error correction term (speed of adjustment) was collected for half-life estimation. By applying Ayto's(1989) half-life formula[1], it showed half of the adjustment took place between 1.2 to 1.4 months. Specifically, half of the disequilibrium on productivity which implied by price and climate was adjusted within 1.4 months. Diagnostic tests (Breusch-Godfrey serial correlation Lagrange multiplier test, ARCH test for heteroscedasticity, Ramsey RESET specification test) were applied across all the models, and the tests confirm that all models possess desired econometric properties. Furthermore, CUSUM and CUSUM Square tests were employed for structural stability test and showed that all the models stable within the 5 percent confidence interval band.

Overall, the study suggested that timing of water availability and temperature during cocoa reproductive stage can be essential in determining yield gaps response to climate. Cocoa, during reproductive stage appears to be more sensitive to water limitation and water status can be a key factor regulating flowering in cocoa. In Perak, the peak of flowering starting September coincides with peak in rainfall. A study reported that major rainy season increased the flower intensity (Adjaloo et al., 2012) but drop-off in flowering was observed during the month with highest rainfall associated with low irradiance levels. Even though flower intensity rarely limiting in cocoa yield (less than 5% of flowers turned to pods), variation in flower numbers is indicative of carbon allocation to reproduction which might affect subsequent cropping (Daymond, 2000).

Today, production of cocoa cultivated in regions that periodically experience increasing trend of evapotranspiration rate and temperature, which tree has not evolved to cope with. High temperature speeds up the evapotranspiration rate of the crops and causes high water deficit. For other crops such as coffee, morphological changes have been observed in response to environmental stress with smaller leaf area and less leaves produced when coffee grown under prolonged water deficit. Cocoa shows reduction in leaf area, root dry weight, plant height and stem girth to help sustain plant water status by reducing transpiration rate (Alban et al., 2016; Lahiveet al., 2018). In Indonesia, 6-year-old cocoa trees grown under Gliricidia shade showed evapotranspiration rates of 949 mm years-1 (Falk, 2004; Kohler et al., 2009). The evapotranspiration in cocoa varies between the wet and dry seasons. During the wet season, estimated daily evapotranspiration can achieve an average of 1.6 mm day-1 while during the dry season, the rate can increase up to 3.2 mm day-1 when net radiation is high (Radersma and de Ridder, 1996).

CONCLUSIONS

Malaysia follows world cocoa bean price in trading which is determined based on New York and London futures exchanges where the main influencing factors are cocoa supply and demand. In this study, the price did not contribute to the cocoa productivity and study also showed that global cocoa supply and demand are extremely price-inelastic in the long-run due to the long cocoa production cycle and large farm investments.

As a conclusion, the relative crop-climate relations in this study were comprehensively studied over long-time periods and the impact of these climate variables were defined in the long-run on cocoa productivity. Based on the predictions, have suggested that cocoa sector might become unfit for production in the future, not only in Malaysia but in West Africa as predicted temperature increases will drive greater evaporative demand which increase the incidence of water deficit. This study is important to understand the response of cocoa to climate change and help to develop adaptation strategies that fit into local climatic conditions. Once the crop model for cocoa has been created, further simulation analysis on validation over different locations will be carried out to judge the model accuracy under different climatic scenarios.

[1] Half-life formula is $\frac{\ln 2}{\alpha}$, where the α is the error correction term from restricted ECM.

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