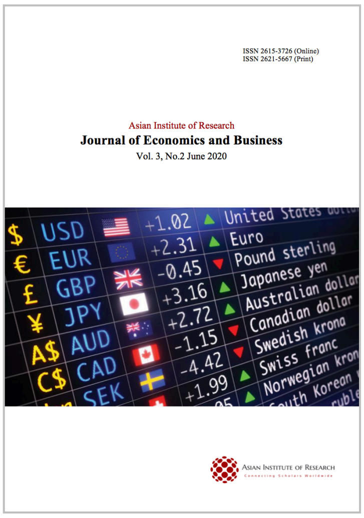

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Climate Change and Cocoa Production in Côte d'Ivoire: Should we Worry?

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Abstract
This study investigates the effects of climate change on cocoa production in Côte d'Ivoire. The data ranged from 1961 to 2016. An *ARDL* model was used to investigate short and long-run dynamics between climate variables and cocoa yield. We found that in the short run, high temperatures have negative impact on cocoa trees and rainfall has a positive impact on cocoa yield. In the long run, while increase in rainfall may negatively impact cocoa yield, increases in temperature could be beneficial to cocoa yield in the country. Given IPCC's weather predictions for the country there is need to worry.

Keywords: Climate change, Cocoa yield, Time series, Bounds tests

JEL Classification: C22, D24, O13, O55, Q15

1. Introduction

By providing 40% of the world cocoa supply, cocoa production in Côte d'Ivoire mobilizes nearly 1 million producers and provides income for more than 5 million people or about 1/5 of the Ivorian population. It is the country's largest foreign exchange provider. It accounts for around 14% of GDP and almost 10% of government tax revenue (World Bank, 2019). However, history retains that the country's economy is very sensitive to fluctuations in world cocoa prices. Indeed, the drop in coffee and cocoa prices in the 1980s led the country into a process of indebtedness causing the deterioration of its economic and financial situations. This prompted the country into the Structural Adjustment Programs (SAP) (Losch, 2000). Similarly, in June 2017 the Ivorian leadership lamented over the brutal fall in world cocoa prices by more than 40% in late 2016, negatively impacting his economy and thus reducing government budget forecasts (Conseil Café Cacao, 2017).

On the other hand, referring to the increase in cocoa production in West Africa, Steijn (2018) argues that the current pace of cocoa production is likely to slow down as cocoa trees are very sensitive to climate change and therefore, periods of drought and rainfall or excessive winds will negatively impact yields in the future. Although N'Zué (2018) argued that climate change has not yet significantly impacted the economic performance of Côte d'Ivoire and thus there was no need to worry more than necessary, some empirical studies have shown that crops (including tree crops) in many parts of the world were affected by progressive climate change, which had impacts on food supply, (Lobell et al. 2008; Läderach et al. 2010) as well as the ecosystems (Schroth et al. 2009).

The cocoa sector, which provides 14% of Côte d'Ivoire's GDP, does not remain on the fringes of these climatic impacts. Indeed, among the factors that influence the supply of cocoa, climate variables (rainfall and temperature) play a determining role. In addition, Carr and Lockwood (2011) argue that cocoa is a tree in the rainforest known for its sensitivity to drought. According to Conseil Café Cacao (2017), drier than normal conditions in the main cocoa regions over the period 2013/2014 to 2015/2016 have dampened world cocoa supply.

This downward trend in cocoa supply will continue as climatologists at the Intergovernmental Panel on Climate Change (IPCC) predict rapid and intense climate change by the end of the 21st century. For Côte d'Ivoire in particular, an average temperature increase in the order of 2°C (up to a peak of 3°C in January) and a variation in precipitation ranging from a drop of 9% to an increase of 9% are expected. These changes were reflected in the country by the recent El Niño episode which caused cocoa production to fall over the periods 2013/2014 and 2015/2016 (Conseil Café Cacao, 2017). This study therefore aims to gain a better understanding of the effects of global warming on cocoa production in Cote d'Ivoire where such studies are limited.

The rest of the paper is structured as follows: in section 2 we review the stylized facts; section 3 provides a review the literature on the impact of global warming on cocoa production; section 4 presents the method of analysis and data used. Sections 5 and 6 present a discussion of the empirical results and concluding remarks respectively.

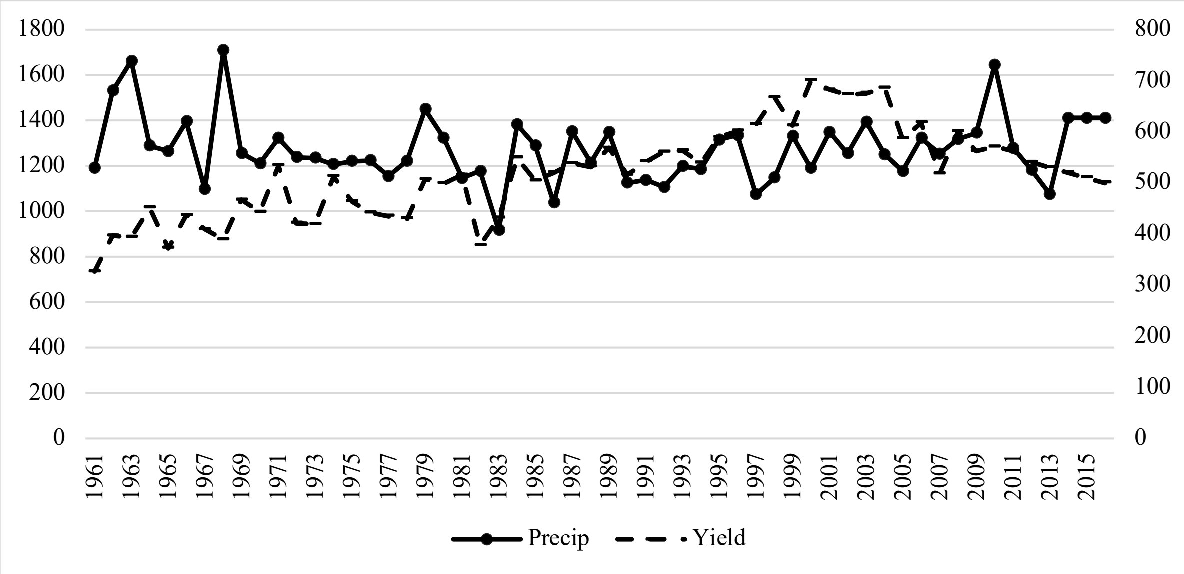
2. Stylized Facts

Interactions between temperature and precipitation have been identified as critical determinants of cocoa viability (Läderach and al, 2013). Figure 1 below shows the trend of rainfall (mm) and cocoa crop yield (kg/ha) over the period 1960 to 2016. It indicates a high volatility of rainfall in Côte d'Ivoire, while the cocoa yield curve has generally been upward sloping.

Over the 1960-1969 decade, the wettest period, precipitation fluctuated between 1,200 mm and 1,700 mm. Cocoa yield followed an upward trend which was politically motivated. Indeed, the authorities wanted to stimulate the cultivation of cocoa as an export crop (Wessel and Foluke 2015). Over the same period, a scenario of decrease (or increase) in precipitation leading to an increase (or decrease) in cocoa yields is observed. For example, precipitation was 1,531.78 mm, 1,662.4 mm and 1,289.42 respectively in 1962, 1963 and 1964; while in these same years, cocoa yields were 397.1,393.8 and 451.5 kg / ha, respectively. Over the decade 1970-1979, the drop in precipitation was of particular importance because it did not exceed 1,200 mm. Cocoa yield evolved like a seesaw.

As for precipitation over the period 1990 to 2004, it was generally modest and fluctuated between a minimum value of 1,075 mm and a maximum value of 1,344 mm; which beneficial for cocoa farming as a rapid increase in yields was witnessed, reaching a record level in 2000 at 700 kg / ha.

Figure 1. Trend of cocoa yield (kg/ha) and precipitation (mm) in Cote d'Ivoire from 1961 to 2016.

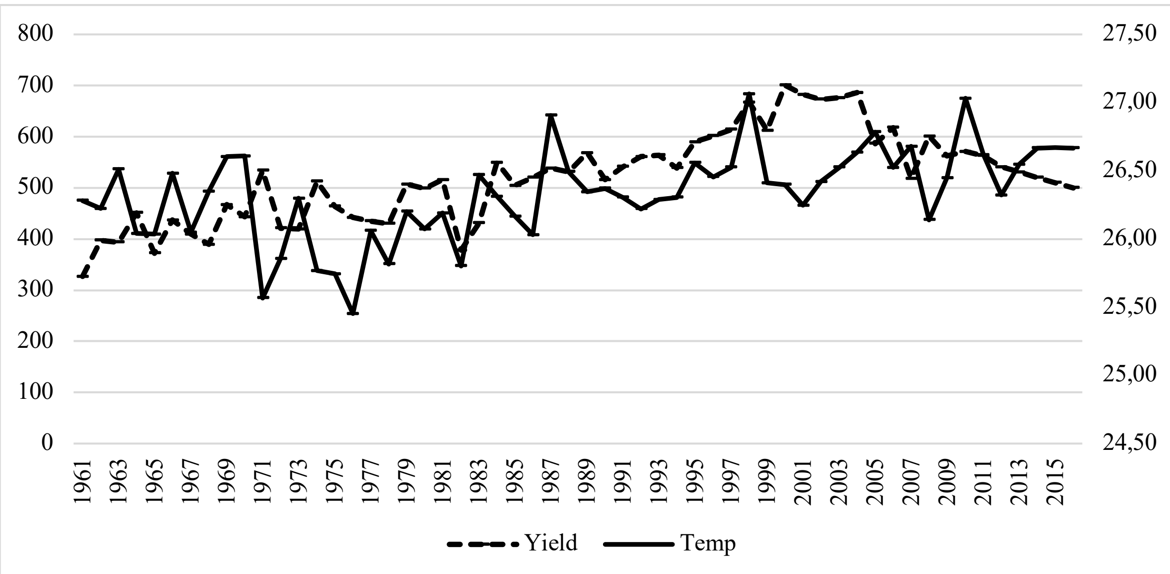


Sources: Author using data from FAOSTAT, Harris and Jones (2017).

Moreover, this peak reached by cocoa yield is also due to the use of a new improved variety of cocoa called "fast growing Mercedes cocoa" (UN-REDD, 2018). From 2005 to 2016, precipitation alternated from high to low levels. The upward trend in precipitation began in 2005 and peaked at 1,644 mm in 2010 after those in 1963 and 1968; according to climatologists, this increase is due to the El Niño episode. The downward trend started in 2011 and continued until 2013 before rising again from 2014. With regard to yield, it followed a downward trend throughout the 2005 to 2016. This phenomenon is attributable to the aging of the cocoa trees (PNUD, 2013). The Ivorian cocoa tree is known to reach its highest production at the age of 16/20 years with 631 kg/ha and then declines to an average production of 244 kg/ha at the age of 36/40 years.

In Figure 2 we consider temperature (°C) and cocoa yield. Both curves are positively sloped. From 1960 to 1970, we observed that temperature stood on average at 26.20 °C with a minimum of 26.03 °C in 1965 and a maximum of 26.6 °C in 1969. Over the period ranging from 1975 to 1989 we observed that after reaching its lowest level in 1976 which stood at 25.45°C, the temperature rose sharply in the years after. During this period, cocoa yield fell drastically and was at its lowest level (378.2 kg/ha) since 1965.

Figure 2. Trend of cocoa yield (kg/ha) and temperature (degree Celsius) in Cote d'Ivoire from 1961 to 2016.



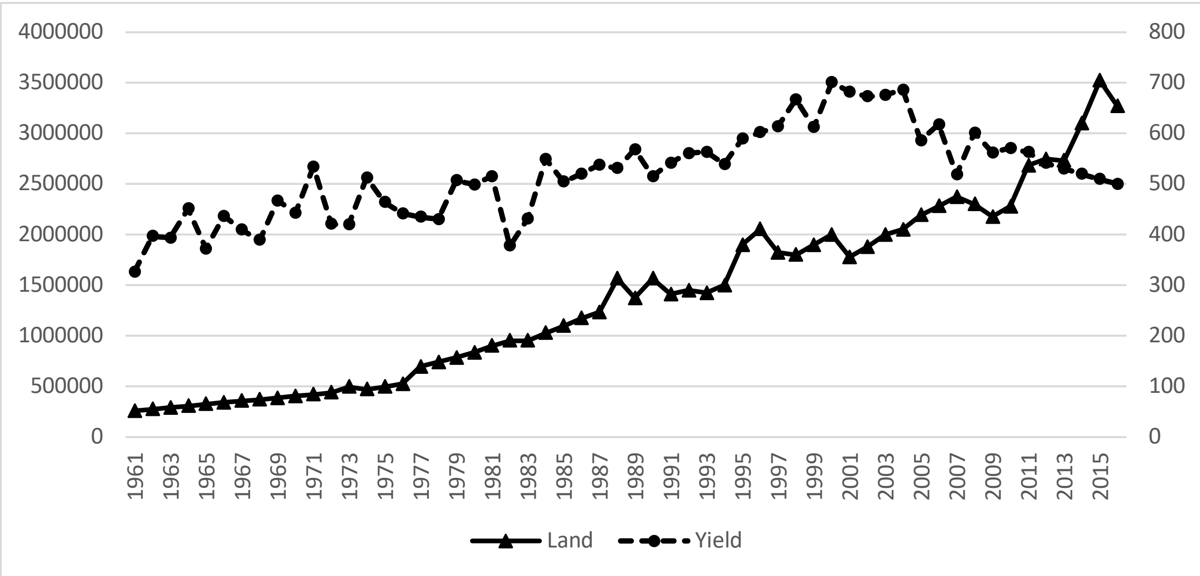
Sources: Author using data from FAOSTAT, Harris and Jones (2017) and WDI.

We observe also that Cocoa yield has a steeper upward slope when temperature stood in the neighborhood of 26.25°C. This could be due to a combination of favorable temperature[1] and the use of the new improved variety of cocoa. Over the period ranging from 2001 to 2010, the year 2010 was the warmest with a difference of +1.2°C (PNCC, 2014). The period from 2005 to 2016 is marked by a fall in cocoa yield despite temperature fluctuating between 26.14°C and 26.78°C with the exception of the year 2010 where the temperature reached another peak standing at 27°C.

Looking at the area of cultivated land, we observe an increase over the years, from 260,000 hectares in 1961 to 1,412,000 hectares in 1990 and 2,036,000 hectares today.

Indeed, in Figure 3 observe that the cultivated area for cocoa as well as cocoa yield over the period of analysis, show upward sloping trends. The increase in the cultivated area is partly linked to the expansion of the cocoa cultivation zones which started in the 1970s, when cocoa production moved from the south-east to the south-west, due to the shortage of arable land in the traditional production area and the availability of large areas of untouched rainforest (Wessel and Foluke, 2015). We also observed an upward trend for cocoa yield from 1960 to 2004, with a historic drop of 318 kg/ha in 1982 and a peak of 700 kg/ha in 2000. From 2005 to 2016 we observe declining yields due to deforestation which renders the land less fertile (World Bank, 2018). Conversely, over the study period i.e. from 1960 to 2016, the area of land occupied by cocoa plantations has continued to increase.

Figure 3. Trend of cocoa yield (kg/ha) and cultivated area dedicated to cocoa (hectares) in Cote d'Ivoire from 1961 to 2016.



Sources: Author using data from FAOSTAT, Harris and Jones (2017) and WDI.

3. Review of Literature

Theoretical Literature

In the economic literature, there are several theoretical models for analyzing the link between climate change and agricultural production. The most utilized are the agronomic approach which is production function based and the Ricardian model.

The agronomic approach stems from Angstrom's (1936) work. It is an experimental approach that seek to assess the direct impact of climate change on various crops. This theory takes into account the influence of the weather on crops in the analysis of agricultural production by combining rainfall and temperature into composite "aridity" indices. It assumes that weather variables as "costless" inputs to the production process *Ceteris Paribus* (Ofori-

[1] According to Ofori Boateng and Insah (2014) good yields of cocoa requires an average temperature of 27°C and annual precipitation between 1100 mm to 3000 mm

Boateng and Insah, 2014). It should be observed that studies carried out using this model conclude that climate change has very damaging effects on agriculture (Rosenzweig 1985; Robertson et al. 1987). In 1995, Darwin and al. revealed that previous agronomic studies did not take into account the adaptation made by farmers and that the few studies, including farmers' adaptation, have omitted the induced effects of climate on the availability of water and allocation of agricultural land.

Failure to take into account farmers' rationality, through the adaptations they make, led to the Ricardian model, which considers the above approach as that of a "dumb farmer scenario". It is an approach developed by Mendelsohn and al (1994) to assess the impact of climatic hazards on agricultural income. By considering farmers' income rather than yield, was a way to account for farmers' adaptation strategies (Ofori-Boateng and Insah, 2011 and 2014). The Ricardian model was criticized for assuming price constancy and also that adaptation strategies were cost-free (Cline, 1996; Deressa et al., 2005; Deschênes and Greenstone, 2007) thus underestimating the true impact of climate change. Overall, unlike the agronomic model which is accused of overestimating the effects of climate change on agriculture, the Ricardian model tends to underestimate climate change damage on agriculture.

Empirical Literature

Several scholars have investigated the link between climate change and the production of perennial crops such as cocoa. Their findings suggest broadly speaking that climate change has negative impact on cocoa farming. However, this impact is spatially differentiated from a geographical perspective. Indeed, while some cocoa producing regions will be unsuitable in the future for cocoa production and thus will require a change in the type of crop to cultivate, others will become suitable (climate wise) for cocoa cultivation (Läderach et al. 2013, Schroth et al. 2017, Ofori-Boateng and Insah 2014 etc…).

Oyekale et al. (2009) investigated the effect of climatic parameters on cocoa production and assessed the degree of vulnerability and adaptation strategies adopted by farmers. They reported that climate change significantly affects cocoa production especially during hot and humid seasons. They recommended that, for production to be meaningful, skilled labor and the correct application of agronomic practices were necessary.

Ojo and Sadiq (2010) investigated the effect of climate change on cocoa yield. They assessed the effect of rainfall and temperature on cocoa yields in Ibadan State, Nigeria over a 10-year period (1999-2008). They concluded that a combination of a temperature of 29°C and minimum rainfall of 900 mm to 1000 mm resulted in higher yields and improved cocoa production in Nigeria.

Moraes et al. (2012) assessed the potential risk of occurrence of moniliasis[2] and the impacts of climate change on this disease, over the decades 2020, 2050 and 2080 in Brazil. They projected that climatic conditions will favor the expansion of moniliasis in the main cocoa-producing regions of Brazil.

Jacobi et al. (2013) assessed the resilience of cocoa farms in the Alto Beni region of Bolivia through a time series analysis covering the period from 1964 to 2010. They found that cocoa farms are very sensitive to climate change and that the establishment of successional agroforestry was a key strategy to adapt to climate change risks and also to facilitate the resilience of cocoa farms.

Kimengsi and Tosam (2013), examined the effect of climate variability on cocoa production in the Meme division in Cameroon over a 21-year period (1990-2010). They argued that high climate variability resulted in a decline in the yield per hectare of cocoa.

Läderach and al. (2013), in their paper entitled " Predicting future climatic suitability for Cocoa farming of the World's leading producer countries Ghanan, and Côte d'Ivoire", showed that some regions currently producing cocoa (the lagoon and Sud-Comoe region in Côte d'Ivoire) will become unsuitable for cocoa cultivation and thus,

[2] One of the most destructive diseases affecting cocoa trees in the world, and responsible for the decline in cocoa production in tropical America

will require a change in cultivation. While in the Kwahu Plateau region of Ghana and the South-West of Côte d'Ivoire, the climatic suitability for cocoa cultivation is expected to increase.

Friedman (2014) examined the bioclimatic suitability of current cocoa growing areas in relation to future climate change projections. The author concluded that climate change reduces cocoa yields. Thus, cocoa cultivation will be increasingly threatened as time goes on.

Ofori-Boateng and Insah (2014), examined the current and future impact of climate change on cocoa production in West Africa from 1969 to 2009. They demonstrated that extreme temperatures have had a negative effect on cocoa production in West Africa, and that increasing temperature and declining trend of rainfall will reduce cocoa production in the future.

Eitzinger et al. (2015) explored the consequences of climate change on cocoa and tomato production in Trinidad and Tobago. They found that reduced rainfall during the dry season and changes in rainfall patterns were the most likely direct causes of reduced crop yields. To reduce the impact of climate change, they recommended that cocoa farmers put in place efficient irrigation systems to ensure the survival of cocoa trees during prolonged drought periods.

Hutchins et al. (2015) in their assessment of climate change impacts on cocoa production and approaches to adaptation and mitigation found that reduced rainfall and increased temperatures, caused a reduction in soil moisture during the dry seasons and decreased soil fertility. Conditions that often lead to cocoa seedling mortality. They also found that in other cocoa production zones, during periods of high rainfall, soil fertility is also negatively impacted by increased leaching of the soils which subsequently has negative impact on cocoa yield if proper fertilizer is not applied to replace the natural nutrients.

Raufu et al. (2015) examined the perceived effect of climate change on cocoa production in South-Western Nigeria. They found that climate variations were detrimental to cocoa production in the study area. However, the implementation of educational programs through extension activities, encouraging young farmers to grow cocoa and assisting farmers, were useful ways to reduce the effects of climate change on tree crops.

Utomo et al. (2015) assessed the environmental performance of cocoa production from cocoa monoculture and cocoa agroforestry systems in order to promote sustainable agricultural practices in cocoa farming. They showed that cocoa and coconut agroforestry system had a better environmental performance than other cocoa monoculture systems. Thus, cocoa and coconut agroforestry could be a sound option to promote environmental sustainability in cocoa farming.

Schroth et al. (2016) analyzed the vulnerability of cocoa to climate change in the West African cocoa belt. The authors highlighted the existence of a strong differentiation of climate vulnerability within the cocoa belt. The most vulnerable areas are located near the forest-savanna transition in Nigeria and eastern Côte d'Ivoire, and the least vulnerable areas are in southern parts of Cameroon, Ghana, Côte d'Ivoire and Liberia. This spatial differentiation of climate vulnerability could lead to further deforestation in new areas favorable for cocoa cultivation.

Ehisuoria and Ilenre (2018), investigated the impact of rainfall and temperature on Cocoa yield in Ekpoma, Nigeria. They found that excessive rainfall, prolonged dry season and inadequate rainfall were factors that reduced cocoa yields.

Gateau-Rey et al. (2018) measured the effect of severe drought related to the El Niño event of 2015-2016 on cocoa trees in northeast Brazil. Their results showed that the drought caused high mortality rate (15%) of cocoa tree and a large decrease in cocoa yield (89%). Drought also increased the rate of moniliasis infection. Thus, they showed that Brazilian cocoa agroforests were under threat and that the increased frequency of severe droughts is likely to lead to a decline in cocoa yields in the coming decades.

Afriyie-Kraf et al. (2020) in their paper on adaptation strategies of Ghanaian cocoa farmers under a changing climate in Ghana concluded that climate change had serious and very serious effects on the cocoa production and on their livelihoods. They recommended the development of adaptation technologies and the implementation of more transformational adaptation policies for producers, as the effects were noticeable among farmers who have tried adaptation techniques (Irrigation of young cocoa plantations, Mixed cropping with cashew trees etc...), and those who have not implemented any adaptation strategy.

4. Method of Analysis

Following the work of Ofori-Boateng and Insah (2014) we use a translog production function applied to the crop yield response approach. The most important aspect of using the production function in crop yield studies is that it allows the incorporation of climate variables as direct inputs into the production process.

Theoretically, the traditional approach to translog function in crop yield studies is of the form:

$$\ln Y_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln(x_i) + \frac{1}{2}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \beta_{ij} \ln(x_i)\ln(x_j) + \sum_{k+1}^{m} \gamma_k Z_k + \varepsilon_t \quad (1)$$

Where ε_t is normally distributed, Y_t is the yield per hectare of the crop, x_i are the inputs, Z_k is the vector of productivity change. In this study, this model relates cocoa yield (*Y*) to capital (*K*), labor (*L*), area cultivated (*S*), temperature (*T*) and rainfall (*P*).

Specifically, we have:

$$Y_t = f(x_t) \quad (2)$$

Where Y_t stands for cocoa yield in Côte d'Ivoire and x_t is the vector of inputs which are labor (*L*) is the share of rural population total population, gross capital formation (*K*) as a percentage of GDP, cultivated area (*S*) in hectares, temperature (*T*) in degree Celsius (°C) and rainfall (*P*) in millimeters. More specifically,

$$x_t = (L_t, K_t, T_t, P_t, S_t) \quad (3)$$

By substituting equation (3) into equation (2), we have:

$$Y_t = f(L_t, K_t, T_t, P_t, S_t) \quad (4)$$

The translog function of our time series is therefore:

$$\begin{aligned}\ln Y_t = {} & \ln A + \alpha_L \ln(L_t) + \alpha_K \ln(K_t) + \alpha_T \ln(T_t) + \alpha_P \ln(P_t) + \alpha_S \ln(S_t) + \beta_{LL} \ln(L_t)\ln(L_t) + \\ & \beta_{KK} \ln(K_t)\ln(K_t) + \beta_{TT} \ln(T_t)\ln(T_t) + \beta_{PP} \ln(P_t)\ln(P_t) + \beta_{SS} \ln(S_t)\ln(S_t) + \theta_{LK} \ln(L_t)\ln(K_t) + \\ & \theta_{LT} \ln(L_t)\ln(T_t) + \theta_{LP} \ln(L_t)\ln(P_t) + \theta_{LS} \ln(L_t)\ln(S_t) + \gamma_{KL} \ln(K_t)\ln(L_t) + \gamma_{KT} \ln(K_t)\ln(T_t) + \\ & \gamma_{KP} \ln(K_t)\ln(P_t) + \gamma_{KS} \ln(K_t)\ln(S_t) + \eta_{TL} \ln(T_t)\ln(L_t) + \eta_{TK} \ln(T_t)\ln(K_t) + \eta_{TP} \ln(T_t)\ln(P_t) + \\ & \eta_{TS} \ln(T_t)\ln(S_t) + \psi_{PL} \ln(P_t)\ln(L_t) + \psi_{PK} \ln(P_t)\ln(K_t) + \psi_{PT} \ln(P_t)\ln(T_t) + \psi_{PS} \ln(P_t)\ln(S_t) + \\ & \phi_{SL} \ln(S_t)\ln(L_t) + \phi_{SK} \ln(S_t)\ln(K_t) + \phi_{ST} \ln(S_t)\ln(T_t) + \phi_{SP} \ln(S_t)\ln(P_t) + \varepsilon_t\end{aligned}$$

(5)

From this form, the following symmetrical terms emerge:

$\theta_{LK} = \gamma_{KL}$; $\theta_{LT} = \eta_{TL}$; $\theta_{LP} = \psi_{PL}$; $\theta_{LS} = \phi_{SL}$; $\gamma_{KT} = \eta_{TK}$; $\gamma_{KP} = \psi_{PK}$

$\gamma_{KS} = \phi_{SK}$; $\eta_{TP} = \psi_{PT}$; $\eta_{TS} = \phi_{ST}$; $\psi_{PS} = \phi_{SP}$

As a result, we go from 30 variables to 20 variables. So we have:

$$\ln Y_t = lnA + \alpha_L \ln(L_t) + \alpha_K \ln(K_t) + \alpha_T \ln(T_t) + \alpha_P \ln(P_t) + \alpha_S \ln(S_t) + \beta_{LL} \ln(L_t)\ln(L_t) + \beta_{KK} \ln(K_t)\ln(K_t) + \beta_{TT} \ln(T_t)\ln(T_t) + \beta_{PP} \ln(P_t)\ln(P_t) + \beta_{SS} \ln(S_t)\ln(S_t) + \theta_{LK} \ln(L_t)\ln(K_t) + \theta_{LT} \ln(L_t)\ln(T_t) + \theta_{LP} \ln(L_t)\ln(P_t) + \theta_{LS} \ln(L_t)\ln(S_t) + \gamma_{KT} \ln(K_t)\ln(T_t) + \gamma_{KP} \ln(K_t)\ln(P_t) + \gamma_{KS} \ln(K_t)\ln(S_T) + \psi_{PS} \ln(P_t)\ln(S_t) + \eta_{TS} \ln(T_t)\ln(S_t) + \eta_{TP} \ln(T_t)\ln(P_t) + \varepsilon_t \quad (6)$$

By simplifying and reorganizing we obtain:

$$\ln Y_t = lnA + \alpha_L \ln(L_t) + \alpha_K \ln(K_t) + \alpha_T \ln(T_t) + \alpha_P \ln(P_t) + \alpha_S \ln(S_t) + \frac{1}{2}\beta_{LL} \ln(L_t)^2 + \frac{1}{2}\beta_{KK} \ln(K_t)^2 + \frac{1}{2}\beta_{TT} \ln(T_t)^2 + \frac{1}{2}\beta_{PP} \ln(P_t)^2 + \frac{1}{2}\beta_{SS} \ln(S_t)^2 + \theta_{LK} \ln(L_t)\ln(K_t) + \theta_{LT} \ln(L_t)\ln(T_t) + \theta_{LP} \ln(L_t)\ln(P_t) + \theta_{LS} \ln(L_t)\ln(S_t) + \gamma_{KT} \ln(K_t)\ln(T_t) + \gamma_{KP} \ln(K_t)\ln(P_T) + \gamma_{KS} \ln(K_t)\ln(S_t) + \psi_{PS} \ln(P_t)\ln(S_t) + \eta_{TS} \ln(T_t)\ln(S_t) + \eta_{TP} \ln(T_t)\ln(P_t) + \varepsilon_t \quad (7)$$

Based on the work of Guan et al (2006), which stated that the effects of climate on the growth of perennial crops such as cocoa and thus on its production is not immediate and following Ofori-Boateng and Insah (2011 and 2014), we lagged our climate variables. A dynamic translog is therefore obtained by introducing p lags on the climate variables and q lags on the dependent variable in equation (7). Thus, we have:

$$\ln Y_t = lnA + \ln Y_{t-q} + \alpha_L \ln(L_t) + \alpha_K \ln(K_t) + \alpha_S \ln(S_t) + \alpha_T \ln(T_{t-p}) + \alpha_P \ln(P_{t-p}) + \frac{1}{2}\beta_{LL} \ln(L_t)^2 + \frac{1}{2}\beta_{KK} \ln(K_t)^2 + \frac{1}{2}\beta_{SS} \ln(S_t)^2 + \frac{1}{2}\beta_{TT} \ln(T_{t-p})^2 + \frac{1}{2}\beta_{PP} \ln(P_{t-p})^2 + \theta_{LK} \ln(L_t)\ln(K_t) + \theta_{LS} \ln(L_t)\ln(S_t) + \theta_{LT} \ln(L_t)\ln(T_{t-p}) + \theta_{LP} \ln(L_t)\ln(P_{t-p}) + \gamma_{KS} \ln(K_t)\ln(S_t) + \gamma_{KT} \ln(K_t)\ln(T_{t-p}) + \gamma_{KP} \ln(K_t)\ln(P_{T-p}) + \psi_{PS} \ln(P_{t-p})\ln(S_t) + \eta_{TS} \ln(T_{t-p})\ln(S_t) + \eta_{TP} \ln(T_{t-p})\ln(P_{t-p}) + \varepsilon_t \quad (8)$$

Given the nature of our data (time series), it is important to assess its. Indeed, the regression of a non-stationary series on another non-stationary series leads to what is known as spurious regression i.e. one that makes no economic sense. In this study, we use two unit root tests i.e. the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) tests. The results of these tests will guide the way forward. Indeed, the test results will enable us determine whether the series are integrated of order zero i.e. *I(0)* or integrated of order one i.e. *I(1)*. Having determined the order of integration, we will then move to assess whether there are the short and long run dynamics or not, between cocoa yield and the variables of interest (temperature, rainfall). This will be done using the Bounds test proposed by Pesaran et al (2001) in an Autoregressive Distributed Lags model (*ARDL*) setting.

For the Bounds test, we use Akaike (AIC) and Schwarz (SC) information criteria to determine the optimal lag order. Thus, based on the procedure of Pesaran et al (2001) we have the following error correction model adapted to our functional form as follows:

$$\Delta \ln Y_t = lnA + \sum_{p=1}^{P} \alpha_Y \Delta \ln Y_{t-p} + \sum_{q=1}^{Q} \alpha_L \Delta \ln(L_{t-q}) + \sum_{q=1}^{Q} \alpha_K \Delta \ln(K_{t-q}) + \sum_{q=1}^{Q} \alpha_S \Delta \ln(S_{t-q}) + \sum_{q=1}^{Q} \alpha_T \Delta \ln(T_{t-q}) + \sum_{q=1}^{Q} \alpha_P \Delta \ln(P_{t-q}) + \frac{1}{2}\sum_{q=1}^{Q} \beta_{LL} \Delta \ln(L_{t-q})^2 + \frac{1}{2}\sum_{q=1}^{Q} \beta_{KK} \Delta \ln(K_{t-q})^2 + \frac{1}{2}\sum_{q=1}^{Q} \beta_{SS} \Delta \ln(S_{t-q})^2 + \frac{1}{2}\sum_{q=1}^{Q} \beta_{TT} \Delta \ln(T_{t-q})^2 + \frac{1}{2}\sum_{q=1}^{Q} \beta_{PP} \Delta \ln(P_{t-q})^2 + \sum_{q=1}^{Q} \theta_{LK} \Delta \ln(L_{t-q})\ln(K_{t-q}) + \sum_{q=1}^{Q} \theta_{LS} \Delta \ln(L_{t-q})\ln(S_{t-q}) + \sum_{q=1}^{Q} \theta_{LT} \Delta \ln(L_{t-q})\ln(T_{t-q}) + \sum_{q=1}^{Q} \theta_{LP} \Delta \ln(L_{t-q})\ln(P_{t-q}) + \sum_{q=1}^{Q} \gamma_{KS} \Delta \ln(K_{t-q})\ln(S_{t-q}) + \sum_{q=1}^{Q} \gamma_{KT} \Delta \ln(K_{t-q})\ln(T_{t-q}) + \sum_{q=1}^{Q} \gamma_{KP} \Delta \ln(K_{t-q})\ln(P_{t-q}) + \sum_{q=1}^{Q} \psi_{PS} \Delta \ln(P_{t-q})\ln(S_{t-q}) + \sum_{q=1}^{Q} \eta_{TS} \Delta \ln(T_{t-q})\ln(S_{t-q}) + \sum_{q=1}^{Q} \eta_{TP} \Delta \ln(T_{t-q})\ln(P_{t-q}) + \ln Y_{t-1} + \alpha_1 \ln(L_{t-1}) + \alpha_2 \ln(K_{t-1}) + \alpha_3 \ln(S_{t-1}) + \alpha_4 \ln(T_{t-1}) + \alpha_5 \ln(P_{t-1}) + \frac{1}{2}\beta_1 \ln(L_{t-1})^2 + \frac{1}{2}\beta_2 \ln(K_{t-1})^2 + \frac{1}{2}\beta_3 \ln(S_{t-1})^2 + \frac{1}{2}\beta_4 \ln(T_{t-1})^2 + \frac{1}{2}\beta_5 \ln(P_{t-1})^2 + \theta_1 \ln(L_{t-1})\ln(K_{t-1}) + \theta_2 \ln(L_{t-1})\ln(S_{t-1}) + \theta_3 \ln(L_{t-1})\ln(T_{t-1}) +$$

$\theta_4 \ln(L_{t-1}) \ln(P_{t-1}) + \gamma_1 \ln(K_{t-1}) \ln(S_{t-1}) + \gamma_2 \ln(K_{t-1}) \ln(T_{t-1}) + \gamma_3 \ln(K_{t-1}) \ln(P_{t-1}) +$
$\psi_1 \ln(P_{t-1}) \ln(S_{t-1}) + \eta_1 \ln(T_{t-1}) \ln(S_{t-1}) + \eta_2 \ln(T_{t-1}) \ln(P_{t-1}) + \varepsilon_t$ (10)

Where Δ is the first difference operator, lnA is the constant, α_Y, α_L, α_K, α_S, α_T, α_P, β_{LL}, β_{KK}, β_{SS}, β_{TT}, β_{PP}, θ_{LK}, θ_{LS}, θ_{LT}, θ_{LP}, γ_{KS}, γ_{KT}, γ_{KP}, ψ_{PS}, η_{TS}, η_{TP} are the coefficients of the short run dynamics, α_1 ,…, α_5 ; β_1,…, β_5 ; θ_1,…., θ_4 ; γ_1,…, γ_3 ; ψ_1 ; η_1, η_2 represent the coefficients of the long run dynamics, *p* and *q* denote the optimal lags order and $\varepsilon_t \sim iid(0,\sigma)$ is the error term.

The dynamic model as specified above raises the problem of the multicollinearity of the variables, and makes it impossible to estimate. We therefore eliminate the correlation source variables because the existence of a very high correlation between the explanatory variables lead to a risk of multicollinearity. Moreover, in the presence of multicollinearity, it is difficult, if not impossible, to isolate the intrinsic effect of each of the explanatory variables on the endogenous (there is confusion of effects), because any variation in one of the explanatory variables implies a variation in the other variables. By dropping each variable one at a time, we are left with variables with significant coefficients. Thus, our *ARDL* model is represented as follows:

$$\Delta \ln Y_t = lnA + \sum_{p=1}^{P} \alpha_Y \, \Delta \ln Y_{t-p} + \sum_{q=1}^{Q} \alpha_L \, \Delta \ln(L_{t-q}) + \sum_{q=1}^{Q} \alpha_K \, \Delta \ln(K_{t-q}) + \sum_{q=1}^{Q} \alpha_S \, \Delta \ln(S_{t-q}) + \sum_{q=1}^{Q} \alpha_T \, \Delta \ln(T_{t-q}) + \sum_{q=1}^{Q} \alpha_P \, \Delta \ln(P_{t-q}) + \ln Y_{t-1} + \sum_{q=1}^{Q} \gamma_{KS} \, \Delta \ln(K_{t-q}) \ln(S_{t-q}) + \alpha_1 \ln(L_{t-1}) + \alpha_2 \ln(K_{t-1}) + \alpha_3 \ln(S_{t-1}) + \alpha_4 \ln(T_{t-1}) + \alpha_5 \ln(P_{t-1}) + \alpha_6 \ln(K_{t-1}) \ln(S_{t-1}) + \varepsilon_t \quad (11)$$

The Bounds test is equivalent to testing the null hypothesis of the absence of cointegration i.e. the coefficients of the level variables are zero. This is done by comparing the Fisher statistic to the critical values that form the bounds. If the Fisher statistic is greater than the upper bound I(1) then the null hypothesis of no cointegration is rejected, which is equivalent to concluding that a cointegrating relationship exists between the variables. If the Fisher statistic is less than the lower bound I(0), then accept the null hypothesis of absence of cointegration. If the Fisher statistic is between the upper and lower bounds (I(1) and I(0)) then no conclusion can be drawn about cointegration.

Our study covers the period ranging from 1961 to 2016. We use annual data on climate variables (precipitation and temperature) obtained from Harris and Jones (2017). The non-climatic variables are from the Food and Agriculture Organization of the United Nations (FAO, 2019) and the World Development Indicators of the World Bank (2019).

5. Empirical Results and Discussion

We start with the descriptive statistics presented in Table 1 below. We observe that, from 1961 to 2016, cocoa yields in Côte d'Ivoire stood on averaged at 520.22 kg/ha. The lowest yield was registered in 1961 and stood at 326.9 kg/ha whereas the highest yield registered in 2000 stood at 700.6 kg/ha. We also observe that land dedicated to cocoa farming stood on average at 1,387,862.839 hectares. It has been increasing over time. Indeed, going from just 260,000 hectares in 1961, it reached its highest level in 2015 at 3,522,413 hectares.

Given that cocoa production is mainly done in rural areas it is important to see the share of rural population in total population. We observe that rural population stood on average at 62.23% of the total Ivorian population. The highest recorded rural population share stood at 81% in the early days of the country's independence from the colonial power in 1961. This was quite significant and thus constituted an abundant workforce for agricultural production. This share of the rural population in the total population has steadily declined over time going from 81.09% in 1961 to 51.12 in 2016. Gross capital formation was low throughout the period of analysis. Indeed, it stood on average at 16.3% of GDP. Its lowest level which stood at 4.7% of GDP was registered in 2011, following the post-electoral crisis, whereas its highest level registered in 1978 stood at 29.76% of GDP during the period characterized as the Ivorian miracle.

Table 1: *Descriptive Statistics of Variables of Interest.*

Variables	Mean	Std. Dev	Min	Max
Yield (Y_t)	520.225	88.806	326.900	700.600
Rurpop (L_t)	62.234	8.232	50.119	81.089
Inv (K_t)	16.305	6.155	4.704	29.762
Cult_area (S_t)	1,387,862.839	880,412.113	260,000	3,522,413
Rainfall (P_t)	1,273.280	147.611	917.033	1,708.070
Temperature (T_t)	26.331	0.334	25.453	27.064

Sources: Author using data from FAOSTAT, Harris and Jones (2017) and WDI.

The temperature registered in the country over the study period stood on average at 26.33°C. The lowest temperature registered stood at 25.45°C and the highest at 27.06°C. The coldest year was 1976 whereas the warmest was 1998. The annual rainfall that the country registered stood on average at 1,273.28mm. We observe that 1983 was the year in which the country registered its lowest level of rainfall which stood at 917.03mm. That was the year of the severe drought that the country experienced. The year with the highest level of rainfall 1968 where the country registered 1,708.070mm.

We conducted the Unit root tests as indicated in the section on methods of analysis. The results presented in Table 2 below reveal that our variables are integrated of different orders i.e. namely *I(0)* and *I(1)*. This makes Granger and Engle's (1987) and Johansen's (1988) tests inappropriate. The most appropriate test when we are faced with mixed order of integration is the Bounds tests of the *ARDL* model of Pesaran et al. (2001). This test assesses the possibility of long term relationships between the variables.

Table 2: Results of Unit Root tests

Variables	Level		First Difference		Conclusion
	ADF	PP	ADF	PP	
lnY_t	-3.289* (0.015)[a]	-3.173* (0.022)			*I(0)*
lnP_t	-6.929** (0.000)	-6.939** (0.000)			*I(0)*
lnT_t	-4.489** (0.000)	-4.479** (0.000)			*I(0)*
LnL_t	-4.273** (0.001)	-8.512** (0.000)			*I(0)*
lnK_t	-2.718 (0.071)	-2.647 (0.084)	**-10.419**** **(0.000)**	**-10.433**** **(0.000)**	*I(1)*
lnS_t	-1.313 (0.623)	-1.512 (0.528)	**-8.332**** **(0.000)**	**-8.496**** **(0.000)**	*I(1)*
lnK_tS_t	**-3.206*** **(0.020)**	**-3.250*** **(0.017)**			*I(0)*

Sources: Author using data from FAOSTAT, Harris and Jones (2017) and WDI.
[a] The values in brackets indicate the p-values. (**) and (*) represent significance at the 1% and 5% probability levels respectively.

We next move to the bounds test. Here, it is critical to determine the optimal lag to be used for the *ARDL(p,q)* model. We make use of the Akaike Information Criterion which indicates that the optimal lag order of our *ARDL* model is (2,1,4,1,2,0,1). The results of the Bounds test are presented in Table 3. The value of the F-statistic obtained (4.062), is above the upper bound at the 2.5% and 5% probability levels. We therefore reject the null hypothesis of no cointegration and conclude that there is evidence of long run dynamics among the variables.

Table 3: Results of the *Bounds Test for Cointegration*

	ARDL(2,1,4,1,2,0,1)		
Ho ➔ *No level relationship*		F_{stat} = **4.062**	
K=6	[I(0) - I(1)]		[I(0) - I(1)]
Critical value at 5%	[- 2,86 - 4,38]	Critical value at 2.5%	[2,75 3,99]
Reject Ho if $F_{stat} > F_{\alpha}$ for I(1) ➔ we conclude that the variables are cointegrated			

Source: Author's calculations

Given the results of the bounds test, we move to estimate our *ARDL*(2,1,4,1,2,0,1) model. The results are presented in Table 4 below. All the diagnosis tests conducted are in support of the model. These tests include the normality test, the heteroscedasticity test, the autocorrelation test and the stability test. For the stability test, the graph of the cumulative sum of squares (CUSUM of Squares) shows clearly that the model is stable.

We then move to analysis the estimated coefficients. Let's consider the error correction term (ECT). We observe that it is negative **(-0.371)** and significant. This confirms the results obtained from the Bound test and provide support for a long run relationship between cocoa yield and the set of explanatory variables. The error correction coefficient expresses the speed with which the dependent variable (*yield*) will adjust to its long run equilibrium after a shock. This speed of adjustment is relatively low since only 37% of the imbalances of a previous year are restored during the following year.

Let's look at the long run coefficients. We observe that the rainfall variable is negative and significant. This is to say that too much rain reduces cocoa yield. The estimated coefficient which could be interpreted as rainfall elasticity is -3.876 indicating that a 1% increase in rainfall in the long run will lead to -3.876% decrease in cocoa yield *ceteris paribus*. This is in line with Hutchins et al (2015) in their assessment of climate change impact on cocoa production. They found that increases in rainfall intensity affect the blooming of cocoa tree's flowers thereby causing a decreased in tree productivity. From the above empirical result, there is a clear indication that, there is a long run causality running from precipitations to cocoa yield. Unlike the long run dynamics, in the short run rainfall has a positive and significant impact on cocoa yield. The positive impact persist till the third year. This finding is in line with results obtained by Ofori-Boateng and Insah (2014). Here also there is a short run causality running from rainfall to cocoa yield.

Now let's consider the temperature variable. We observe that in the short run higher temperatures are harmful to cocoa yield whereas in the long run the impact of temperature on cocoa yield is positive and significant at the 10% probability level. This is in line with findings from Ofori-Boateng and Insah (2011), Läderach et al (2010) and Hutchins et al (2015). In the long run, the coefficient associated with temperature is 19.313. Thus, given the climatic situation of the country, especially the cocoa production zones, a 1% increase in temperature in the long run will lead to 19.313% increase in cocoa yield.

Table 4: Estimation r*esults of the ARDL*(2,1,4,1,2,0,1) model

Variables	*ARDL*(2,1,4,1,2,0,1)	
	Coefficients	p-value
Long run dynamics		
C	-20.281	(0.040)**
lnS_t	2.166	(0.100)
lnP_t	**-3.876**	**(0.052)***
lnT_t	**19.313**	**(0.076)***
lnK_t	**12,202**	**(0.056)***
lnL_t	-1.188	(0.634)
lnK_tS_t	**-0.874**	**(0.053)***
ECT (u_{t-1})	**-0.371**	**(0.020)****
Short run dynamics		
ΔlnY_{t-1}	-0.330	(0.019)**

ΔlnS_t	**-1.618**	**(0.002)*****
ΔlnP_t	**1.402**	**(0.000)*****
ΔlnP_{t-1}	**1.266**	**(0.000)*****
ΔlnP_{t-2}	**0.747**	**(0.001)*****
ΔlnP_{t-3}	**0.375**	**(0.004)*****
ΔlnT_t	**-3.575**	**(0.011)****
ΔlnK_t	**-7.106**	**(0.008)*****
ΔlnK_{t-1}	**0.107**	**(0.071)***
ΔlnK_tS_t	**0.496**	**(0.007)*****
Normality (Jarque-Bera)	2.070	(0,259)
Heteroscedasticity (White / Breuch-	52.000	(0,435)
Godfrey-Pagan)	0.010	(0,924)
Autocorrelation (Breuch-Godfrey)	2.437	(0,119)

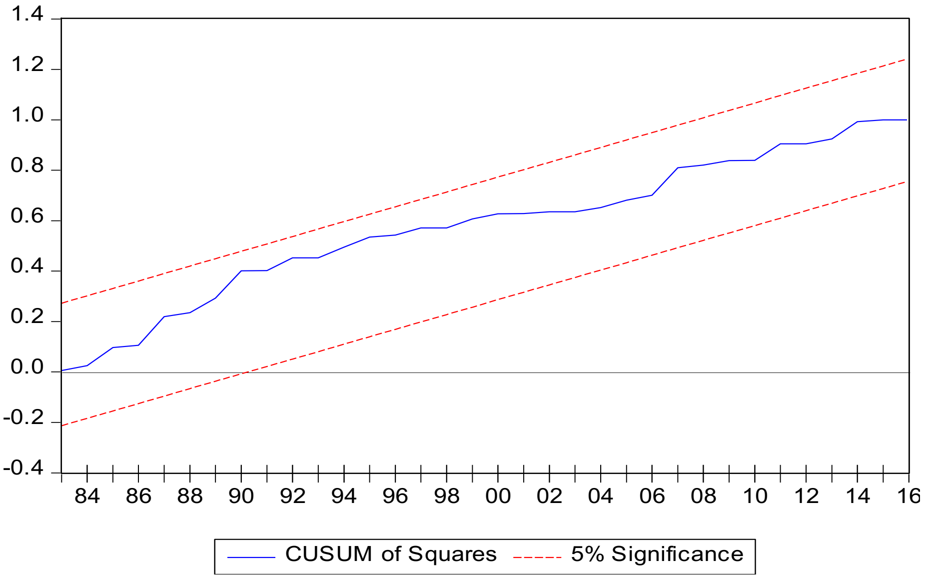
Source : Author's calculations

Asterisks (***), (**) and (*) indicate the significance at the 1%, 5% and 10% probability levels respectively.

Now, let's look at the other variables i.e. gross capital formation as a proxy for investment and rural population as a proxy for labor. In the short run, the capital variable has a negative impact on cocoa yield. However, the lag variable has a positive and significant impact on cocoa yield. This is so because there is a time lag for investment to produce the necessary impact on cocoa yield. We can see that in the long run, the gross capital formation variable has a positive impact on cocoa yield. There is here also a long run causality running from investment to cocoa yield. Thus in the long run, a 1% increase in investment will boost cocoa yield by 12.2%.

When we consider the relationship between the cultivated area and cocoa yield, we found a negative **(-1.618)** and significant coefficient in the short run. This indicates that a 1% increase in the cultivated area significantly reduces the yield by 1.62%. This result is in line with the findings of Vigneri et al. (2016) that cocoa profitability declines for farmers cultivating larger areas. The interaction between investment and cultivated area has a positive (**0.496**) and significant impact on cocoa yield in the short run but not in the long run.

Figure 4. Cumulative Sum of Squares for model stability tests



Source : Author's estimation

6. Conclusion

The objective of this paper was to provide a better understanding of the effects of global warming on cocoa production in Côte d'Ivoire. To achieve this, we used data from the World Development Indicator and FAOSTAT from 1961 to 2016. The climatic variables considered were temperature (in degrees Celsius) and rainfall (in millimeters of rain). After conducting a bounds test to assess whether there is a long run relationship among the variables we estimated an *ARDL(2,1,4,1,2,0,1)* model. The empirical results confirmed the existence of long run dynamics via the negative and significant error correction term. The results also indicated that rainfall positively affect cocoa yield in the short run but not in the long run. Indeed, in the long run the impact is negative. Unlike rainfall, the temperature variable has a negative impact on cocoa yield in the short run but positive impact in the long run. Other key results include the positive impact of the interaction between investment and cultivated area on cocoa yield in the short run as well as that of gross capital formation in the long run. Given these results it would be good if thresholds for both rainfall and temperature are determined. Such thresholds would provide clear indications to policy makers in terms of the type and timing of mitigation strategies to implement. Knowing that the IPCC predicts for Côte d'Ivoire an average temperature increase of around 2°C (peaking at 3°C in January) and an average decrease in rainfall, it is clear that cocoa plantations are likely to face a bleak future, which is worrisome for the Ivorian cocoa economy.

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