Tea Production Response to Climate Change in Kenya: An Autoregressive Distributed Lag Approach.

George Mbugua Kariuki[†], Jennifer Njaramba[‡] and Charles Ombuki[⁑]

Abstract

Tea sector plays a critical role in socio economic development in Kenya. It is a leading foreign exchange earner, a major source of livelihood for most rural communities and significantly contributes to poverty reduction. However, in the last three decades there has been , unstable trends in tea production that has been linked to climate driven stresses. Over the last two decades, tea producing areas in Kenya have been exposed to extreme climate events that include temperature rise, eractic rainfall and growing incidence of extreme weather events such as hail storms, drought and frost. These events are expected to have adverse effects on the largely rainfed tea production with potentially irreversible socio economic effects. This study sought to ascertain the effects of climate change on tea production in Kenya while controlling for economic incentives. The study adopted the Autoregressive distributed lag econometric modeling approach using data for the period between 1979 and 2019. The findings indicate that rainfall being experienced in the usual dry period of January and February, price of tea, and area under tea crop, have a positive and significant effect on tea production. However, rainfall variability, rainfall amount in extended long rain periods, maximum temperature, spending on agricultural development, real effective exchange rate, and price of fertilizer have a negative effect on tea production. Given the negative effects of climate change on tea production, there is a need for collaborative efforts towards developing definite, viable and sustainable adaptation options targeting tea farming.

Key Words: Tea production, Climate Change, ARDL, Rainfall Variability, Temperature Variability

JEL Classification Codes: A1, A12, B4, C01, C5

[†] Corresponding Author, School of Economics, Kenyatta University P.O Box 43844-00100 Nairobi,E-mail:kariuki.george1@ku.ac.ke, Mobile phone: +254723856354

[‡] Lecturer, School of Economics,Kenyatta University

[⁑] Associate Professor, School of Business and Economics, Machakos University

1.0 Background

Climate change is emerging unequivocally as a major global challenge within agricultural systems including tea production (Ahmed et al. 2018; Chang and Bratloff, 2015). Agriculture is highly dependent on climate and a critical part of the economies in majority of developing countries, especially in Sub Saharan Africa (SSA), (Adhikari, Nejadhashemi and Woznicki, 2015). SSA is considered highly vulnerable and perceived to have low resilience and adaptive capacity to climate change (Chijioke *et al.*, 2011; Shah *et al.*, 2008). Increasingly irregular and erratic nature of weather conditions have a direct and in most cases adverse influence on quality and quantity of agricultural production that creates additional burden on food security, threatens rural livelihoods and hamper efforts on poverty reduction (Bore and Nyakundi, 2016; Chang and Bratloff, 2015). Even though it is difficult to predict full implications of climate change on agriculture, the expectation is that "the impacts will be of different levels and of a different nature in each region, ecological zone and production system" (FAO, 2017:5).

In Kenya, agricultural sector has limited diversification with tea being a major cash crop for the economy. Tea production substantially contributes to poverty reduction, job creation, foreign exchange earnings and is a major source of livelihood for most rural communities (Chang and Bratloff, 2015). Globally, Kenya ranks third in tea production behind China and Sri-Lanka and is the leading black tea exporter worldwide. Tea is one of the leading foreign exchange earners in Kenya and accounts for 21.8% of total export earnings and offers direct and indirect employment to over 6 million people (Bore and Nyakundi, 2016). The crop is largely grown under the smallholder growers who process and market their crop through Kenya Tea Development Agency (KTDA) Ltd. For instance in 2019, small holders produced 57% of tea in the country and the balance of 43% was produced by the large scale estates, which are managed by major multinational firms (ROK, 2020).

Tea is largely grown under rainfed mono-cropping system in specific agro ecological zones, thus highly sensitive to change in agro-climatic variables that interfere with conditions necessary for optimal growth and production (Ahmed, *et al.*, 2018; Bore *etal.*, 2016). Tea producing zones in Kenya are already experiencing climate change, "identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer "(Intergovernmental panel on Climate Change (IPCC), 2014:120). The zones have experienced higher temperatures, reduced and erratic rainfall and increased episodes of hail and frost (Cheserek, *et al.*, 2015). Variability of these agro climatic conditions not only present ecological stress and constraints that affect the quantity and quality of tea yield but also directly and indirectly affects, consumer demand, prices, rural livelihoods and regional economies, (Ahmed, *et al.*, 2018). Over the years Kenyan tea sector has recorded reduced annual production growth rates, falling from a high of 9.95% between 1970 and 1980 to a low of 2.07% between 2010 and 2019(ROK, 2020).

The fluctuations in tea production are witnessed despite efforts by government and non-government stakeholders to provide economic incentives to farmers aimed towards raising tea production. Climate change is likely to undermine these efforts through its influence on farming decisions and adversely impact realized output. Consequently, threatening rural livelihoods and hampering the country's development efforts as envisaged under Kenya Vision 2030 and Sustainable Development Goals (SDGs).

Given the foregoing, this study seeks to ascertain the effects of climate change operationalized as change in means and variability of temperature and precipitation on tea production in Kenya while controlling for economic incentives. The study adds Knowledge to the limited but growing literature on climate change and tea production in Kenya, thereby availing information for designing policies on mitigation and adaptation to climate change.

This paper is organized in the following manner: Section 1.1 outlines the climate change in tea producing areas in Kenya; section 1.2 reviews tea production in Kenya; section 2 provides a review of theoretical and empirical literature, section 3 outlines the methodology, this include theoretical and empirical models that informs the study; Section 4 presents results of data analysis and discussion and under section 5 the conclusion of the study is made.

1.1 Climate Change in Tea Growing Areas in Kenya

Tea growing areas in Kenya have experienced extreme climate events that include: temperature rise, eractic rainfall and growing incidence of extreme weather events such as hail storms, drought and frost (Cheserek, et al., 2015). For instance in Kericho, a major tea producing area Wachira (2009) and Omumbo et al., (2011) observed a warming trend in maximum, minimum and mean temperatures and a decline in rainfall amounts in the last four decades. To demonstrate such occurences, Figure 1 shows average annual maximum and Minimum temperature deviations, while Figure 2 shows rainfall deviations in tea growing areas in Kenya.

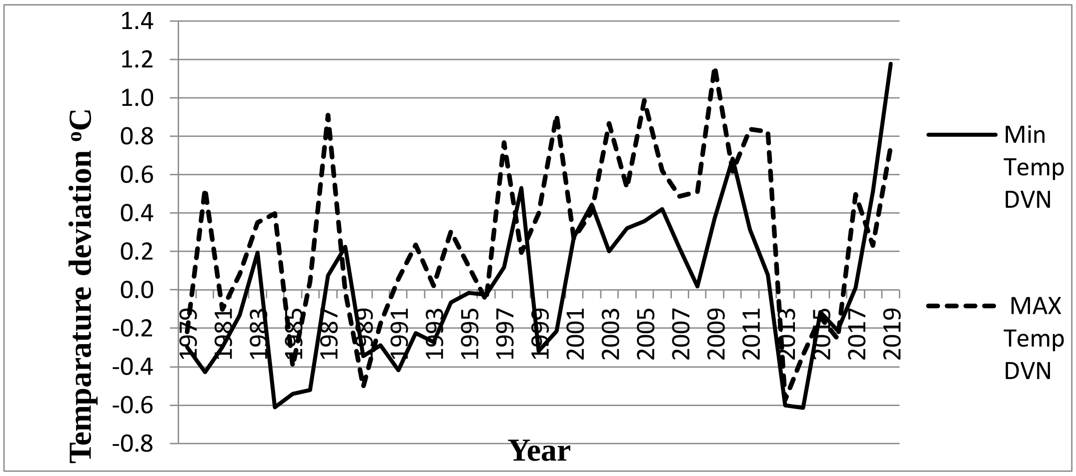

Figure 1. Annual average maximum and minimum temperature variations (1979-2019)
Source: Kenya Meteorological Department

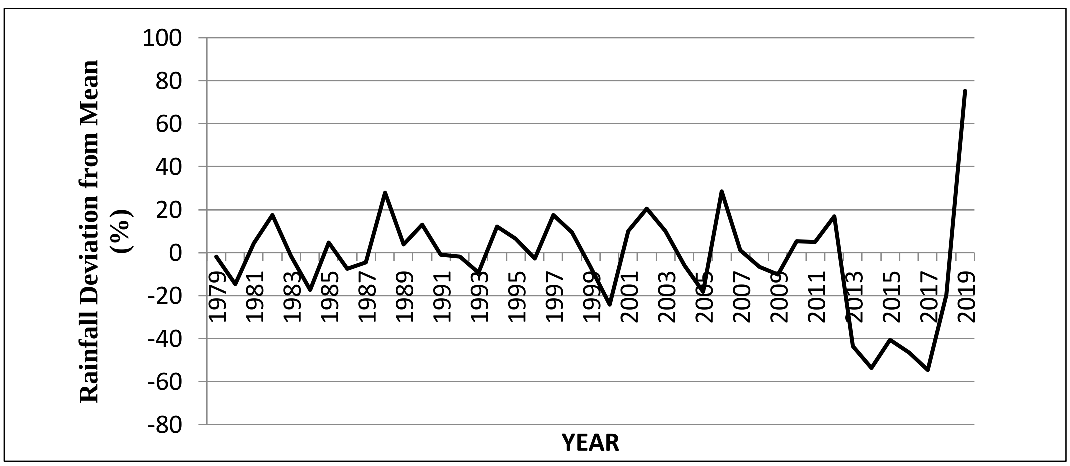

Figure. 2. Annual rainfall deviation (%) from the mean (1979-2019)

Source: Kenya Meteorological Department

These deviations were computed using data from weather stations located in tea growing areas, namely, Kericho, Nyeri, Kakamega, Meru, Embu and Kisii. The year to year variation of average temperature for the period 1979 to 2019 shows a slight increase in temperature with fluctuations of up to -0.6 ^{o}C and 1.2^{o}C for average annual minimum temperature and -0.5 and 1.16 ^{o}C for the average annual maximum temperature. The deviation of annual rainfall amount from the mean of 1545 mm indicate drought and flood conditions in the crop growing regions. The fluctuations depict occurrence of extreme weather events that have been witnessed in Kenya. (Rarieya and Fortun, 2010; KIPPRA, 2013; ROK, 2020). These events pose a serious challenge as tea plant requires well distributed rainfall and the optimum mean tempearture in the range of 18^{o}C to 30^{o}C. These occurences escalate vulnerability of smallholder tea farmers.

1.2 Tea production in Kenya

Tea is one of the most economically valued crop in Kenya with its production not only influenced by agro climatic conditions but also impacted on, by the various targeted economic incentives. The economic incentives provided to farmers are aimed at influencing farmer's decision on the process of tea production towards raising tea production. These incentives include:higher producer prices; inputs subsidy; provision of agricultural credit, research and extension services, government expenditure on agriculture, institutional and macroeconomic reforms. However, despite these incentives, tea production has been fluctuating. Figures 3 and 4 show tea production, area under tea, and tea production growth rate in Kenya for the period 1979 to 2019, respectively.

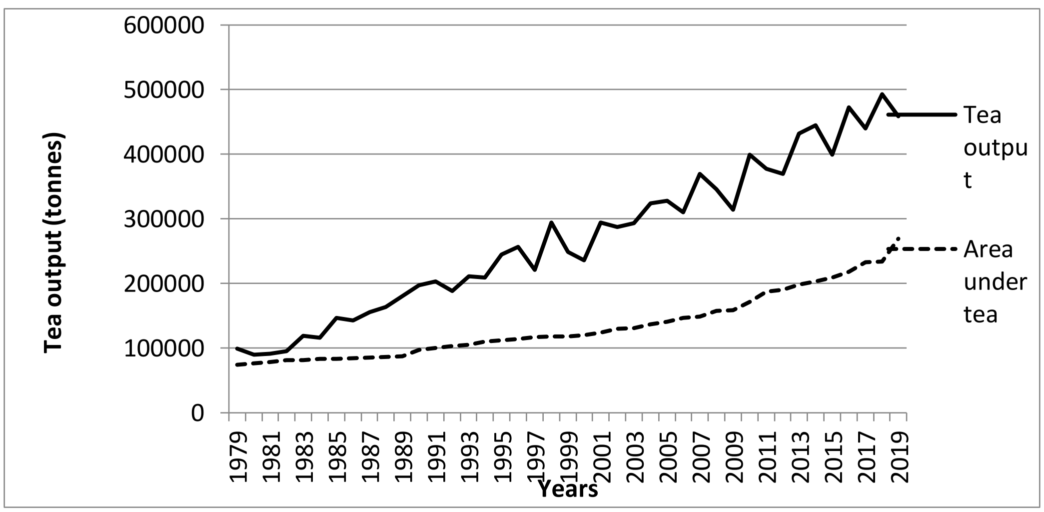

Figure 3. Tea Production (tonnes) and area under tea (Ha) in Kenya (1979-2019)
Source: Republic of Kenya. Economic Survey (Various Issues).

Figure 3 depicts a steady increase in both the amount of tea produced and area under tea production. Tea production rose from a low of 89,893 tonnes recorded in 1980 to a high of 492,990 tonnes in 2018, while area under crop rose from 76,541 Ha to 234,300 Ha under the same period. However, there has been fluatuations in tea production growth rate as shown in Figure 4, with 17 years interspersed under the studied period recording negative growth rates.

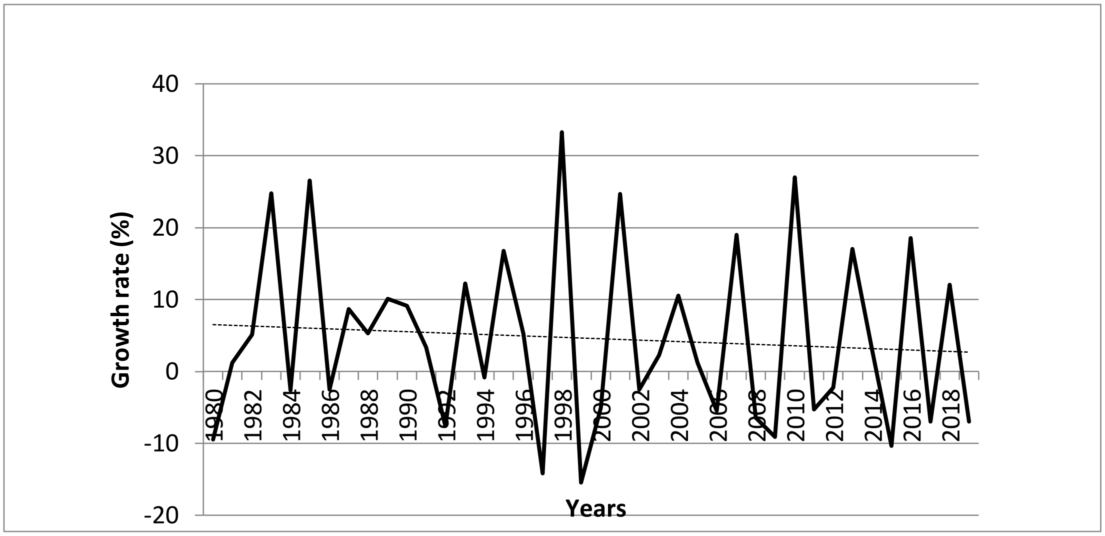

Fig 4. Tea Production Growth Rate Trend in Kenya (1979-2019)
Source: Republic of Kenya. Economic Survey (1979-2020).

For instance, production in 2019 fell by 6.9% culminating to a decline in value of exports by 18.2% from Ksh. 138.8 billion to Ksh.113.6 billion in the same year. The fall in tea production in Kenya is against the expected 2.9% annual growth of black teas by 2023 (Chang, 2015).

2.0 Literature Review

2.1 Theoretical Literature Review

Profit Maximization, Risk Aversion and Utility Maximization theories explain the farm output decision making process. According to the profit maximization theory the problem facing the firm is to determine the level of output to produce, level of inputs to employ, prices of output and prices of inputs so as to maximize profits, subject to technological and market constraints. The quantity of a product produced and supplied depends on its own price and the price of inputs (Mas-colell *et al.,* 1995; Nicholson *et al*., 2008; Varian, 1992).

According to the Risk Aversion theory farmers make choices from available risky alternatives with a risk-averse household prefering a smooth consumption stream to a fluctuating one. Decision making by farmers aimed at enhancing food security and increase farm income, in the environment of risk and uncertainty may imply that production of crops will respond to changing rainfall and temperature patterns among other economic variables. In line with this theory climate, risk is captured in the study by considering how changes in mean and variability in rainfall and temperature influence crop production (Mas-colell *et al*., 1995; Morduch, 1994).

Utility maximization approach encompass the dual character of farm households as both families and enterprises and thereby take account of the consumption side of household decision making process (Mendola, 2007). Given the maximum income level derived from profit-maximizing production, family labor supply and commodity consumption decisions can be made. With this sequential decision making, a recursive model that encompasses profit and utility maximization components is adopted as the appropriate analytical framework (Singh *et al.*, 1986).

2.2 Emprical Literature Review

Several studies have analysed the effects of climate change on crop production using experimental and non experimental designs. Okoth (2011) using simulation method, assessed the potential impact of future climate change on tea production in Kericho County, Kenya. The analysis showed increasing trend in maximum and minimum temperatures in most seasons. Study projections indicated that increase in rainfall will raise production while an increase in maximum temperature was found to generate a potential fall in production.

Mwaura and Okoboi (2014) observed that rainfall variation and temperature variation from their long term means had significant effects on crop output in Uganda. Hamjah (2014) found Sunshine hours and wind speed during summer had negative and significant effect on tea production in Bangladesh . Cheserek et al., (2015) indicated that three tea estates in Kenya had experienced increasing temperatures and rainfall distribution was unpredictable. The study findings also indicated that when soil moisture is not limiting, a significant positive relationship between mean air temperature and yield of tea was observed. Eitzinger et al., (2011) observed that the suitability of tea growing areas in Kenya is expected to drop and could see the potential fall by around 40 percent by 2050.

Majority of tea response studies and climate change are experimental studies and are unable to capture the dynamics of farmers decision making. To overcome the shortcomings in literature and to generate more precise estimates, this study estimated an ARDL model that employed national long term data, sufficient enough to capture the effects of climate change on tea production.

3.0 METHODOLOGY

3.1. Household Utility Maximization Model

A household is assumed to maximize utility from consuming consume three goods, a farm produced good (X_a), a market purchased good (X_m) and leisure (X_l) . This is subject to an income constraint where expenditure on the market purchased good is equal to the sum of net income from the farm produced good and income derived from other sources other than from the farm or labor supply. Thus, the household chooses optimal levels for consumption of X_a, X_m and (X_l) and as well make production decisions on the farm produced good Q_a. The of surplus of Q_a is marketed as a source of income (Singh *et al.*, 1986). Q_a is influenced by factor inputs such as, labor (L),fertilizer (V), size of land (A), Fixed stock of capital(K) and agro-climatic factors (W).
Thus, the household production technology can be specified as:

$$Q_a = Q\ (L, V, A, K, W) \tag{1}$$

Accordingly, the objective of the household can be stated as:

$$\text{Maximizing } U = U\ (X_a, X_m, X_l) \tag{2}$$

Subject to an income constraint specified as

$$P_m X_m + P_a X_a + P_l X_l = P_l T + (P_a Q_a(L,V,A,K,W) - P_l L - P_v V) + E \quad (3)$$

Where P_m is the price of the market-purchased commodity; P_a is the price of farm output; P_L is the wage; P_V is the price of fertilizer; T is the total stock of household time, E is any non-labor, nonfarm income and other variables are as previously defined.

Let Y denote total income as:

$$Y = P_l T + (P_a Q_a(L,V,A,K,W) - P_l L - P_v V) + E \quad (4)$$

Therefore, the household maximization problem may be expressed in a Lagrangian function as:

$$Z = U(X_a, X_m, X_l) + \lambda(Y - P_m X_m - P_a X_a - P_l X_l) \quad (5)$$

Equating the partial derivatives of (5) with respect to L,V, X_a, X_m ,X_l and λ to zero, yields the following first-order conditions necessary for maximization problem:

$$\frac{\partial Z}{\partial L} = P_a \frac{\partial Q_a(L,V,A,K,W)}{\partial L} - P_l = 0 \quad (6)$$

$$\frac{\partial Z}{\partial V} = P_a \frac{\partial Q_a(L,V,A,K,W)}{\partial V} - P_V = 0 \quad (7)$$

$$\frac{\partial Z}{\partial X_a} = U_{X_a}(X_a, X_m, X_l) - \lambda P_a = 0 \quad (8)$$

$$\frac{\partial Z}{\partial X_m} = U_{X_m}(X_a, X_m, X_l) - \lambda P_m = 0 \quad (9)$$

$$\frac{\partial Z}{\partial X_l} = U_{X_l}(X_a, X_m, X_l) - \lambda P_l = 0 \quad (10)$$

$$\frac{\partial Z}{\partial \lambda} = Y - P_m X_m - P_a X_a - P_l X_l = 0 \quad (11)$$

Since the functional forms are not specified, the standard profit maximizing conditions given in (6) and (7), can be written in general as:

$$F(P_a, P_m, P_v, P_l, L, V, A, K, W) = 0 \quad (12)$$

Using the implicit function theorem (Chiang, 1984), from (11) the input demand for labor and capital can be written generally as:

$$V = f(P_a, P_m, P_l, P_v, L, V, A, K, W) \quad (13)$$

$$L = f(P_a, P_m, P_l, P_v, L, V, A, K, W) \quad (14)$$

Once the profits are maximized, its value can be substituted into the constraint equation to yield:

$$Y^* = P_m X_m + P_a X_a + P_l X_l \qquad (15)$$

Where Y^* denotes total income for a profit maximizing household. Having optimized on profit, the household maximizes utility subject to the total income. The solution to (4), (5) and (15) can implicitly be written as:

$$F(X_a, X_m, X_l, P_a, P_m, P_v, P_l, Y^*) = 0 \qquad (16)$$

Again, using the implicit function theorem (Chiang, 1984), from (16) the input demand for farm produced good can generally be written as:

$$X_a = f(P_a, P_m, P_l, P_v, Y^*) \qquad (17)$$

Equation (17) shows that the demand for farm produced good is affected by price of outputs, prices of variable inputs and total income. The presence of profits in Y^* further shows that farm technology, quantities of fixed inputs and agro-climatic conditions affect the demand for the farm produced good (Singh *et al.*, 1986).

If the farmer is a price taker in all markets, for all commodities which he both consumes and produces; the farmer's solution gives an output supply dependent on output prices $(P_i, i = 1, \dots, n)$, variable input prices $(P_v, v = 1, \dots, V)$, production technology, quasi fixed inputs of land and capital $(A_j, j = 1, \dots, J)$ and agro-climatic conditions (W). The output supply function for crop i can therefore be expressed as:

$$Q_i = f\left(P_i, P_v, A_j, W\right) \qquad (18)$$

An increase in output prices with fixed input raises the profits serving as an incentive to farmers to produce more. Conversely, an increase in prices of inputs raises the cost of production serving as a disincentive to increase production (Singh *et al.*, 1986).

According to Key et al. (2000), fixed and variable transaction costs raise the total cost of production. The fixed transaction costs are lump sum while the variable transaction costs increase the per unit cost of accessing the market which raise the price effectively paid for inputs and lowers the price effectively received for output. Consequently, this creates a price band within which households find it unprofitable to supply output or buy inputs. Thus, net prices can be expressed as:

$$P^*{}_i = P_i - t^s(Z^s_{it}) \qquad (19)$$

$$P^*{}_{vi} = P_{vi} - t^b\left(Z^b_{it}\right) \qquad (20)$$

Where $P^*{}_i$ is net output price received; $P^*{}_{vi}$ is the net input prices paid; P_i is the output market price, P_{vi} is the input market price; t^s is the transaction cost associated with marketing output and

$t^b$are transaction cost associated with purchase and use of inputs. Z is a vector of all factors that influence transaction costs such as rural infrastructure and macroeconomic conditions. Incorporating (19) and (20) into (18) yields equation (21) implying that factors influencing transaction costs influence output supply:

$$Q_i = f\left(P_i{}^*, P_v{}^*, A_j, W\right) \tag{21}$$

Following the utility maximization theory, equation (21) is augmented to account for factors that influence the farmers' production decisions namely, rural infrastructure, human capital, technology and agro-climatic conditions (Muchapondwa, 2009). Temperature and rainfall are observable by farmers and likely to influence crop management as demonstrated in (1) and (17). In Kenya, majority of farmers base their decisions on perceived change in climate over the previous years and what they perceive as expected future weather conditions (Blanc, 2011; Recha *et al.*, 2008).

In addition, to enhance crop production, the Kenyan government provides funds for infrastructure development, subsidizes fertilizers and funds agricultural research. As an export crop, the relative price of exports and imports between Kenya and other trading partners, measured by real effective exchange rate(REER), is expected to have a significant impact on the level of tea produced. If REER rises ceteris paribus, the purchasing power of domestic currency rises undermining the competitiveness of exports (Oriavwote *et al*., 2013). Incorporating these factors in (21) yields:

$$Q_i = f(P_i{}^*, P_v{}^*, W, G) \tag{22}$$

Where variables are as defined earlier and G is a vector that includes: area under crop, development expenditure on agriculture, REER and fixed inputs (A_j).

3.2 Empirical Model

Tea farmers produce for income generation but part of their land is used for production of food crops. If there is a need to increase production of food crops, more land is allocated for their production. Income from the cash crops is used to purchase goods from the market which, together with the farm produced goods and leisure, constitute the consumption basket of the household. Following the utility maximization problem, equation (22) may be generalized to specify the output supply model for a particular crop (j) given as:

$$Q_j = \alpha j e_T + P_j\beta_j + W_j\theta_j + G_j\pi_j + \varepsilon_j \tag{23}$$

Where: Q_j is a (Tx1) vector of observations on tea crop (j); P_j is a (TxK) matrix of observations on all prices of output and input; W_j is a (TxH) matrix of agro-climatic variables specific to tea growing areas and season; $G_j$is a (TxM) matrix of other factors influencing tea output; α is the unknown intercept; e_T is a column vector of I's with dimension T; β_j, θ_j and π_j are vectors of unknown coefficients corresponding to P_j , W_j and G_j respectively; ε_j is the stochastic error with zero mean and constant variance, uncorrelated with the explanatory variables and its previous realizations.

The farmers are assumed to be forward looking, seek to maximize crop production in a dynamic situation, and take into consideration their past experiences in making production decisions in the future. To capture these dynamics fully an ARDL model is specified, where lags of dependent and explanatory variables are included in the model. The lagged values enable the model to capture the full dynamics of output supply as it takes into consideration, the role of observed variables in influencing farmers decision (Muchapondwa, 2009; Ogazi, 2009).
Therefore, the model in (23) can be modified to include the lags of the dependent and explanatory variables in the form of an ARDL model, specified as:

$$Q_{jt} = \alpha_{j0} + \sum_{i=1}^{P} \delta_{ji} Q_{jt-i} + \sum_{k=1}^{K} \sum_{i=0}^{P} \beta_{jki} P_{jkt-i} + \sum_{h=1}^{H} \sum_{i=0}^{P} \theta_{jhi} W_{jht-i} + \sum_{m=1}^{M} \sum_{i=0}^{P} \pi_{jmi} G_{jmt-i} + \varepsilon_j \quad (24)$$

This can be rewritten as,

$$Q_{jt} - \sum_{i=1}^{P} \delta_{ji} Q_{jt-i} = \alpha_{j0} + \sum_{k=1}^{K} \sum_{i=0}^{P} \beta_{jki} P_{jkt-i} + \sum_{h=1}^{H} \sum_{i=0}^{P} \theta_{jhi} W_{jht-i} + \sum_{m=1}^{M} \sum_{i=0}^{P} \pi_{jmi} G_{jmt-i} + \varepsilon_j \quad (25)$$

By employing a lag operator and dropping the subscript j for ease of illustration, the corresponding equation in lag polynomial is

$$A(L)Q_t = \alpha_0 + \sum_{\mathrm{k}=1}^{\mathrm{K}} \beta_k (L) P_{kt} + \sum_{h=1}^{H} \theta_h (L) W_{ht} + \sum_{m=1}^{M} \pi_m (L) G_{mt} + \varepsilon_t \quad (26)$$

Where:

$$A(L) = 1 - \sum_{i=1}^{P} \delta_i \mathrm{L}^{\mathrm{i}} \ , \ \beta_k(L) = \sum_{\mathrm{i}=0}^{\mathrm{P}} \beta_{ki} \mathrm{L}^{\mathrm{i}}, \ \ \theta_h(L) = \sum_{h=0}^{H} \theta_{hi} \mathrm{L}^{\mathrm{i}}$$

and $\pi_m(L) = \sum_{m=0}^{M} \pi_{mi} \mathrm{L}^{\mathrm{i}}$

The distributed lag form of the model that defines long run relationship is given as:

$$Q_{jt} = \frac{\alpha_0}{A(L)} + \frac{\sum_{\mathrm{k}=1}^{\mathrm{K}} \beta_k (L)}{A(L)} P_{kt} + \frac{\sum_{h=1}^{H} \theta_h (L)}{A(L)} W_{ht} + \frac{\sum_{m=1}^{M} \pi_m (L)}{A(L)} G_{mt} + \varepsilon_t \quad (27)$$

Where: $A(L) \neq 0$

The short-run dynamics of ARDL model can be found through the following equation;

$$\Delta Q_{jt} = \alpha_{j0} + \sum_{i=1}^{P} \delta_{ji} \Delta Q_{jt-i} + \sum_{k=1}^{K} \sum_{i=0}^{P} \beta_{jki} \Delta P_{jkt-i} + \sum_{h=1}^{H} \sum_{i=0}^{P} \theta_{jhi} \Delta W_{jht-i} + \sum_{m=1}^{M} \sum_{i=0}^{P} \pi_{jmi} \Delta G_{jmt-i} + \varphi_i ECT_{t-1} + \varepsilon_t \quad (28)$$

ECT_{t-1} is the lagged residual acquired from the estimated cointegration model equation 24. φ_i is the speed of adjustment parameter which is expected to be negative for significant ECM model. The Error Correction Term specifies that any divergence from the long-run equilibrium between variables is corrected in each period and how much time it will take to go back to the long-run equilibrium position. The number of lags is determined using Akaike Information criterion (AIC) as shown in Table A2.

3.3 Definition and Measurement of Variables

Tea output is the quantity harvested, measured in tonnes, for a given year; price of output is the average market price for tea in a given year in Kenya shillings per kg; price of fertilizer is the price of fertilizer measured in growth terms by the difference between input price index for the given period and that in the previous year; wage rate is the average wage in agricultural sector measured by the minimum wage for rural farm worker in Kenyan shillings; land use is the area under crop production measured by the number of hectares; government spending on agriculture is the amount of money allocated for development in the sector in a given fiscal year measured in Kenyan shillings; Rainfall amount is the sum total monthly rainfall values recorded in the periods JF, extended long rains period (March to September) and short rains period (OND) in a given year measured in Millimeters. Rainfall Variability is a measure of the variation in monthly precipitation totals in a given year. This index is the ratio of the standard deviation of the monthly total precipitation to the mean monthly total precipitation (coefficient of variation) and is expressed as a percentage. Temperature Variability is the amount of temperature variation in a given year based on the ratio of the standard deviation of the monthly mean temperatures to the mean monthly temperature (coefficient of variation (CV)). Maximum temperature in a given year is the average for the monthly means of maximum temperatures measured in degree Celsius. Minimum temperature is the average for monthly means of daily minimum temperatures in a given year measured in degree Celcius

3.4 Model Estimation, Unit root tests, Cointegration and Diagnostic tests

The ARDL model was estimated by Ordinary Least Squares (OLS). Prior to model estimation, series were subjected to various diagnostic tests to guarantee results are efficient and consistent. An optimal lag length of order 2 was determined based on the AIC. Each of the series used in the study was tested for unit root based on Augmented Dickey Fuller (ADF), Phillips and Perron (PP) and Kwiatkowski Phillips, Schmidt and Shin's (KPSS) unit root tests. The ADF and PP tested the null hypothesis of unit root . To confirm the results, KPSS was employed to eliminate a possible low power against stationary near unit root processes which occurs in the ADF and PP tests. KPSS tests a null hypothesis of stationarity of a series. (Dickey and Fuller, 1979; Green, 2008; Gujarati, 2004; Kwiatkowski, Schmidt & Shin 1992).

The explanatory variables being a mix of I(0) and I(1) were subjected to ARDL bound testing cointegration test by Pesaran and Shin (1999) and extended by Pesaran, shin and Smith (2001). In bound testing, cointegration among the variables is tested by testing the null hypothesis of no cointegration H_0: $\delta_{ji} = \beta_{jki} = \theta_{jhi} = \pi_{jmi} =0$ against the alternative of cointegration among the variables H_1: $\delta_{ji} \neq \beta_{jki} \neq \theta_{jhi} \neq \pi_{jmi} \neq 0$. The ARDL bound test is based on Wald or F-statistic.

3.5 Data Type and Source

The study used annual time series data for the period between 1979 and 2019. The data was obtained from government publications, Kenya Meteorological Department, World Bank, IMF and FAOSTAT database. Weather variables used were computed using data from Kericho, Kabete, Nyeri, Kakamega, Meru, Embu and Kisii weather stations located in tea growing areas in Kenya.

4.0 Results and Discussions

4.1. Descriptive Statistics

The study variables statistics are shown in Table 1. The statistics are based on 41 annual observations spanning between 1970 and 2019. The statistics include: Minimum, Maximum, the Mean and standard deviation of thevariables.

Table1: Descriptive Statistics

Variable	Mean	Maximum	Minimum	Std. Dev.
Tea output -tonnes	269969.5	492990	89893	118020.8
Area undertea production-ha	134480.7	269400	74300	51372.4
Real wage-Kshs.	159257.8	246585.7	96349.74	34443.22
Reer	96.39	159.20	58.59	23.77
Rainfall variability	52.92	84.94	24.22	11.31
Rainfall short rain-mm	463.69	1189.9	182.57	195.05
Rainfall long rains-mm	915.2648	1420.95	410.2517	221.0969
Minimum temperature-^{o}c	13.36	14.54	12.75	0.39
Maximum temperature-^{o}c	24.73	25.60	23.86	0.44
Tempariture variability(CV)	0.293206	0.511966	0.216052	0.056158
Spending on agricultural development-Kshs	7538.57	33951.54	793	9014.73
Price of tea in Kshs per kilogram	130.47	391.86	14.12	98.86

4.2. Unit Root, Cointegration and Diagnostic Tests

The unit root test results shown in Table A1 indicate that variables used in the study are a mixture of I(0) and I (1). The cointegration results reported in Table A3 show that the calculated value of F-stat (3.765727) is greater than the upper bond values (Fu) of 3.61 at 5% level of Significance. Thus the null hypothesis is rejected and therefore the variables are cointegrated. To ensure that estimates obtained were unbiased and consistent , normality test, Ramsey RESET test for specification error, Breusch-Godfrey Serial Correlation LM test and ARCH Heteroskedasticity test were also carried out. As shown in Table A4, the P values associated with the computed test statistics were greater than 0.05 and therefore the series were nornally distributed, there was no misspecification error and model estimates were considered to be unbiased and consistent.

4.3 Long run Elasticity and Semi Elasticity Estimates

The longrun elasticity and semi elasticity estimates are shown in Table 2.

Table 2: Long run Elasticity and semi elasticity estimates
Dependent Variable : Log Tea output

Independent Variables	Coefficient	t-Statistic	Prob.
LOGSPENDAGRIC	-0.113850**	-2.260880	0.0364
LOGREER	-0.669343***	-5.085587	0.0001
LOGPRICE	0.355020**	2.710958	0.0143
LOGFERTPRICE	-0.214587***	-3.435997	0.0029
LOGAREA	0.817097**	2.529859	0.0210
LOGWAGE	0.057054	0.606836	0.5515
RAINFALL_VARIABILITY	-0.004881**	-2.589165	0.0185
RAINFALL_SHORT_RAIN	0.000127	0.978261	0.3409
RAINFALL_JF	0.000676*	1.788940	0.0905
RAINFALL_LONG_RAINS	-0.000224*	-1.997921	0.0611
MAXTEMP	-0.122288**	-2.213392	0.0400
MINTEMP	0.088385	0.968327	0.3457
TEMP_CV	-0.193570	-0.619428	0.5434
C	8.037305**	2.516723	0.0215

***, **,* coefficient significant at 1%, 5% and 10% levels of significance respectively.
Source: Authors computation

The results indicate that in the long run, the coefficients on the price of tea and the area under tea crop are positive and significant at 5% level of significance. The coefficients of rainfall variability, maximum temperature and spending on agricultural development are negative and significant at 5% level of significance. The coefficients of real effective exchange rate and fertilizer price are negative and significant at 1% level of significance. The positive coefficient of rainfall in dry period of January and February and the negative coefficient of extended long rains are weakly significant at 10% level of significance. Conversely, coefficients of temperature variability, minimum temperature, rainfall amount in the short rains period and the wage rate are not significant.

On the response of tea output to climatic variables, the semi elasticity estimates of tea output with respect to maximum temperature shows that an increase of average maximum temperature by 1^{o} C reduces tea output by 0.12% Thus the expected rise in temperature in the next decades due to climate change is likely to further exacerbate tea production in Kenya. While, this study finds minimum temperature had insiginificant effect on tea production, Okoth (2011) finds that increase in minimum temperature have a potential to increase tea production in the long term. On the effect of maximum temperature the study findings are consistent with that of Okoth (2011) and Seo et al., (2005) that maximum temperature have the potential harm tea production.

Semi elasticity estimates for the response of tea output to rainfall in the dry period of January and February before the onset of long rains indicate that an increase in rainfall by 100 mm raises tea production by 0.06%. This shows that early rains in the year are beneficial to tea production. Thus, an increase in rainfall in this period is of great benefit to tea crop production. The findings are consistent with those of Seo et al., (2005) and Okoth (2011) that increase in precipitation is likely to be beneficial to tea production. However, Cheserek (2015) found a weak negative relationship and a weak positive relationship between rainfall and tea production in Timbilil and Magura tea estates respectively.

In the extended long rains period, findings indicate that an increase in rainfall by 100 mm reduces tea output by 0.02%. Though weak, the negative significance serves as a pointer that increase in rainfall raises tea production with diminishing marginal benefits, with the tea crop unable to tolerate excess water especially in the long rains period. Consequently with climate change, high intense rainfall beyond the usual experience from time to time in the wet season will continue to have adverse effects on tea production. To affirm this, one of the KTDA officials noted that in Nyeri county "some tea bushes have dried up and died because of diseases or harsh weather conditions. Some 1.5 million tea bushes have dried up and need to be replaced" (Muchiri, 2019).

The elasticity estimate of tea output with regard to rainfall variability show that as rainfall variability increases by 10%, tea output reduces by 0.05%. The result signifies that, greater variation in monthly precipitation totals, eratic and intense rainfall raises climate risk faced by tea farmers leading to reduced production. Moreover, as a mitigating effect to climte risk, some farmers in Kenya have opted to diversify or switch toward other crops or participate in out of farm activities in partial or total abandon of the tea farming resulting to further reduction in tea output.

On tea production response to economic incentives, when price of tea increases by 1%, tea output increases by 0.36%. This indicates that farmers respond positively to higher prices, translating to increased earnings and serves as a motivation to tender their crop leading to higher output. This finding corroborates occurrences in Kenya where some small holder farmers have abandoned tea farming and switched to daily farming, poultry and horticulture, while others threaten to uproot tea bushes due to fall in tea prices and bonuses (Magati, 2019).

In an interview with small holder tea farmers in Kisii and Nyamira counties as reported in The Star daily Newspaper in Kenya, Magati (2019) notes that as a result of "a astring of dismal…. and ' shameful earnings"small holder farmers could not hold any longer. One of the farmers asserted that " I have other options, my land can equally support banana and vegetables", While another cticised members of parliament for not cushioning them from low prices. While clearing tea bushes to make way for planting blue gum trees the farmer affirmed that his decision is final saying that " I don't have second thoughts on this matter. By Monday I want the tea out of my farm, for good," (Magati, 2019).

The elasticity estimate with respect to area under crop shows that when land allocated to tea production increases by 1%, tea output increases by 0.82%. The elasticity estimate with respect to price of fertilizer implies that a 1 % increase in fertilizer price lowers tea output by 0.21%. Though inelastic, it shows that an increase in the price of fertilizer has adverse effects on tea output and thus subsidized fertilizer price will enhance use of fertilizers and boost tea output. The elasticity estimate of tea output with respect to REER show that a 1% increase in REER lowers output by 0.67%. Thus the competitiveness of Kenyan exports has significant influence on the level of tea production. A low level of competitiveness of Kenyan exports reduces the capacity of Kenyan tea to compete favorably in the international market.

When government raises its development spending in agriculture by 1% tea output drops by 0.11%. This result may appear against the norm, an inspection into the distribution of the allocation among agricultural subsectors explicates the finding. First, due to structural rigidities the absorption rates of the funds into the sector is low which reduces the expected impact into the sector. Second, a greater part of the resources have been allocated to support export promotion, large scale production of stables, increasing access to artificial inputs and national expanded irrigation programs such as Galana- Kulalu irrigation project, uplifting of Mwea irrigation scheme, coffee waivers and crop diversification of miraa farmers among others. These aspects do not support the small holder tea farmer in any way. Consequently the tea farmer not only feels neglected but finds other subsectors to be favourable alternatives with some farmers abandoning tea farming.

4.4. ARDL-Error Correction Model (ECM) Estimates

The shortrun elasticity and semi elasticity estimates from the dynamic ECM model are shown in Table 3.

Table 3: ARDL-Error Correction Model (ECM) Estimates

Explanatory Variables	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGSPENDAGRIC)	-0.139567***	0.037892	-3.683251	0.0017
D(LOGREER)	-0.504175***	0.156129	-3.229212	0.0047
D(LOGPRICE)	-0.180521**	0.081728	-2.208808	0.0404
D(LOGPRICE(-1))	-0.159555*	0.078966	-2.020558	0.0585
D(LOGFERTPRICE)	-0.078039**	0.036593	-2.132603	0.0470
D(LOGFERTPRICE(-1))	0.118864**	0.047533	2.500682	0.0223
D(LOGAREA)	0.615469**	0.257080	2.394079	0.0278
D(LOGWAGE)	0.042975	0.075069	0.572480	0.5741
D(RAINFALL_VARIABILITY)	-0.003676**	0.001444	-2.545747	0.0203
D(RAINFALL_SHORT_RAIN)	0.000096	0.000106	0.905387	0.3772
D(RAINFALL_JF)	0.000509*	0.000245	2.075329	0.0526
D(RAINFALL_LONG_RAINS)	-0.000169*	0.000088	-1.907487	0.0725
D(TEMP_CV)	-0.145805	0.231799	-0.629014	0.5372
D(MAXTEMP)	-0.092112**	0.037417	-2.461755	0.0241
D(MINTEMP)	0.066575	0.064306	1.035278	0.3142
CointEq(-1)	-0.753239***	0.158147	-4.762901	0.0002

***, **,* coefficient significant at 1%, 5% and 10% levels of significance respectively.
Source: Authors computation

The results are consistent with the long run findings. The coefficient sign on the ECM term is negative and significant indicating a fast adjustment process. The coefficient value of -0.7532 shows that any disequilibrium is expected to be corrected by 75.32% in the first year. The higher speed signals that tea farmers ar e able to respond relatively fast to external shocks.

To gurantee the robustness of the model and study results the study used a cumulative sum (CUSUM), and cumulative sum squares (CUSUMSQ) tests. The results shown in Figure A 1 and Figure A2 show that the CUSUM and CUSUMSQ lines are within the critical band at 5% level of significance. Thus the long run and shortrun ARDL models are stable. This implies that the study model is robust along with the stability of both long run and short run coefficient acceptability over the study period 1979–2019.

5.0 Concluion

From the study findings, it is evident that climate change poses an imminent threat to tea production in Kenya. Erratic rainfall patterns and increasing maximum temperature are exposing farmers to climate risk leading to lower production. With climate projection indicating an increase in mean temperature and temperature variability in Kenya, mitigating and adaptation measures are critical to slow down the adverse effects on tea production. The observed outcomes make Kenyan tea farmer especially the small holder more vulnerable and exacerbate macroecomic challenges of reduced incomes, loss of foreign exchange earnings, unemployment and poverty. To reverse this trend requires collaborative efforts towards developing definite, viable and sustainable adaptation options targeting tea farming. In addition, despite the challenges poised by climate change, the government needs to ensure that tea policy reforms are targeted towards raising competitiveness of Kenyan tea in the international market and ensure that tea prices and bonuses are paid on time and guarantee minimum return that will make alternatives to tea farming less lucrative.

6.0 References

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Table A1: Unit Root Results

Variable	**Type of test**	**Form of test**	**Test statistic**	**Critical value at 5 %**	**Conclusion**
Maximum Temperature	ADF	Intercept	-4.48	-3.62	Stationary
		Trend & Intercept	-4.58	-3.54	Stationary
	PP	Trend and Intercept	-4.56	-3.52	Stationary
	KPSS	Intercept	0.26	0.46	Stationary
Minimum Temperature	ADF	Intercept	-2.37	-2.93	Non Stationary
		Trend & Intercept	-3.01	-3.52	Non stationary
		1st difference	-5.94	-2.94	Stationary, therefore I(1)
	PP	Intercept	-2.22	-2.93	Non stationary
	KPSS	Intercept	0.52	0.46	Non stationary
Rainfall JF	ADF	Intercept	-1.83	-2.93	Non Stationary
		Trend And Intercept	-4.69	-3.52	Stationary
	PP	Intercept	-7.22	-2.93	Stationary
	KPSS	Intercept	0.36	0.46	Stationary
Rainfall- Long rains	ADF	Intercept	-3.86	-2.93	Stationary
		Trend & Intercept	-4.21	-3.52	Stationary
	PP	Intercept	-3.86	-2.93	Stationary
	KPSS	Intercept	0.38	0.46	Stationary
Rainfall-Short rains	ADF	Intercept	-5.04	-2.93	Stationary
		Trend & Intercept	-4.92	-3.52	Stationary
	PP	Intercept	-4.54	-2.93	Stationary
	KPSS	Intercept	0.11	0.46	Stationary
Rainfall Variability	ADF	Intercept	-5.26	-2.93	Stationary
		Trend & Intercept	-5.40	-3.52	Stationary
	PP	Intercept	-7.01	-2.93	Stationary
	KPSS	Intercept	0.09	0.46	Stationary
Temperature Variability	ADF	Intercept	-3.34	-2.93	Stationary
		Trend & Intercept	-3.46	-3.52	Stationary
	PP	Intercept	-3.53	-2.93	Stationary
	KPSS	Intercept	0.20	0.46	Stationary

Table 1: Unit Root Results contd…

Log Tea Output	ADF	Intercept	-3.13	-3.62	Non Stationary
		Trend & Intercept	-2.10	-3.54	Non stationary
		1st difference	-8.45	-2.94	Stationary, therefore I(1)
	PP	Trend and Intercept	-1.47	-3.52	Non stationary
	KPSS	Intercept	0.77	0.46	Non stationary
Log area- tea production	ADF	Intercept	2.28	-2.93	Non Stationary
		Trend & Intercept	-0.30	-3.52	Non stationary
		1st difference	-5.48	-2.94	Stationary, therefore I(1)
	PP	Intercept	2.73	-2.93	Non stationary
	KPSS	Intercept	0.78	0.46	Non stationary
Log Price of Tea	ADF	Intercept	-1.71	-2.93	Non stationary
		Trend And Intercept	-1.85	-3.52	Non stationary
		First difference	-6.07	-2.93	Stationary, therefore I(1)
	PP	Intercept	-1.85	-2.93	Non stationary
	KPSS	Intercept	0.75	0.46	Non stationary
Log Wage	ADF	Intercept	-0.83	-2.93	Non Stationary
		Trend & Intercept	-0.87	-3.52	Non stationary
		1st difference	-3.76	-2.94	Stationary, therefore I(1)
	PP	Intercept	-1.29	-2.93	Non stationary
	KPSS	Intercept	0.78	0.46	Non stationary
Log REER	ADF	Intercept	0.24	-2.93	Non Stationary
		Trend & Intercept	-1.63	-3.52	Non stationary
		1st difference	-6.94	-2.94	Stationary, therefore I(1)
	PP	Intercept	0.42	-2.93	Non stationary
	KPSS	Intercept	0.52	0.46	Non stationary
Log Spending in Agriculture	ADF	Intercept	-0.80	-2.93	Non Stationary
		Trend & Intercept	-2.48	-3.52	Non stationary
		1st difference	-7.17	-2.94	Stationary, therefore I(1)
	PP	Intercept	-0.64	-2.93	Non stationary
	KPSS	Intercept	0.69	0.46	Non stationary

Table A2: Lag Order Selection Criteria

VAR Lag Order Selection Criteria
Endogenous variables: LOGTEAOUTPUT LOGSPENDAGRIC LOGREER LOGPRICE LOGFERTPRICE LOGAREA LOGWAGE MAXTEMP MINTEMP RAINFALL_JF RAINFALL_LONG_RAINS RAINFALL_SHORT_RAIN
Exogenous variables: C
Sample: 1979 2019
Included observations: 39

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-705.5712	NA	15.55113	36.79852	37.31039	36.98218
1	-332.9564	496.8197	0.000173	25.07469	31.72894*	27.46218
2	-75.68230	184.7096*	6.55e-06*	19.26576*	32.06239	23.85708*

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Table A3: Results of F bound test for cointegration

ARDL Bounds Test
Sample: 1981 2019
Included observations: 39
Null Hypothesis: No long-run relationships exist

Test Statistic	Value	k
F-statistic	3.765727	6
Critical Value Bounds		
Significance	I0 Bound	I1 Bound
10%	2.12	3.23
5%	2.45	3.61
2.5%	2.75	3.99
1%	3.15	4.43

Table A4: Diagnostic Tests

Test	Test Statistic	Statistic value	P Value
Normality test	Jarque- Bera	0.55	0.76
Breusch-Godfrey Serial Correlation LM test	Observed R squared	4.03	0.13
ARCH Heteroskedasticity test	Observed R squared	2.05	0.15
Ramsey RESET	F statistic	4.33	0.53

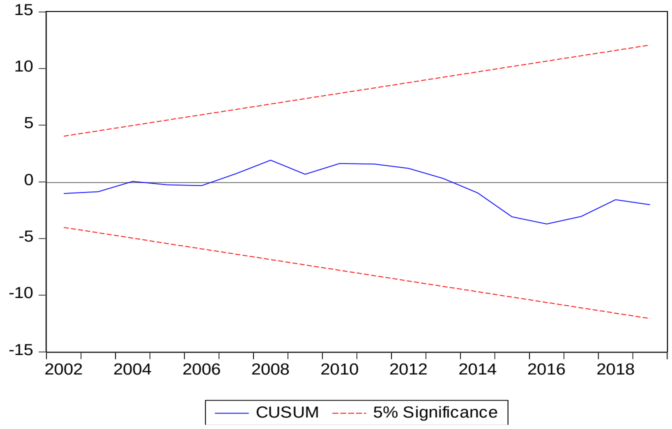

Figure A1: Cusum

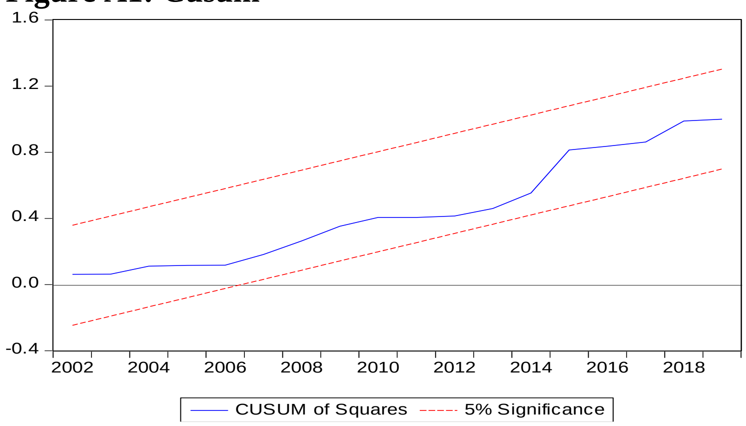

Figure A2: Cusum sum of squares