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Climate Change and Agricultural Yield in the Republic of Congo: An Analysis Using the ARDL Approach

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Abstract

The objective of this study is to analyze the effect of temperature variations on agricultural yield in the Republic of Congo over a period from 1990 to 2020. Following the estimation of the ARDL model, the results of the estimation, in the short run, confirmed the hypothesis of a negative and significant relationship between temperature rising and agricultural yield in the Republic of Congo. In the long run, these effects subside overtime, and subsequently improve agricultural yields. These results allowed us to formulate economic policy implications for sustainable agriculture, adapted to climate change, and climate change mitigation.

Keywords

Temperature, Rainfall, Agricultural Yield, ARDL, Congo

1. Introduction

The issue of agricultural yields has become of increasing concern since some studies have shown the impact of climate change on low-income economies, revealing that climate remains the main determinant of agricultural productivity, and has low adaptive capacities (IPCC, 2021; Nordhaus, 2020; Mendelsohn & Dinar, 2009; Mendelsohn & Nordhaus, 1999).

The agricultural sector accounts for a large share of the economic activity sectors, mainly in rural areas. This sector is the main source of income and employment for more than 70% of the world's poor population living in rural areas (WDI, 2014). In the Congo, the individual or family rural agricultural model, reduced to the use of rudimentary tools and techniques, with very little innovation and spread throughout the national territory, dominates agriculture. This rural agriculture is limited to the production of food crops for subsistence, in particular cassava, yams, taro, groundnuts, beans, maize, vegetables and various fruits. In rural areas, agriculture is the main activity of women, who produce 80% of the foodstuffs. In addition, they process and market the harvested products and at the same time carry out their traditional tasks (cleaning, cooking, childcare, collecting water and wood, etc.). The working day is long, estimated at 16 hours on average. The disappearance of rent crops has led to the involvement of men in food crops (cassava, yams, beans, etc.). Men, especially young men, now perform some of the tasks traditionally reserved for women (CERAPE-Sofreco, 2012: p 39).

Climate change is a growing threat to agricultural sectors. The negative effects on agricultural production and on the livelihoods of farmers, foresters and fishermen are already being felt in many regions. They will only get worse over time. If climate change is not addressed, agricultural productivity will decline, with serious consequences for food security. Millions of low-income people will be threatened by hunger and poverty. The fifth IPCC report (2014) has thus reinforced its certainty about the main cause of global warming, and has never been more certain about the responsibility of human activities as the main cause of the variation of these climate parameters. However, this responsibility is estimated in this report, as "extremely likely" (with a probability of 95%). Climate studies predict that the climate in Central Africa will warm from about 0.5˚C in the 20th century to between 2˚C and 3˚C in the 21st century (Christensen et al., 2007). The results of Bouka-Biona & Mpounza (2009) works on the Congo show that the average temperature will increase across the country by 0.7˚C in 2025, 1˚C in 2050 and 3˚C in 2100. Rainfall will increase by 1% by 2025, 2% to 3% in 2050 and 4% to 10% on the continental part. During the rainy season (March, April and May), it will rain more in the central part of the country (8% in 2050 and up to 20% in 2100), while during the sowing season (September, October and November), it will rain more in the northern part of the country (5% in 2050 and up to 16% in 2100). Overall, in recent years, farmers are no longer able to predict the beginning and end of rainy seasons (Diop, 1996; Houndénou et al., 2008). This makes agricultural planning uncertain. Diouf et al. (2000) have shown a trend of shortening of the crop-growing season, observed since the end of the 1960s, correlating with aridification. According to Thornton et al. (2006), this growing season is one of the elements affected by climate change. Thus, by 2100, arid and semi-arid areas are expected to expand, reducing the area suitable for agriculture and the potential for agricultural production, making access to food difficult (Sultan et al., 2011).

According to the World Bank (2013)'s report, as the world warms, people may suffer from hunger and water shortages, and coastal areas may be flooded. With less rain, crops will fail and livestock will die, increasing the risk of famine and food insecurity in low-income countries. Furthermore, according to the World Bank (2003)'s report, this warming may lead to an increase in poverty levels. As issues of global climate warming are being debated, the relationship between climate change and agriculture prompts the following question: *What are the effects of climate change on agricultural yields in the Republic of Congo*? The answer to this question highlights the impact of climatic indicators (notably temperature variation) on agricultural yields in Congo. Due to the low percentage of harvests, it is argued, in this study, that rising temperatures negatively influence agricultural yields.

In general, this paper is structured around five (5) points which are: 1) Introduction; 2) Climate Change and Agriculture in Congo; 3) Literature review; 4) Methodological Approach and Interpretation of Results; 5) Conclusion and Policy Implications.

2. Climate Change and Agriculture in Congo

This section presents the situation of climate change (through rainfall patterns and temperature variation) and agriculture in the Republic of Congo.

2.1. Climate Change

According to the Intergovernmental Panel on Climate Change GIEC (2007), climate change is defined as “a change in the state of the climate that can be detected by changes in the mean and/or variability of its properties, and that persists for an extended period”. For the United Nations Framework Convention on Climate Change (UNFCCC, 2008), climate change refers to changes that are attributed directly or indirectly to human activity that alters the composition of the global atmosphere. Beyond these definitions, climate change is being manifested in increased frequency of dry spells and droughts, changes in rainfall patterns, increased intensity of extreme weather events, increased temperatures, temperature variability and sea level rise. All of these effects have implications for crop production.

According to the data from the “Centre de Recherche sur les Tropiques Humides (CRTH)” of Marien NGOUABI University and the “National Agency of Civil Aviation (ANAC), Maya-Maya”, Congo rainfall patterns over the last two decades (2001-2010 and 2011-2020) have shown significant variations with respective decadal averages of 123.07 mm and 129.48 mm. Rainfall flows in 2002, 2010 and 2020 were up to 143.01 mm, 138.45 mm and 138.75 mm respectively. Average maximum temperatures, over the same decades, also varied significantly with respective maximum (minimum) temperatures of 30.79˚C (21.67˚C) and 30.84˚C (21.18˚C). The average maximum temperature levels in 2002, 2009 and 2019 were up to 30.59˚C, 30.61˚C and 31.17˚C respectively, while the average minimum temperatures were 21.90˚C; 21.67˚C and 22.19˚C respectively. The annual average of rainfall (*Prec*) and maximum temperature (*Tm*) evolution in Congo (Brazzaville), over the period from 1990 to 2020, is shown in the following **Figure 1**.

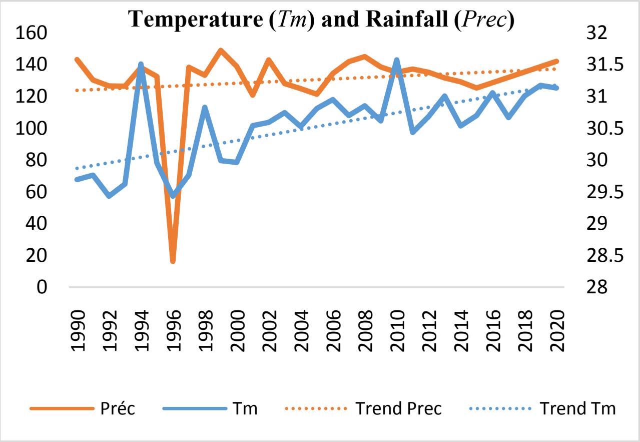

Figure 1. Climatic variations (temperature and Rainfall) evolution. Source: author, using data from ANAC (2021). Note: Trend Tm, Trend Prec represent, respectively, the trends of temperature, and rainfall.

Figure 1 above shows the cross-sectional evolution of average maximum temperatures and average Rainfall in Congo over the period 1990 to 2020. Overall, the evolution of average (maximum) temperatures shows a fluctuating pattern over time, with recurrent and alternating oscillations, showing an upward trend. Compared to the year 2001, the average maximum temperature in 2020 has increased by +0.59˚C. The highest average maximum temperature (31.57˚C) was recorded in 2010, while the lowest (29.43˚C) was registered in 1992 and 1996. The rainfall pattern in Congo, over the period 1990 to 2020, shows a fluctuating pattern over time, with recurrent and alternating oscillations, showing an upward trend. Compared to the year 2001, an increase in the average rainfall pattern of 21.24 mm was recorded in 2020. The highest rainfall level (148.96 mm) was registered in 1999, while the lowest (16.26 mm) was recorded in 1996.

2.2. Agriculture

The agricultural sector accounts for a large share of economic activities, mainly in rural areas. This sector is the main source of income and employment for more than 70% of the world's poor population living in rural areas (WDI, 2014). The effects of climate change on agricultural production will be mainly negative for developing countries, mainly in Sub-Saharan Africa, South Asia and South-East Asia. Decreases in productivity could have serious consequences for food security. Millions of low-income people, who are already highly insecure, will be affected. Small-scale producers are among the most vulnerable. In Congo, agriculture in rural areas is the main activity of women, with the level of employment in this sector in 2005, 2014 and 2017 being, respectively, 39.96%, 38.22% and 37.22% of total employment (WDI, 2021).

Women produce almost 80% of the food. In addition, they process and market the harvested products and at the same time carry out their traditional tasks (cleaning, cooking, childcare, collecting water and wood, etc.). The working day is long, 16 hours on average. However, the disappearance of cash crops has led to the involvement of men in food crops (cassava, yams, beans, etc.). Men, especially young men (CERAPE-Sofreco, 2012: p. 39), now perform some of the tasks traditionally reserved for women. According to the FAO (2018), the agricultural sector in Congo has seen a significant increase in current food production indices in recent years. The crop production index in 2005, 2009 and 2014 was 73.16; 87.86 and 100.79 respectively (WDI, 2021). The evolution of agricultural yields, as measured by Food Production Index in Congo (Brazzaville) over the period from 1990 to 2020, is presented in the following **Figure 2**.

Figure 2 above shows the evolution of food production in Congo over the period from 1990 to 2018. Overall, the evolution shows an increasing linear trend with negligible oscillations over time. The general trend is therefore upwards. Compared to 1990, an increase in the food production index of 135.72% was recorded in 2020. The highest food production index (109.14) was recorded in 2020, while the lowest (45.09) was observed in 1991.

2.3. Cross Evolution of Climatic Change and Agricultural Yield in Congo

This sub-section presents the cross-sectional evolution of climatic variations and agricultural yield (**Figure 3**) in the Republic of Congo. These variables are measured, respectively, by the averages of maximum temperature (in ˚C) and rainfall (in mm), and the food production index.

This Figure, of the cross evolution between climatic variations and agricultural yield, shows positive trends for all variables. These trends show oscillating, alternating, recurrent and ascending variability, thus showing a positive correlation between the three variables (*Ipv*, *Tm and Prec*).

3. Literature Review

Analyzing the effects of climate change on agriculture inevitably means examining the relationship between climate indicators and agricultural performance. This section presents the theoretical review and the empirical review.

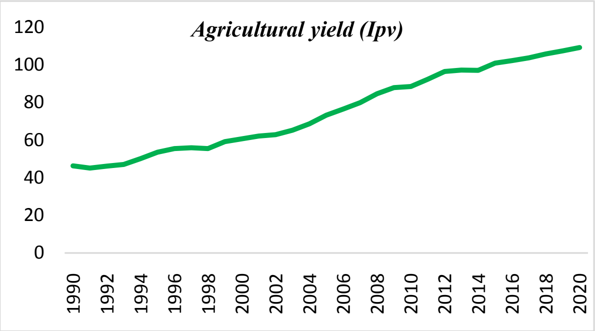

Figure 2. Evolution of agricultural yield (Ipv). Source: author, using FAO (2021) data.

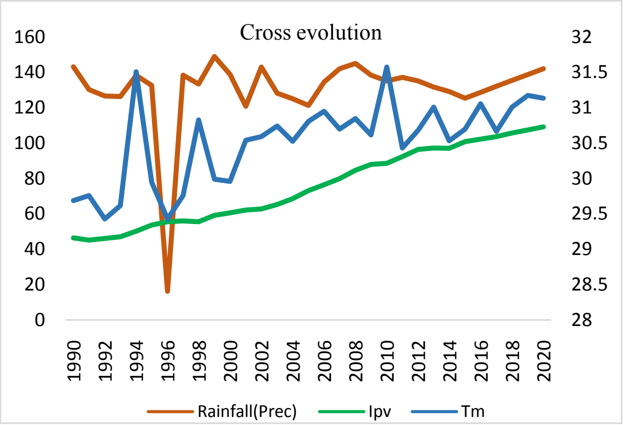

Figure 3. Crossed evolution of climatic hazards (temperature and rainfall) and agricultural yield. Source: author, using data from ANAC (2021) and FAO (2021).

3.1. Theoretical Review

In the theoretical literature, two main approaches are used. We distinguish the classical approach from the Ricardian approach.

- **Classical approach**

The classical production function approach (Adams et al., 1995) simulates crop response using interdisciplinary models while relying on estimated effects to simulate changes in production.

Although it has limitations on the integration of adaptation measures (Schimmelpfennig et al., 1996), this methodological approach has advantages in that it offers detailed information on the physical, biological and economic responses of crops, as well as possible adjustments. It is also noted that what are perceived as limitations of this approach are often seen as advantages of the other approach (Mendelsohn et al., 2007).

- **Ricardian approach**

Inspired by Ricardo's observations, and initially developed by Mendelsohn et al., 1994), the Ricardian approach (Mendelsohn et al., 1994), based on statistical relationships between climatic variables and economic indicators, takes into account the measures of adaptation to local climatic conditions in this approach. The principle of this approach is based on the value of land, derived from the efficiency of its use and the existence of competitive markets, thus representing the present value of net revenues. The effects of changes in economic, climatic and non-economic variables on the value of arable land are calculated using non-aggregate data.

Other studies, such as those by Terjung et al. (1984), deduce that water quantities for irrigation will be higher in the face of rising temperatures, if technological changes have not been made. In addition, Reilly et al. (1994) believe that as the temperature moves away from the favourable growing temperature of the crop, the growth of the crop is affected. Similarly, if temperature variability is high, yields are lower. The authors conclude that areas with high temperatures are likely to be more affected.

3.2. Empirical Review

The empirical literature highlights changes in climatic variables such as temperature and rainfall that have a significant effect on crop yields. As in the theoretical literature, the empirical work is classified according to the classical and Ricardian approaches. For example, the work by Warwick (1984) was among the first to use the classical production function approach to analyze the effect of climate on agricultural production. Similar to those carried out in the 1930s, a regression was used to simulate the increase in temperature. This resulted in a decrease in agricultural production.

Easterling et al. (1993) using the classical production function approach also found that climate change in the US, in the absence of technology changes or CO_2 increases, could lead to a reduction in production. They are therefore a source of economic losses. Rosenzweig & Parry (1994), using this approach, made a global assessment of the potential impact of climate change on the world's food supply and suggested that a doubling of the concentration of carbon dioxide in the atmosphere will lead to a slight decrease in world agricultural production.

In contrast, there are studies that have used the Ricardian model to determine the effects of climate on the agricultural sector. Among these studies is the work by Mendelsohn et al. (1994) who explored the effect of climate change on the net worth of arable land in the US. Using county-level cross-section data, they found that higher temperatures throughout the year (except in the autumn season) have a negative effect on average land values. Similarly, Schlenker et al. (2006), also using county-level agricultural data in the USA, as well as climatic indicators, soil characteristics and socio-economic conditions, showed that global warming causes profit losses in these different US counties.

Maddison (2007) constructed a Ricardian model using data from 11 African countries. They found that some African countries would suffer considerable losses in agricultural production by 2050. Studying the relationship between climate and farmers' net profit data, Molua & Lambi (2006) use a sample of 800 farms in Cameroon. They found that decreasing rainfall patterns have a negative effect on net profit. On the other hand, increasing temperature also has negative effects on net profit.

The Ricardian approach also allows comparisons between the potential effects on developed and developing countries. Thus, considering the USA and India, Mendelsohn et al. (2001) analyzed the sensitivity to climate change of each of these countries. The results of the works show that the Indian agricultural sector is much more sensitive to the effects of changing climate parameters. India is more likely to suffer from the negative effects of global warming than the US. They concluded that the level of development has a significant effect on sensitivity to climate change.

4. Methodological Approach and Interpretation of Results

This section presents, first, a modelling of the relationship between climate change and agricultural yield and, second, the presentation and interpretation of the results.

4.1. Modelling the Effects of Climate Change on Agricultural Yield

To analyze the effects of climate change on agricultural yield, the methodology borrowed from Mendelsohn & Dinar (2003) allows us to formulate the theoretical model. This model, which is based on an exogenous vision of growth, takes into account other factors such as human capital in the so-called augmented production function.

This model is translated into the following equation:

$$Ra = \int R_{ha} - \mathrm{e}^{-\theta t} d_i \tag{1}$$

$$Ra = \int \left[\sum_{i}^{n} P_i Q_i \left(I, C, E, S \right) - \sum XI \right] \mathrm{e}^{-\theta t} \mathrm{d}t \tag{2}$$

where $i = 1, 2, \cdots, n$ crops; *t*: time; and θ: the update rate. With:

Ra: *Net agricultural income per hectare*,

P_i: *The market price of the crop i*;

Q_i: *The produced quantity of the crop i*;

I: *All inputs or outputs*;

C: *The vector of climate variables*;

E: *The set of edaphic factors*;

S: *The set of socio-economic variables*;

X: *The prices vector of production factors*.

This model is based on the assumption that farmers maximize their output through the choice of inputs (*I*), depending on the characteristics of their farm subject to climatic conditions (*C*), soil conditions (*E*), the characteristics of socio-economic variables (*S*) and input prices (*X*). This model examines how the set of exogenous variables, *C*, *E*, and *S*, affect farm performance. The model is based on observed responses of crops to climatic change. It uses observations of agricultural performance across different climatic zones (Mendelsohn et al. (1994); Mendelsohn & Dinar (1998). This model also measures farm profitability according to local climate while considering other factors.

By introducing quadratic terms for the climate variables, the Ricardian model, developed by Mendelsohn & Dinar (2003), which analyses the non-linearity of the relationship between agricultural yield (*Ra*) and climate hazards, is as follows:

$$Ra = \alpha_0 + \alpha_1 C + \alpha_2 C^2 + \alpha_3 E + \alpha_4 S + \varepsilon \tag{3}$$

where ε is the error term. *C* and C^2 capture respectively, the linear and quadratic terms for temperature and precipitation. *E* represents the edaphic factors. With α_0: the constant, α_1, α_2, α_3 et α_4: the elasticities associated with the respective parameters. To understand the different channels through which climatic hazards affect agricultural production, the function borrowed from Mendelsohn & Dinar (1998) is presented as follows:

$$Ra_t = f\left(C, E, S\right)_t \tag{4}$$

Crop yield is therefore a function of climatic hazards (C), edaphic factors and socio-economic factors. The model specified for the relationship between climatic hazards and crop yield is based on the work of Mendelsohn et al. (1994). Taking into account the climatic characteristics, endogeneity and the natural logarithm of the variables, this specified model is as follows:

$$LIpv_t = \alpha_0 + \alpha_1 LTm_t + \alpha_2 LPrec_t + \alpha_3 LPib_t + \varepsilon_t \tag{5}$$

The independent variables include the linear terms for temperature (Tm) and precipitation ($Prec$), and the linear term for the socio-economic variable. Data on edaphic factors, which are not available, are not considered in this study. *With* α_0: the constant; α_1, α_2 et α_3: the elasticities associated with the respective climatic and socio-economic variables; ε_t: the error term. Our specified model has one endogenous variable ($LIpv_t$) and three (03) exogenous variables (two climatic variables and one socio-economic variable) presented in the following section.

4.2. Presentation and Interpretation of Results

This section covers the presentation of variables and analysis of descriptive statistics, and the presentation and analysis of results.

4.2.1. Presentation of Variables and Descriptive Statistics

This section presents the variables used in this study and analyses the descriptive variables.

1) *Presentation of variables*

The different variables used in this study are presented in the following **Table 1**:

The data is drawn from the World Bank's World Development Indicators (WDI, 2021, 2022) and the National Agency of Civil Aviation (ANAC, 2021). The study is conducted over a period from 1990 to 2020. The choice of this period is dictated by the availability of data. We recall that Tm is the maximum average temperature variable measured in degrees Celsius.

2) *Descriptive Analysis of Variables*

For the descriptive analysis of the variables, we use the normality tests to show the variables significance towards a normal distribution. The descriptive statistics are presented in the following **Table 2**.

The Shapiro Wilk normality test shows the significance at 1% for the $LPrec$ and $LPib$ variables, at 5% for the $LIpv$ variable and at 10% for the LTm variable. Similarly the multivariate normality test of Doornik-Hansen, shows the significance at 1%. In conclusion the distributions tend towards a normal distribution (with a sample of 31 observations, a study over the period from 1990 to 2020), which allows us to carry out stationarity tests.

Table 1. Presentation of variables.

Variables	Description of Variables	Source
LIpv	The agricultural yield indicator covers food crops that are considered as edible and contain nutrients. Coffee and tea are excluded because even though they are edible, they have no nutritional value. This variable, which captures agricultural yield, has been used by several economists (Ouédraogo et al. (2006); Bsais & Mokkadem, 2019; Molua & Lambi, 2006). The expected sign is positive or negative.	(WDI, 2022)
LTm	"Climate Change is attributed directly or indirectly to human activity that alters the composition of the global atmosphere". Beyond this definition, Climate Change is characterised by an increase in average atmospheric and ocean temperatures, massive melting of snow and ice, and a rise in mean sea level. Temperature has been used as an indicator of climate change in the work of (Molua & Lambi, 2006; Reilly et al., 1994; Mendelsohn et al., 1994). The expected sign is negative.	(ANAC, 2021)
LPrec	Rainfall is measured as the amount of water that falls to the ground per unit area. The unit used is the millimetre of precipitation per square metre. Assuming a homogeneous distribution of precipitation over this surface, 1 millimetre of rainfall represents 1 litre of water per square metre. This indicator was used by Ouédraogo et al. (2006); (Bsais & Mokkadem, 2019). The expected sign is positive.	(ANAC, 2021)
LPib	Gross domestic product (USD, constant 2010). This indicator, which captures the impact of economic growth on agricultural output, has been used by several economists as one of the socio-economic variables influencing agricultural production output (Mendelsohn et al., 1994; Mendelsohn & Dinar, 1998). Thus, this measure is chosen in our study as an indicator of economic growth. The expected sign is positive.	(WDI, 2021)

Source: author, from literature review.

Table 2. Descriptive statistics.

Variables	*LIpv*	*LTm*	*LPrec*	*LPib*
Mean	4.28	3.41	4.82	22.98
Maximum	4.69	3.45	5.00	23.40
Minimum	3.80	3.38	2.78	22.59
Standard deviation	0.29	0.019	0.38	0.29
Observations	31	31	31	31
Normality tests				
Shapiro Wilk W test	0.91**	0.93*	0.28***	0.87***
Doornik-Hansen test	Chi(2) = 358.86***			

Source: author, on Stata 15. ***, ** and * explain the significance at the 1%, 5% and 10% levels, respectively.

4.2.2. Presentation and Analysis of Results

This section presents the results of the various tests and model estimation performed.

1) *Presentation and analysis of test results*

The results of the various tests are presented and analyzed as:

- ***Stationarity analysis***

The estimation of an econometric model is conditioned by the existence of stationarity of the variables. This means that the variables must be integrated in the same order. In this study, the variables are examined using two stationarity tests: the Augmented Dickey Fuller (ADF) test and the Philips Perron (PP) test. The use of the latter is conditioned by the fact that the variables under study must be normally distributed, following a normal distribution. The results of the stationarity tests are presented in Table 3.

The results obtained show that some variables are stationary in level and others in first difference. Nevertheless, a variable that is stationary at a lower level is also stationary at a higher level. This shows that all variables are stationary of order one (1).

- ***Cointegration analysis***

After having determined the order of integration of the different variables, we estimate the ARDL or Black Box approach according to the cointegration, in order to analyze the long-run relationship between the variables. To do this, we use the Bounds Test (Pesaran et al., 2001) which determines the F-statistic. In this study, the *F-statistic* is equal to 13.50. The latter is compared to the critical values below and above the significance levels of 5%, 2.5% and 1%. The results show that the F-statistic is higher than all critical values of the upper bound I(1). These results verify a long-run cointegration relationship between the variables, and are reported in the following Table 4.

Table 3. Stationarity tests.

Variables	ADF tests		PP test		Decision
	Trend	No constant	Trend	No constant	
LIpv	−1.25	6.63***	**−1.25**	6.63***	I(0)
LTm	−5.64***	0.39	5.64***	0.39	I(0)
LPrec	−5.69***	−0.31	−5.69***	−0.31	I(0)
LPib	−1.48	3.82***	−1.49	3.82***	I(0)
LIpv	−1.34	3.58***	−1.25	5.92***	I(1)
LTm	−5.28***	0.57	−5.64***	0.51	I(1)
LPrec	−4.16***	−0.14	−5.70***	−0.22	I(1)
LPib	−1.86	2.33**	−1.63	3.49***	I(1)

Source: author, on Stata 15. ***, ** and * explain the significance, respectively, at the 1%, 5% and 10% thresholds. I(1) and I(0) explain the stationarity, respectively, in first difference and at level.

Table 4. Result of the ARDL bounds test.

F-statistics	13.50	
Critical values		
Significance level	I(0) Bound	I(1) Bound
5%	3.23	4.35
2.5%	3.69	4.89
1%	4.29	5.61

Source: author, on Stata 15.

2) *Analysis of the model estimation results*

This section presents and analyses the results of the model estimation. These results are summarized in Table 5 and Table 6 (for the short and long run respectively) below.

The results of the estimations, after the processing and validation of the model, show that the exogenous variables retained within the framework of this study explain the endogenous variable up to 91.26% (R^2 = 91.26%). The results of the estimation present a negative and significant recall force coefficient at the 1% level (−0.59 [−6.18]), the application of an ARDL model is therefore confirmed (see Appendix 1).

In the short run, the estimation results reveal that temperature (*LTm*) and gross domestic product (*LPib*) have a negative and significant influence on agricultural yield (*LIpv*), while rainfall and agricultural yield show a positive and significant relationship. Thus, a one-point increase of temperature (*LTm*), gross domestic product (*LPib*) and Rainfall (*LPrec*), all other things being equal, leads respectively to a significant decrease of 4.70 and 0.30 (at the 1% level), and a significant increase of 0.02 (at the 1% level) in agricultural yields (*LIpv*). In the long run, the effects of temperature, gross domestic product and precipitation on agricultural yields are positive. Only the variables temperature and gross domestic product showed significant results at the 1% level. Thus, a one-unit increase in the level of temperature and gross domestic product, all other things being equal, leads to a significant increase in agricultural yields of 8.32 and 0.55 respectively.

4.2.3. Interpretation of Results

Two lessons are formulated from these results:

- **Temperature Rising: a hindrance on agricultural yield in Congo.**

It appears that the temperature increase moves in the opposite direction to the agricultural yield. That is, the increase in temperature has a negative influence on agricultural yield. This finding validates the results of the work of Easterling et al. (1993) who, using the classical production function approach, found that climate change in the United States, in the absence of technology modification or CO_2 increases, leads to a reduction in agricultural production. Similarly, the

Table 5. Estimation result (short run). Endogenous variable: Agricultural yield (LIpv).

Variable	Coefficient	t-statistics	Probability
$D(LTm)$	−4.70	−6.26	0.000
$D(LTm(-1))$	−3.75	−5.25	0.000
$D(LPrec(-2))$	0.02	3.09	0.009
$D(LPib)$	−0.30	−3.55	0.004

Source: author, on Stata 15.

Table 6. Result of the long-run estimation. Endogenous variable: Agricultural yield ($LIpv$).

Variable	Coefficient	t-statistics	Probability
LTm	8.32	9.28	0.000
$LPrec$	0.05	1.69	0.118
$LPib$	0.55	13.96	0.000
C	−21.98	−6.67	0.000
Recall force	−0.59	−6.18	0.000
% R^2	91.26		

Source: author, on Stata 15.

work of Warwick (1984), one of the first to use the classical production function approach to analyze the effect of climate on agricultural production, gave a negative result (a reduction in agricultural production). Thus, our lesson is explained by the approach of Reilly et al. (1994), which states: if the temperature deviates from the favourable growing temperature for the crop, the growth of the crop is affected. Similarly, if temperature variability is high, yields are lower. The authors conclude that areas with high temperatures are likely to be more affected.

- **The effect of temperature rising on agricultural yields diminishes over time.**

In the long run, temperature favors agricultural yields. This supports the approach of the Intergovernmental Panel on Climate Change ((GIEC, 2007): report edited by Pachauri and Reisinger) on climate change mitigation. It states that sustainable forest management should contribute to both carbon sequestration and to improving temperature quality through its ecological services.

In the Republic of Congo, this mitigation is due to the geographical advantages of the Congo Basin, a large forest reserve of global importance. At the local and regional level, these ecological services promote climate regulation and cooling through evapotranspiration, as well as the mitigation of climate variability. Secondly, we highlight the maintenance of the hydrological cycle and flood control in a region of high rainfall. The forests of the Congo Basin are currently among the areas with the lowest deforestation rates in the world (Wasseige et al., 2014). Deforestation represents 0.15% of the Congo Basin's forest area compared to 0.51% in tropical America or 0.58% in tropical Asia (Bellassen et al., 2008). Currently, biodiversity loss is low in the forests of the Congo Basin. The Congo Basin accounts for 70% of Africa's forest cover and is home to much of Africa's biodiversity. The states of Cameroon, Gabon, Equatorial Guinea, Central African Republic, Democratic Republic of Congo, and Republic of Congo share the Congo Basin ecosystem. Within the 530 million hectares of the Congo Basin, 300 million are covered by forest. More than 99 percent of the forest area is primary or naturally, regenerated forest, as opposed to plantations, and 46 percent is dense lowland forest.

5. Conclusion and Policy Implications

This study analyzed the effects of rising temperatures on agricultural yields using the ARDL approach. To achieve the result, annual frequency data spread over 31 years, from 1990 to 2020, were mobilized and combined with a multi-step procedure: from stationarity analysis (ADF and PP tests) to ARDL estimation, via the cointegration test (Bounds test for ARDL). The ADF and PP unit root tests showed that the variables or series are stationary at level but they are also all stationary in the first difference. These variables are integrated of the same order (1) or stationary and significant in the first difference. After the analysis of the stationarity of the series or variables, we analyzed the Bounds test. According to its criteria, the variables are cointegrated. This allowed us to estimate an ARDL. The results of the estimation, in the short run, confirmed the hypothesis of a negative and significant relationship between rising temperature and agricultural yield in the Republic of Congo. However, in the long run, these effects subside, showing a positive relationship. The effects of gross domestic product on agricultural yield are significantly positive (in the long run) and negative (in the short run). In contrast, the effects of rainfall (*LPrec*) on agricultural yield (*LIpv*) are positive and significant in the short run. In the long run, this positive relationship is not significant.

The lessons learned from the results allow us to formulate some economic policy implications:

- A policy geared towards sustainable agriculture, adapted to climate change. To achieve this, governments must support farmers in accessing new agricultural technologies and in emphasizing certain types of ploughing, livestock rearing and the use of improved and selected seeds that have positive effects on agricultural production. These seeds contain genetic potential that is adapted to climatic change.
- A policy of mitigating the effects of climate change through the sequestration of carbon dioxide by forests. The implementation of a sustainable forest management policy is necessary to maintain ecological services. These include climate regulation and cooling through evapotranspiration on the one hand, and maintenance of the hydrological cycle and flood control in a high

rainfall region, on the other.

- ➢ Mitigation is also essential for the long-term food security of the world's population. To achieve this, governments must encourage humans in:
- Reducing food loss and waste which would improve the efficiency of the food system, reduce pressure on natural resources and GHG emissions;
- Rebalancing diets towards less animal-based food would be an important contribution, with likely associated benefits for human health.
- ➢ From coherence between climate and development goals, governments should: promote natural resource management, support and facilitate collective action, build institutions and policies for more resilient and lower-emission systems, and address transboundary issues.
- ➢ Another way to follow would be the strategic use of climate finance by supporting the environment for climate-smart agriculture, integrating climate change into national budgets, and unlocking private capital for climate-smart agricultural investment.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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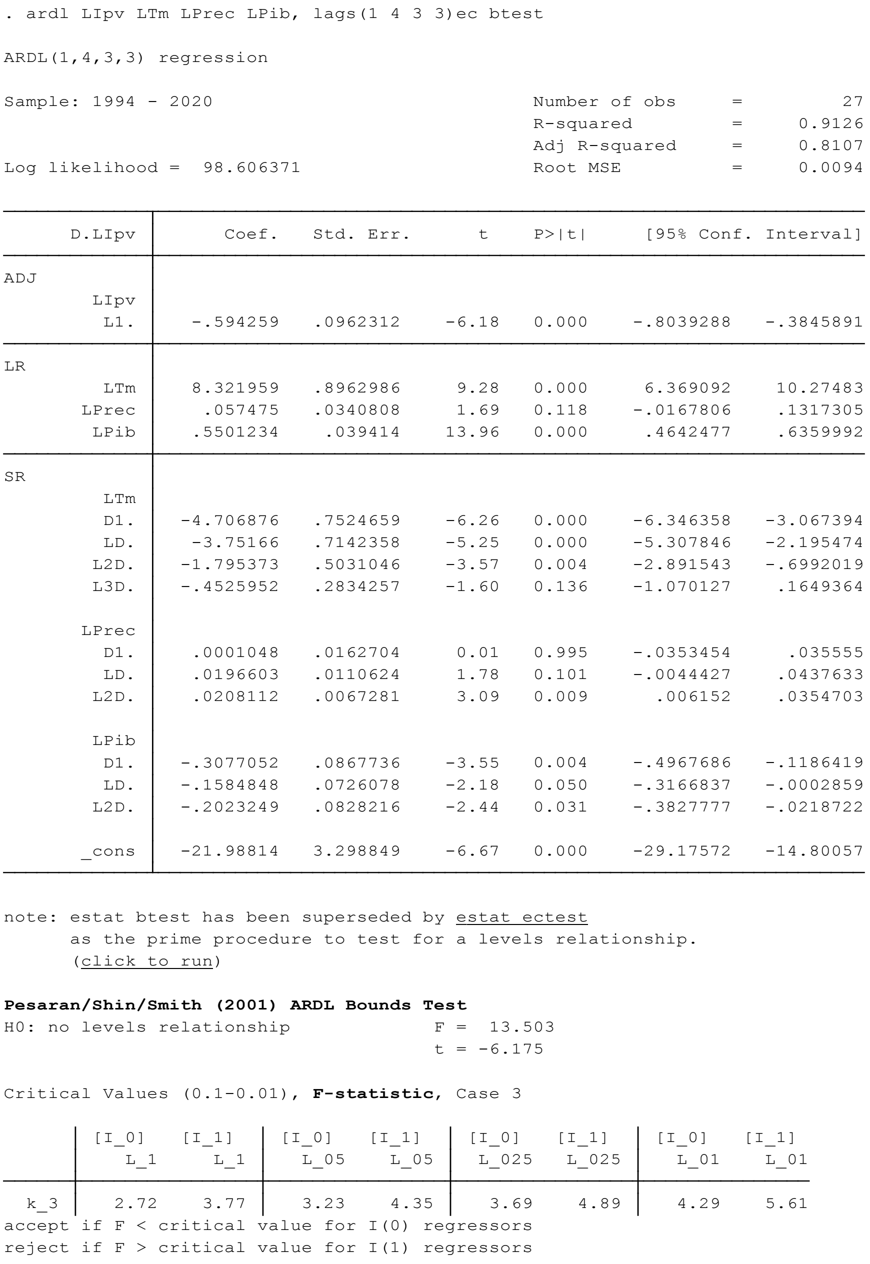
Appendices

Results of the estimation and Bounds test on Stata 15.



```
. ardl LIpv LTm LPrec LPib, lags(1 4 3 3)ec btest

ARDL(1,4,3,3) regression

Sample: 1994 - 2020                              Number of obs     =         27
                                                 R-squared         =     0.9126
                                                 Adj R-squared     =     0.8107
Log likelihood =  98.606371                      Root MSE          =     0.0094

------------------------------------------------------------------------------
      D.LIpv |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
ADJ          |
        LIpv |
         L1. |   -.594259   .0962312    -6.18   0.000    -.8039288   -.3845891
-------------+----------------------------------------------------------------
LR           |
         LTm |   8.321959   .8962986     9.28   0.000     6.369092    10.27483
       LPrec |    .057475   .0340808     1.69   0.118    -.0167806    .1317305
        LPib |   .5501234    .039414    13.96   0.000     .4642477    .6359992
-------------+----------------------------------------------------------------
SR           |
         LTm |
         D1. |  -4.706876   .7524659    -6.26   0.000    -6.346358   -3.067394
         LD. |   -3.75166   .7142358    -5.25   0.000    -5.307846   -2.195474
        L2D. |  -1.795373   .5031046    -3.57   0.004    -2.891543   -.6992019
        L3D. |  -.4525952   .2834257    -1.60   0.136    -1.070127    .1649364
             |
       LPrec |
         D1. |   .0001048   .0162704     0.01   0.995    -.0353454     .035555
         LD. |   .0196603   .0110624     1.78   0.101    -.0044427    .0437633
        L2D. |   .0208112   .0067281     3.09   0.009      .006152    .0354703
             |
        LPib |
         D1. |  -.3077052   .0867736    -3.55   0.004    -.4967686   -.1186419
         LD. |  -.1584848   .0726078    -2.18   0.050    -.3166837   -.0002859
        L2D. |  -.2023249   .0828216    -2.44   0.031    -.3827777   -.0218722
             |
       _cons |  -21.98814   3.298849    -6.67   0.000    -29.17572   -14.80057
------------------------------------------------------------------------------

note: estat btest has been superseded by estat ectest
      as the prime procedure to test for a levels relationship.
      (click to run)

Pesaran/Shin/Smith (2001) ARDL Bounds Test
H0: no levels relationship                    F =  13.503
                                              t = -6.175

Critical Values (0.1-0.01), F-statistic, Case 3

      | [I_0]   [I_1] | [I_0]   [I_1] | [I_0]   [I_1] | [I_0]   [I_1]
      |   L_1     L_1 |  L_05    L_05 | L_025   L_025 |  L_01    L_01
------+---------------+---------------+---------------+--------------
  k_3 |  2.72    3.77 |  3.23    4.35 |  3.69    4.89 |  4.29    5.61
accept if F < critical value for I(0) regressors
reject if F > critical value for I(1) regressors
```