Climate variability and macroeconomic output in Ethiopia : the analysis of nexus and impact via asymmetric autoregressive distributive lag cointegration method

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Title: Climate variability and macroeconomic output in Ethiopia: The analysis of nexus and impact via asymmetric autoregressive distributive lag cointegration method

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Abstract

Ethiopia showed a rapid, yet, a none resilient economic growth much threatened by climate variability. In Ethiopia, the adverse effects of climate variability are stipulated among the significant factors constraining its economic development. There are relatively few studies about the adverse effects of climate variability on the Ethiopian macroeconomy. In this context, little is known about the exact effects of the ongoing climate variability on Ethiopian macro-economic growth. This study intends to examine whether climate variability factors, for instance rainfall and temperature, have an effect on the macroeconomic output of Ethiopia. An asymmetric autoregressive distributive lag cointegration method is used to investigate time-series data for the years 1950–2014. Diagnostic tests show the relevance of the applied method and robustness of our results. The study finds climate variability affects Ethiopia's economic growth in the long-run. Rainfall and temperature fluctuation induce significant negative impacts. A percentage annual temperature variability for instance decreases the Ethiopian annual gross domestic yield (GDP) up to 4.5 percent. In the short run, climate variability particularly rainfall and temperature changes also have a profound effect on Ethiopia's economic output. Within such confirmed climate change impacts, Ethiopia should carry out more on adapting and mitigating the impacts as it is presented on its climate resilient economic growth policies and strategies. In spite of the policy contribution of the results, the study will motivate further research and will also serve as a benchmark for the coming Ethiopian studies.

Keywords*:* Economic output, Ethiopia, NARDL, rainfall, temperature

JEL classification codes: O10; Q54

1. Introduction

A resilient economic growth is the backbone of an economy's development. It remains the most pertinent strategic agenda for policymakers (Abdullah 2012). It is additionally seen as the fundamental need for developing nations, and a prerequisite for reduction of absolute poverty and continued increases in living standards and reinforced social cohesion (World Bank 2012).

From the existing literature, conclusions can be drawn that Ethiopia has made significant progress in economic growth and development in the past two decades (GGGI 2015; Donnenfeld et al. 2017; Jayapregasham et al. 2018; Yishak 2019; World Bank 2020). The steady economic growth brought poverty reduction and incredible progress towards major development indicators. The specific positive changes in economic and social development include increased life expectancy, reductions in income poverty and malnutrition, increased school enrolments, and expanded access to health services, freshwater, and improved sanitation (Donnenfeld et al. 2017; Jayapregasham et al. 2018; WFP 2020). In fact, the progress which Ethiopia achieved is a relative comparison of its state before the end of the 1990s regardless of the comparison with other developing countries.

Despite its economic development progress, Ethiopia maintains at the lowest levels of global development indices and lags behind other developing countries (Donnenfeld et al. 2017). In accordance with the United Nations Development Program's (UNDP) 2020 Human Development Indicator (HDI), Ethiopia's HDI value for 2019 is 0.485, which put the country in the low human development category, positioning it at 173 out of 189 countries and territories (UNDP 2020). Ethiopia also maintains some of the lowest levels of access to basic services of any country in the world. Ethiopia was ranked 174th (out of 186 countries) in terms of access to clean water, and 161st in terms of access to improved sanitation. The country has one of the lowest primary education survival rates in the world; nearly half of all students who begin primary school do not reach Grade 8. Lastly, Ethiopia is largely an agrarian society, with close to 70% of the labor force involved in the agricultural sector, primarily as subsistence farmers, making a large proportion of the population vulnerable to climate-related shocks (Yishak 2019).

Ethiopia's economic system has faced many shocks during the last 60 years, although the nation has realized optimistic economic progress since 2006. The descending and unsustainable pattern of economic progress in Ethiopia has been reviewed by many worldwide studies and reports such as by the United Nations as well as World Bank. These reports show that Ethiopia experienced periods of economic expansion commencing as of the end of 1990s with almost no change in poverty incidence. Economic growth rates in Ethiopia are yet very low. The nation also faces significant constraints such as pronounced poverty level and backward worldwide economic integration. Ethiopia is also a low-income country, and its historical past of economic growth is erratic (World Bank 2012; UNDP 2010, 2011, 2015, 2020).

Several challenges remain for Ethiopia's development to be lagging behind other developing countries and the observed shocks. According to (World Bank (2015), some of these are; limited competitiveness of the economy, underdeveloped private sector, and poor resilience to shocks such as climate variability. Climate variability is a major development challenge to Ethiopia. Climate change is expected to adversely affect all economic sectors, eco-regions, and social groups. Agriculture is one of the most vulnerable sectors as it is highly dependent on rainfall (Radeny et al. 2015; WFP 2020).

As stated in IPCC (2014), over the coming century, anthropogenic climate change is likely to have severe impacts on both national economies and individual livelihoods in developing countries such as Ethiopia. Ethiopia's economic development is mainly at risk to climate change and variability because of its greater reliance on climate-sensitive economic sectors such as agriculture (IFAD 2016; Mekuyie and Mulu 2021). Based on GGGI (2015), climate change could put Ethiopia's vision of reaching middle-income status at risk, in the worst-case scenario, the negative impact on GDP could be a reduction up to 10% or more by 2050 (World Bank 2010).

Figuring out the nations' economic growth pattern is of high interest in both development economics and economic theory. This relates to a dynamic empirical issue. In this regard, economic theory provides convenient guidance, useful for identifying, studying, and decoding the growth characteristics of developing nations such as Ethiopia (M'Amanja and Morrissey 2006). Within economic theory, Ethiopia's lingering behind in economic development has been featured as the concern of various parties. Accordingly, there arises a renewed interest in understanding the main factors driving the circumscribed economic growth and output in Ethiopia, such as the ongoing climate change.

The study by the Ethiopian Panel on Climate Change and authored by Tesfaye et al. (2015) reported that climate change is a common phenomenon in Ethiopia. Over the past 50 years, the country's annual temperature is increasing by about 0.37˚C whereas the rainfall has no clear trend and there is high variability with the rising frequency of floods and droughts. The study also reported climate change projection until 2090. Thus, there will be temperature increments by 2.2°C and 3.3°C in 2050 and 2090 respectively, but the rainfall trend is uncertain. Such erratic projections imply that Ethiopia is vulnerable to adverse effects from climate variablity due to the sensitivity of its socio-economic systems (GGGI 2015; Tesfaye et al. 2015; Yalew et al. 2016).

Pursuant to Gebreegziabher et al. (2016) understanding the potential economy-wide impacts of climate change for a given country is critical both in designing national adaptation strategies as well as formulating effective global climate policy agreements. While there has been a paramaount interest of investigating about climate change impacts, only a small share of earlier studies focus on the economic wide impacts of climate change over Ethiopia. Most of the earlier studies such as by Deressa et al. 2008; Deressa and Hassan 2009; Deressa et al. 2011; Muluneh et al. 2015; Alemayehu and Bewket 2016; Tadese and Alemayehu 2017 focused on some specific economic sectors such as agriculture, the livelihood of people, health, and climate adaptation strategies (Mekuyie and Mulu 2021).

Despite the importance of the subject, there exists only limited literature assessing the biophysical and economic impacts of climate change in Ethiopia (Yalew 2016). The limitation of such studies is not only in availability but also in modeling techniques and the data type they used. Most of the previous studies were based on cross-sectional household survey data than nationwide climate and economic data. Moreover, those few studies conducted over the past decades in Ethiopia have reported mixed relationships with climate change and economic progress.

In order to overcome such a research gap and explicate how Ethiopia's economic growth is affected by the ongoing climate variability, we have undertaken a study using advanced and robust modeling techniques and nationwide representative time series data. The main objective of this study is to offer research evidence on the potential economy-wide impacts of climate variability overall in Ethiopia using an asymmetric autoregressive distributive lag cointegration method.

The purpose of our study is to strengthen the limited existing research by examining climate variability impacts on the macroeconomic output of Ethiopia. Our study is the first of its kind applying nonlinear autoregressive distributive lag (NARDL) cointegration technique using time-series data of 65 years.

The following sections of this study present literature review (Section 2), materials and methods (Section 3), empirical results and discussion (Section 4), policy and managerial implications (Section 5), and the conclusion (Section 6).

2. Literature review

There are vast economic studies who have analyzed economic growth and the determinant factors. These studies have identified part of factors, with empirical and theoretical treatment, that would influence any country's economic growth. Unique emphasis has been laid upon the factors that have been popularized by growth models, such as capital, technology, labor, and their related indicators (Abdullah 2012).

Developing realization of the conceivable economic consequence derived by climate change has drawn the attention of policymakers. For example, the Intergovernmental Panel on Climate Change (IPCC) and various research groups have perceived that climate change is not only an environmental quandary, but also it is liable to have drastic effects on economic activity in the long-term (Kato et al. 2013). Economists and climate scientists have made use of the latest model-based projections of changes in climate factors and brought results ranging from rich negative influences to modest influences at global scale perspective (see, e.g., Nordhaus and Boyer 2000; Fankhauser and Tol 2005; Nordhaus 2006).

The economic enquiry of climate variability and its impact on economic growth is a relatively new approach, and a subject with highest attention (Abidoye and Odusola 2015). Despite many scholars have studied climate variability and its association with the micro-economy (e.g., Di-Falco and Veronesi 2013; Van Passel, Massetti, and Mendelsohn 2017), the relationships between climate change and macroeconomic growth are less studied. The few studies that have mentioned climate variability and its consequence on macroeconomic development are those by Nordhaus (2006), Dell et al., (2012), Abidoye and Odusola (2015), and Burke et al., (2015).

A leading study that researched the potential effects induced by climate changeability on the worldwide economy is by Dell et al., (2012). Their primary outcome indicated a pronounced negative impact of higher temperatures on growth of less developed nations. Notably, they observed that a 1°C rise in temperature in a specified year diminishes economic growth in that year by around 1.1 percent. In wealthy countries, alterations in temperature have been observed to have no discernible outcome on economic growth; likewise, changes in precipitation have not any real results on economic growth of poor or rich nations. The authors concluded that temperature raises reduce economic growth of poverty-stricken countries by 0.6 to 2.9 percent rate.

In studying the empirical association among economic growth and climate variability in Africa, Abidoye and Odusola (2015) used yearly data of 34 African countries from 1961–2009. Their finding indicated that a 1°C increase in temperature results in a 0.27 percent reduction in GDP growth.

Using Burke, Hsiang, and Miguel’s (2015) background, Lee, Villaruel, and Gaspar (2016) investigated the nonlinear reaction of economic development due to notable temperature and rainfall fluctuations. They concluded that with the exception of agricultural yield, the rising temperature significantly affects overall economic productivity. They also anticipated the overall economic productiveness of growing Asian countries might be at least 10 percentage lower by 2100. Akram (2012) scrutinized the economic influences endured by climate change for selected Asian countries for the duration of 1972–2009. Their investigation uncovered that economic growth is adversely influenced by temperature, precipitation, and population growth changes, while urbanization and human development motivate economic growth.

In Ethiopia, the few nation and economy-wide analytical studies performed about economic consequence derived by climate change (variability) are by Remarkably, Grey and Sadoff (2007); Senay and Singh (2008); and Ali (2012). Remarkably, Grey and Sadoff (2007) used an economy-wide model and determined that drought and flood impacts on Ethiopia weakened economic growth by greater than a third. Cheung, Senay, and Singh (2008) undertook a climate's economic impact study in Ethiopia and found that climatic shocks considerably bring down growth rates. Ali (2012) studied the cost of rainfall variability in Ethiopian economic growth applying a co-integration analysis. His findings indicated that rainfall variability fluctuation negatively affects Ethiopian economic growth, while change in rainfall magnitude and variability has a long-term drag influence.

The primary focus of our literature survey, such as the one we presented above was to review nation and economy-wide studies on the impacts of climate change for Ethiopia. With respect to this purpose, we evaluated the available studies in terms of methodological, geographical, sectoral scope, and the unit of analysis. In the course of this activity, we came to the following conclusion. To the best of our literature survey, nation and economy-wide studies on the impacts of climate variability for Ethiopia are scanty. If available, most of the studies are those which either are purely about climate science or focusing on the effects of climate change on agriculture in general and crop production in particular. These studies also undertake households as a unit of analysis than the macro perspective of the whole country. In this regard, while climate change might be expected to have nationwide effects, often the interest of the available studies is on the household or micro-level representation (Gebreegziabher et al. 2016). The majority of these studies are also engaged micro-economic analyses conducted using cross-sectional data and did no longer demonstrate the climate change influences on the entire economy.

With the aforementioned gaps, the old and recent studies we reviewed for Ethiopia consist of those by Deressa et al. 2008; Deressa and Hassan 2009; Admassu et al. 2013; Aragie 2013; Müller et al. 2014; Waha et al. 2013; Yalew et al. 2016; and Tadese and Alemayehu 2017.

With respect to methodological approaches, the available Ethiopian studies had used either a Ricardian or a dynamic computable general equilibrium (CGE) model which mostly relies on cross-sectional or future projected data. Good examples are studies by Deressa and Hassan, 2009; Mideksa 2010; Ferede et al. 2013; and Gebreegziabher et al. 2013. Unfortunately, the Ricardian approach is a highly criticized approach for assuming perfect autonomous adaptation and adjustment in farming decisions and implementations; Which is hardly possible in reality at least in the Ethiopian context (Yalew 2016). In the same vein, the CGE model needs very certain projections of the climate variability, and if we will use uncertainly projected climate data, the results of the model will be biased and very difficult to distinguish whether the economic losses are due to socio-economic changes or climate change. Thus, Ethiopian studies which used CGE are criticized to use uncertain projections, and so, the results are not reliable.

The novelty of our study is therefore on accounting for such gaps of the previous studies and looking for reliable results. We broadened the present study to macro-level representing the whole nation. We also applied the best available econometric technique, the non-linear asymmetric autoregressive distributive lag cointegration method, which helped us to discover the best and reliable findings regarding climate variability and macroeconomic output interactions in Ethiopia.

3. Materials and Methods

3.1. Theoretical background

To investigate the association among climate variability and economic output in Ethiopia, we begin with the Solow–Swan's neo-classical growth model, which was originally developed in 1956 and is designated in terms of traditional inputs, for instance labor and capital. Dell, Jones, and Olken (2009), Ali (2012), and Abidoye and Odusola (2015) consolidated climatic variables in the Solow–Swan model of their version. The application of this model offered them a theoretical bench mark for incorporating climate variability in growth equations. They also recommended the procedures of decomposing the consequence of climate changes on economic growth.

The Solow–Swan (1956) fundamental model considers two variables: labor and physical capital. Assuming that economic agents mix labor and capital to in producing an output, the economy-wide production model is given as follows:

$$Y = AK^{\alpha}L^{\beta} \tag{1}$$

where: Y = output, K = capital, L = labor, A = total factor productivity (a variable containing technology), and α and β are the capital and labor elasticity of output, respectively.

Consistent with Ali (2012), we assumed that technology A grows at a constant rate of g according to $A = A_0e^{gt}$. The constant A_0 represents country specific factors such as resource endowment, institutions, and climate. However, if at least one segments of the components that are incorporated into this parameter are not consistent over a long period, they ought to become part of the dynamic production function. Accordingly, we explicitly model climate variability by including temperature and precipitation, assuming a growth-drag effect:

$$A(t) = \Omega T(t)^{\sigma}R(t)^{\delta} \tag{2}$$

Where Ω is a time-invariant constant, T is temperature, and R is precipitation (rainfall). Substituting equation 2 into equation 1, we get:

$$\mathrm{Y(t)} = \Omega T(t)^{\sigma}R(t)^{\delta}K(t)^{\alpha}L(t)^{\beta} \tag{3}$$

For the purpose of empirical simplicity, we make logarithm conversion of equation (3), and we use β for all coefficients:

$$lnY_t = \beta_0 + \beta_1 lnT_t + \beta_2 \ln R_t + \beta_3 lnK_t + \beta_4 lnL_t + \varepsilon_t \quad (4)$$

Where Y is the level of per-capita income (or real per-capita GDP) derived by dividing it by the population and obtaining the series in per-capita terms; K is the physical capital measured by gross fixed capital formation (at constant USD prices in 2011); L is the labor force measured by number of employees (number of persons engaged in the workforce); T is a climatic variable measured as the average annual temperature; R is a climatic variable measured as the average annual rainfall; and ε is the random error term. The definition of these variables are presented in Table 1 and their derivation is adapted from the study of Dell et al.,(2012).

3.2. Description of the study area, data and estimation strategy

This study is undertaken in Ethiopia, a Sub-Saharan African country. Ethiopia is located at 3 degree and 14.8 degree latitude, 33 degree and 48 degree longitude in the Eastern part of Africa laying between the Equator and the Tropic of Cancer. It is bounded on the Northeast by Eritrea and Djibouti, on the east and Southeast by Somalia, on the south by Kenya and on the west and Northwest by Sudan.

Place Map 1 here

Regarding data use, we utilized yearly time-series data of Ethiopia collected from 1950–2014. Data on GDP (in constant 2011 USD) and capital stock in 2011 national prices was acquired from Penn World PWT 9.0 files organized by Feenstra, et al (2015). Climate data, specifically precipitation and temperature data, were acquired from World Bank database issued in its website in 2016. The variables represent the real GDP per capita, labor force, capital stock, precipitation, and temperature; their descriptive statistics are revised in Table 1.

Place Table 1 here

An autoregressive-distributed-lag (ARDL) cointegration technique familiarized by Pesaran and Shin (1998) is used for estimating our growth model presented in equation 4. It has three favorable advantages than the past and traditional cointegration methods. Initially, it does not need the factors in the model to be integrated in the same order, and it can be applied when the principal regressors are integrated at order one, order zero, or fractionally. Thus, it avoids issues related the degree of integration. Second, ARDL is comparatively more effective when there is limited sample sizes of the database. Third, by using the ARDL technique we can attain unbiased result of the long-term model. Overall, the ARDL technique is robust for time series data analysis than other classical techniques. On the other hand, ARDL models is criticised for panel data while there is the presence of a stochastic (random) trend in the data. As long we are relying on time series data we will apply the ARDL technique cognisant of the above advantages. To apply this method to our study, equation 5 is formulated as follows:

$$\Delta \ln Y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta \ln Y_{t-i} + \sum_{i=1}^{p} \alpha_{2i} \Delta \ln T_{t-i} + \sum_{i=1}^{p} \alpha_{3i} \Delta \ln R_{t-i} + \sum_{i=1}^{p} \alpha_{4i} \Delta \ln K_{t-i} + \sum_{i=1}^{p} \alpha_{5i} \Delta \ln L_{t-i}$$
$$+ \beta_1 \ln Y_{t-1} + \beta_2 \ln T_{t-1} + \beta_3 \ln R_{t-1} + \beta_4 \ln K_{t-1} + \beta_5 \ln L_{t-1} + \varepsilon_t \quad (5)$$

Where Δ denotes the first difference operator, α_0 represents the drift component, ε_t is the white noise, p is best (optimal) lag residuals, α_s is the short-term impact of regressors in the model, and βs is long-term elasticities.

According to by Pesaran and Shin (1998), in the application of an ARDL cointegration testing there are three phases. First, the F-test is used to define the occurrence of cointegration association among the regressors. At the point when long-term relationships exist between the regressors, estimation of the short-term and long-term parameters can be accomplished. The long-term estimation coefficients are outlined by the ARDL approach, while the short-term parameter can be realized by estimating the error correction model. The adjustment coefficient in the model specifies speed of adjustment needed to return to balance. Thus, the general error correction models are specified as follows in equation 6:

$$\Delta \ln \mathrm{Y}_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta \ln \mathrm{Y}_{t-i} + \sum_{i=1}^{p} \alpha_{2i} \Delta \ln \mathrm{T}_{t-i} + \sum_{i=1}^{p} \alpha_{3i} \Delta \ln \mathrm{R}_{t-i} + \sum_{i=1}^{p} \alpha_{4i} \Delta \ln \mathrm{K}_{t-i} + \sum_{i=1}^{p} \alpha_{5i} \Delta \ln \mathrm{L}_{t-i} + \lambda \mathrm{ECM}_{t-1} + u_t \quad (6)$$

Where λ is the speed of regulation in parameters and ECM is the residual taken from equation 5.

Whereas the typical ARDL models indicated in equations 5 and 6 allow evaluation of the long-term relations between time-series regressors, they only help the assessment of linear or symmetric relations. Subsequently, it is expected that macroeconomic factors for instance climate factors have symmetric (linear) effects on economic growth. However, investigation of nonlinearity or asymmetry is essential because climate regressors such as temperature and rainfall have an asymmetric nature and relation with macroeconomic factors such as economic growth, agricultural productivity, and crop production (Burke, Hsiang, and Miguel 2015; Fezzi and Bateman 2015; Nsabimana and Habimana 2017; Cheah, Yiew, and Ng 2017).

When an asymmetric relation is anticipated, a nonlinear (asymmetric) ARDL model is prescribed to model our data and demonstrate the long-term as well as short-term relations. In this way, we followed the NARDL technique created by Shin etal. (2014) as an asymmetric expansion of the standard ARDL model. The NARDL model is intended to catch each short and long-term asymmetries in a regressor of interest concurrently with booking all merits of the traditional ARDL approach (Cheah, Yiew, and Ng 2017). In view of Shin etal. (2014), the initial phase in the asymmetric cointegrating relationship under the NARDL method is to disintegrate the exogenous factors in equations 5 and 6 into partial sum processes, as follows:

$$\mathrm{Y}_t = \beta^+ X_t^+ + \beta^- X_t^- + \mu_t \quad (7)$$

Where Y_t represents a $k \times 1$ vector of our dependent regressor (Y) at time t; X_t is a $k \times 1$ vector of multiple exogenous regressors decomposed as $X_t = X^+$ and X^-; μ_t is the error term; and β^+ and β^- denote associated asymmetric long-term parameters, indicating that X responds asymmetrically during an up and down fluctuating outcomes. By using a partial sum process, we can explain the increase (X^+) and decrease (X^-) in our exogenous regressors as follows:

$$\ln Y_t = \beta_0 + \beta_1 \ln T_t^+ + \beta_2 \ln T_t^- + \beta_3 \ln R_t^+ + \beta_4 \ln R_t^- + \beta_5 \ln K_t^+ + \beta_6 \ln K_t^- + \beta_7 \ln L_t^+ + \beta_8 \ln L_t^- + \mu_t \quad (8)$$

Finally, introducing equation 8 to equation 5 leads to the following NARDL model with long-term and short-term asymmetries:

$$\begin{aligned}\Delta \ln Y_t &= \alpha_0 + \alpha_1 \ln Y_{t-1} + \beta_1 \ln T_{t-1}^+ + \beta_2 \ln T_{t-1}^- + \beta_3 \ln R_{t-1}^+ + \beta_4 \ln R_{t-1}^- + \beta_5 \ln K_{t-1}^+ + \beta_6 \ln K_{t-1}^- \\ &+ \beta_7 \ln L_{t-1}^+ + \beta_8 \ln L_{t-1}^- + \sum_{i=1}^{p} \kappa_i \Delta \ln Y_{t-i} + \sum_{i=1}^{p} (\phi_i^+ \Delta \ln T_{t-1}^+ + \phi_i^- \Delta \ln T_{t-1}^-) + \sum_{i=1}^{p} (\tau_i^+ \Delta \ln R_{t-1}^+ + \tau_i^- \Delta \ln R_{t-1}^-) \\ &+ \sum_{i=1}^{p} (\pi_i^+ \Delta \ln K_{t-1}^+ + \pi_i^- \Delta \ln K_{t-1}^-) + \sum_{i=1}^{p} (\psi_i^+ \Delta \ln L_{t-1}^+ + \psi_i^- \Delta \ln L_{t-1}^-) + \varepsilon_t \quad (9)\end{aligned}$$

In view of the survey of theoretical literature for linearity, we decide upon the most suitable NARDL model that matches our data. We accordingly estimate the next new NARDL model with asymmetry enforced on the long-term impact of rainfall, temperature, capital, and labor force on economic output. The deliberation of the unrestricted trend and constant is shown in equation 10:

$$\begin{aligned}\Delta \ln Y_t &= \alpha_0 + \xi Tr + \alpha_1 \ln Y_{t-1} + \beta_1 \ln T_{t-1}^+ + \beta_2 \ln T_{t-1}^- + \beta_3 \ln R_{t-1}^+ + \beta_4 \ln R_{t-1}^- + \beta_5 \ln K_{t-1}^+ + \beta_6 \ln K_{t-1}^- \\ &+ \beta_7 \ln L_{t-1}^+ + \beta_8 \ln L_{t-1}^- + \sum_{i=1}^{p} \kappa_i \Delta \ln Y_{t-i} + \sum_{i=1}^{p} (\phi_i^+ \Delta \ln T_{t-1}^+ + \phi_i^- \Delta \ln T_{t-1}^-) + \sum_{i=1}^{p} (\tau_i^+ \Delta \ln R_{t-1}^+ + \tau_i^- \Delta \ln R_{t-1}^-) \\ &+ \sum_{i=1}^{p} (\pi_i^+ \Delta \ln K_{t-1}^+ + \pi_i^- \Delta \ln K_{t-1}^-) + \sum_{i=1}^{p} (\psi_i^+ \Delta \ln L_{t-1}^+ + \psi_i^- \Delta \ln L_{t-1}^-) + \varepsilon_t \quad (10)\end{aligned}$$

According to Pesaran et al. (2001), unit root testing can be executed to guarantee that all regressors introduced in the equation are not integrated at order two that is, I(2) to evade spurious results. In the event of I(2) regressors presence, ARDL outputs make no sense. When we identified order two integrated regressors, the Pesaran, Shin, and Smith (2001) F statistics is not interpreted.

As a result, running unit root tests continues to be vital to ascertain that no regressor is integrated into I(2) or beyond. This study used state-of-the-art unit root testing methods, such as Ng–Perron, Clement–Montanes–Reyes, and Zivot–Andrews, to inspect the integration order (Perron 2017).

We conclude this section by informing that among the series of equations we formulated, we will use equation (10) to be estimated with the NARDL approach. All unit root testing and NARDL modeling were undertaken using EViews 10 and Stata version 15 statistical software.

4. Results and discussion

4.1. Empirical examination and statistical validity

The unit root assessment presented in Table A1 demonstrate that every time series regressors inclusive of the dependent in the investigation are integrated at the same order I(1), except for the regressor annual rainfall (lnR), which is stationary at level I(0). Consequently, the NARDL is applicable for the cointegration analysis of the model. In addition, none of the series are staying to be above I(1), further confirming that the NARDL approach is relevant to this study.

We employed the Akaike Information Criterion (AIC) to suggest a suitable lag length in capturing the dynamic relationships in the NARDL system. Lütkepohl (2006) reasoned that AIC has admirable predictive properties when the data sample is small. When applying the NARDL technique, a lag period of 2 for the dependent (lnY), and of 4 for the exclusive regressors, is suggested by the AIC. Subsequent to estimating the NARDL model, we initially exhibited the asymmetric cointegration test result as a yardstick of our analysis. The empirical outcomes of the cointegration test statistics are revealed in Table A2 in the appendix.

The F-statistic estimate of 5.45 is exceeding the 5 percent upper-bound critical value (4.57), signifying abandonment of the null hypothesis postulating no long-term relationship at the 5 percent significance level when real GDP is engaged as the dependent regressor. This analytical finding ends in the realization that a long-term nonlinear relationship between real GDP, temperature, rainfall, and the remaining factors survives for the time of 1950–2014 in Ethiopia. This

Declaring the foundation of long-term cointegration among the factors, we realized asymmetries among the paired regressors in short and long-run. The asymmetry test results for the four sets are presented in the appendix (Table-A3). Regarding the relation between rainfall and real GDP, we perceive that the null hypotheses of long- and short-term symmetries are repudiated; promoting the opportunity of using NARDL when long- and short-term asymmetry appeared. The asymmetric link between temperature and real GDP is also detected in long and short-term durations. Thus, we can demonstrate the opportunity of the usage of NARDL in the occurrence of long and short-term asymmetry. Regarding the capital stock-real GDP link, we had been not able to reject hypothesis of none long- and short-term symmetries; Therefore, a symmetric ARDL model is considered for explanation of the relations of the two regressors. As to the labor force, an asymmetric link with real GDP is discovered only at short run, inferring the opportunity of using NARDL for at least the short-term case.

The result of the error (equilibrium) correction term (ECT) is calculated and used to see the speed at which earlier variations from the equilibrium are corrected in the current period. ECT gives reaction whereby short-term dynamics converge to the long-term equilibrium path in the model with reasonable speed of adjustment. The guideline behind ECT is that a positive coefficient demonstrates a disparity, while a negative coefficient designates convergence. For this reason, a negative coefficient and a statistically significant ECT are obligatory in order to comprehend the long-term relation between regressors (Banerjee, Dolado, and Mestre, 1998). For our study, both the long-term cointegration and short-term statistical requirements are established affirming the adequacy of the NARDL approach for our analysis. This allows us to estimate the nonlinear (asymmetric) long- and short-term elasticity coefficients, as indicated in Tables 2 and 3.

To ratify consistency of the results and robustness of the models, regression diagnostic tests were conducted, as shown in Table A4 in the appendix. The estimated results of the serial correlation test of the residual show that it does not appear among the variables of the model. Normality based on the Jarque-Bera (1980) test reveals that the time-series data of all variables are normally distributed at a 5 percent significance assumption. The test results also showed no problem with heteroskedasticity, and the nonlinearity of an error term is approved. These statistical validity tests and the required findings will help us present our results and discuss them.

4.2. Results

In view of the results in Table 2, the long-term coefficient of the upward adjusting (increasing) annual rainfall (R^+) influences the Ethiopian yearly GDP increase, while the downward adjusting (decreasing) annual rainfall (R^-) has no statistical paramountcy. The long-term coefficient of the positive part (upward) yearly rainfall change is 0.35, statistically significant at 10 percent. Relating to the link between rising and declining temperature variability (T^+ and T^-) and real GDP, we distinguish a long-run asymmetric association. The documented relations are both negative with a statistical significance of 5 percent and 1 percent. The long-run coefficients of the positive and negative (upward and downward) changes of annual temperature variability (T^+ and T^-) are -3.88 and -4.890. Our results regarding the effect of temperature is consistent with what was found by Dell et al., (2012), Cheung, Senay, and Singh (2008). On the other hand, Ali's (2012) findings regarding the effect of rainfall is in support of our finding.

All results concerning capital stock are insignificant for positive along with negative changes (K^+ and K^-), showing that capital stock changes have a symmetric long-run effect on

Ethiopia's GDP, rather than the assumed nonlinear relationship. Regarding the nexus between rising and declining labor changes (L^+ and L^-) and real GDP, we did not notice a long-term asymmetric relationship.

Insert Table 2 near here

About the short-run effects, our results in Table 3 corroborate the presence of asymmetry (nonlinearity) for the rainfall, temperature, and labor force equations. Besides, the ECT is negative, as anticipated, and the adjustment speed is 128 percent at 1 percent statistical significance. This shows any deviation from the long-term disequilibrium between variables is adjusted and corrected at high speed (at 128 percent) in less than one year.

In relation to the short-term asymmetric properties, we detected that a right away increase in rainfall (the upward positive shock in its lag of 2, R^+_{t-2}) contributes to real GDP decline. The enforcement of this effect is when positive rainfall (R^+_{t-2}) increases by 1 percent equated to the 2012 pattern, real GDP declines by 0.44 percent. The converse can be seen when there occurs an immediate drop in rainfall in lag terms 2 and 3 (□R^-_{t-2} and□R^-_{t-3}). When there is a 1 percent decrease in rainfall compared to 2011 and 2012 patterns, it leads to a real GDP increase of 5.8 and 5.3 percent.

With respect to the short-term influence of temperature, a prompt increment (positive shock) conveys a positive change in real GDP, and a quick decline (negative shock) makes a reduction in the country's real GDP, both at a statistical significance of about 1 percent. The estimated coefficient of the lagged positive shock of temperature is about 4.5 percent in its lag of 2 or 3. This infers that a 1 percent instant increase in temperature prompts to a 4.5 percent increase in real GDP. Contrariwise, a 1 percent immediate decline in temperature prompts to a 2.6–4 percent reduction of short run real GDP. The non-weather regressor, labor force, is also found to meaningfully affect real short run GDP. When the once-lagged labor force increases by 1 percent, real GDP increases by almost 3.08 percent.

The structural break analysis for our NARDL model is not like the classical treatment (Shin et al. 2014). Therefore, the main objective of using or inserting the time variable is to restructure the trends observed in the series, and thus to simulate years that had structural breaks. Here the time variable from (1961-2011) is directly inserted in to the stata software. We call it this inserted variable as time dummy variable. Thus, the time variable was utilized to reenact the trends observed in the series, and the dummy variable to simulate years that had structural breaks. The predicted coefficient for the trend variable is highly significant at almost the 1 percent level. This signifies that our consideration of trend in the short-term functional model was binding. Nevertheless, the structural brake dummy was found insignificant in the short-run.

Insert Table 3 near here

As the last phase of our analytical result, we inferred aggregate impacts of the asymmetric independent variables on real GDP. The results regarding the short- and long-term asymmetry can be demonstrated by using a cumulative dynamic multipliers graph, as shown in Figures 1 and 2.

Figure 1 clarifies the shape of the cumulative dynamics of real GDP (output change) regarding a percentage increase (decrease) in one of our weather variability indicators, annual rainfall. The rainfall cumulative multiplier shows that both the positive and negative dynamic changes have an asymmetric short and long-run effect, portrayed by the fact that the difference line that does not stay on zero over the 60 years. Moreover, positive and negative changes showed positive effect on GDP, while more impact is produced by the positive change, as presented in Figure 1. The effects terminate immediately and new equilibrium is achieved after almost nine years.

Insert Figure 1 about here

Concerning the dynamic effects of positive as well as negative variations in annual temperature on economic output, both changes have a very short duration of positively affecting economic output. After year one, joint positive and negative variations show a short and long-run negative effect. Their influence almost commences to be neutral after year 9, and moves with the new long-term equilibrium.

Place Figure 2 here

4.3. Discussion

The estimated result regarding rainfall indicates that, in the long-run, a percentage increase of an increasing annual rainfall variability (R^+) makes the Ethiopian annual GDP increase by 0.35 percent asymmetrically. The simulated result also gave us a general impression that when annual rainfall rises and falls, economic output responds immediately; however, a positive change in the same variable would have stronger consequences than a negative change in the long-run. This result has something to tell that drought mitigation is important in all meanness to maintain the required amount of rain fall, and as a result GDP will not be affected rather will show improvement. The result also signals how Ethiopia economy will stay rain fed, unless some other production ways such as modern irrigation are devised.

In relation to temperature effects, we are able to see that in the long-run, a percentage rise in upward annual temperature variability (T^+) makes the Ethiopian annual GDP decline by 3.88 percent asymmetrically, and a downward annual temperature variability (T^-) also makes the Ethiopian annual GDP decline by 4.89 percent asymmetrically. Thus, we can see that the Ethiopian economy is extremely delicate to smaller changes in temperature in both the rising and descending directions with long-run basis. The overall implication of temperature variability effect on real GDP (output) is that when temperature rises and falls, economic output again responds instantly; however, a negative shock to the same variable has stronger significance.

For further clarity of the climate variability impacts on Ethiopian economy, we compute the annual economic output gain or loss following these effects. We took the 2019 GDP as a bench mark. As we found from the World Bank data base, Ethiopia's 2019 GDP is estimated 95.913 billion US dollars (WB, 2019). This would mean an adapted and mitigated rain fall impacts would benefit Ethiopia to have an extra 336 million US dollars output in 2019 only. The gain from temperature adaptation and mitigation is higher. Our calculation based on 2019 GDP output is reaching up to 4.7 billion US dollars output. Overall, the effect of temperature variation is higher than the effect of rain fall variability. Policy and managerial interventions for this effect is required for Ethiopia to show the desired economic growth.

Our findings are along with more recent studies undertaken about climate change impacts on economic growth in Ethiopia or elsewhere. Yalew *et.al.*, (2017) in their study "Economic effects of climate change in developing countries: Economy-wide and regional analysis for Ethiopia" found a result which supports our finding. Their result showed that in worst case climate change scenario, the effects on national GDP may add up to a decline of eight percent. Although their result looks a little higher, our results also showed an output decline intensifying up to five percent in the long run.

Dell, Jones, and Olken (2009) find that higher temperatures would cut income, particularly in poor countries. This finding matches on what our study indicated that temperature fluctuation has more effects than rain fall variability. The Brown etal., (2011) study in relation to hydroclimate risk to economic growth in sub-Saharan Africa is also in support of our finding. Their findings showed that persistent negative precipitation anomalies (drought) are found to be the most significant climate influence on GDP per capita growth. There are also some findings for South East Asia such as Bangladesh which coincides with our findings. Akram (2012), for instance documented climate change has significant influences on GDP growth in Bangladesh.

5. Policy and Managerial Implications

In this case study, attempts have been taken to find the impacts of climate variability on the economic growth of Ethiopia. The results prove that, climate variables such as temperature and rainfall have a significant impact on Ethiopia's economic output and growth. In particular, temperature increase has significant negative impact on economic growth. This result tips the need of policy and managerial interventions for mitigating and adapting the effects. In fact, Ethiopia well recognized the climate change impacts. This recognition is manifested by the policies, strategies and programs put in place for the adaptation and mitigation of the on-going impacts.

Ethiopia's formal commitment to combat climate change started after negotiations with the United Nations Framework Convention on Climate Change (UNFCCC) in 2007 (Gashaw *et al.,* 2014). The first significant policy regulations document after this negotiation was the National Adaptation Programme of Action (NAPA) and Nationally Appropriate Mitigation Action (NAMA) in 2007. In 2011, the government initiated the Climate Resilient Green Economy (CRGE) strategy and launched it in 2012 (Ternald, 2019). The CRGE strategy was designed by further integrating and incorporating the NAPA and NAMA ideas into sector wide policy. Since 2016, there are also policy actions taken such as the Ethiopian Intended Nationally Determined Contribution (INDC), submitted to the UNFCCC (Endalew, 2016).

Although Ethiopia has joined the National and International activities of adapting and mitigating climate change effects with UNFCCC affiliated polices and strategies, a lot of policy and managerial issues remain to be revised. The policies, strategies and programs, and projects put in place are prepared with crude identification of the specific climate change impacts either on the entire economy or the specific economic sectors. Kidane et al., (2009) for instance evaluated NAPA's projects are specific only to certain subjects than the whole economy in a climate resilient way. They showed that, NAPA broadly focus in the specific project activities such as; human and institutional capacity building, improving natural resource management, enhancing irrigation agriculture and water harvesting, strengthening early warning systems, and awareness raising about improving dry lands livelihood systems. The NAPA also focused primarily on efforts to reduce greenhouse gas emissions than some higher broader mitigation and adaptation interventions.

The CRGE as an enhanced version of NAPA and NAMA focused only on four economic pillars, agriculture, forestry, power, and transport sectors. This limited focus implies that a number of adaptation and mitigation needs were missed in the remaining economic sectors as well. In fact, the CRGE and some other programs extracted from it offer a promising attempt at ensuring an economic development. Nevertheless, according to Cesar (2013) there are certain managerial issues overlooked, and yet which need to be given more attention in the development and implementation of CRGE. Some of these issues are involvement of the public and the poor to a larger extent, ensuring broad-based income distribution, and thematic expansion into issues such as biodiversity conservation and sustainable ecosystem management.

Overall, our view in this regard is, despite both the CRGE and INDC offers a promising attempt at ensuring economic development, a full-scale adaptation and mitigation policy adjustments are required to have a climate resilient economic growth. Such policy and managerial revisions would refer the findings of this case study as a benchmark. Our findings which show the effect of climate change both in the short and long run economic growth will help qualify the specific components of the available policies, strategies and programs to be revised as per the magnitude of the effects. As per the findings, there should be a stronger emphasis on a climate resilient economy. In this regard we share Tiratu's (2016) perspectives which highlight that climate change related policies should be revised to guarantee that the well-being of the people and the economic growth and prospects of the country are not damaged by the impacts.

6. Conclusion

The long-term NARDL model results confirmed a positive as well as significant asymmetric association between yearly rainfall and real GDP. Then again, temperature resulted in a negative influence on Ethiopia's real GDP. Regarding the short run, we witnessed an asymmetric significance from positive and negative rainfall and temperature shocks. Regarding the direction and extent of the effects, results were mixed. The workforce also had a pertinent long-term asymmetric consequence on real GDP change in Ethiopia. Unexpectedly, capital stock did not have an asymmetric significant consequence in either the long or the short run. This indicates that Ethiopia should emphasis on capital formation, as the results pointed out that ongoing efforts have not had any statistically significant power on real GDP change.

Generally, the positive association between rainfall and real GDP in Ethiopia in the short and the long-run demonstrate that the nation ought to have an alternative strategy in place to simply being a rainfed economy. The nation is likewise influenced by temperature variability in the long-run. In light of our findings, we deduce that the Ethiopian government has to play a role in raising real GDP by focusing on a climate-resilient economy, yet working more on capital formation would also boost the economy.

This study offered further insights into the nationwide economic effects of climate variability in Ethiopia. We also contributed a comprehensive study that could serve policymakers and academics in Ethiopia or elsewhere. Nevertheless, as with every other study, our study has had certain limitations. The major one is regarding the data quality and set. For this study, the data set we used is for a short time period. There would have been a possibility of finding more reliable results if long-span data would be available. Best efforts are made to apply an ARDL technique that is safe for such data type. Regarding the data quality, we use an International source for climate data. We would have a good finding if National metrological data were used. Hence, future studies should overcome these limitations for more reliable findings.

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Table 1: Descriptive statistics of study variables

Variable [a]	Obs	Mean	Std. Dev.	Min	Max
Real per-capita GDP (Y*)	65	36222.07	28725.44	9410.58	142242.60
Annual rainfall (R)	65	727.19	57.90	537.46	897.11
Annual temperature (T)	65	23.16	0.53	22.29	24.49
Physical capital (K*)	65	123176.10	61034.14	62192.48	385112.00
Labor force (L*)	65	19.23	10.66	7.42	45.28

*Values are in million USD
a All variables have been converted to the natural logarithm

Notes: *Y* is the level of per-capita income (or real per-capita GDP in USD) derived by dividing it by the population and obtaining the series in per-capita terms; *R* is a climatic variable consisting of precipitation and measured in millimeters; *T* is a climatic variable consisting of temperature measured in degree Celsius; *K* is physical capital measured by gross fixed capital formation at constant prices in 2011 USD; and *L* is labor force measured by number of employees (number of persons engaged in the workforce).

Table 2: Long-term NARDL model

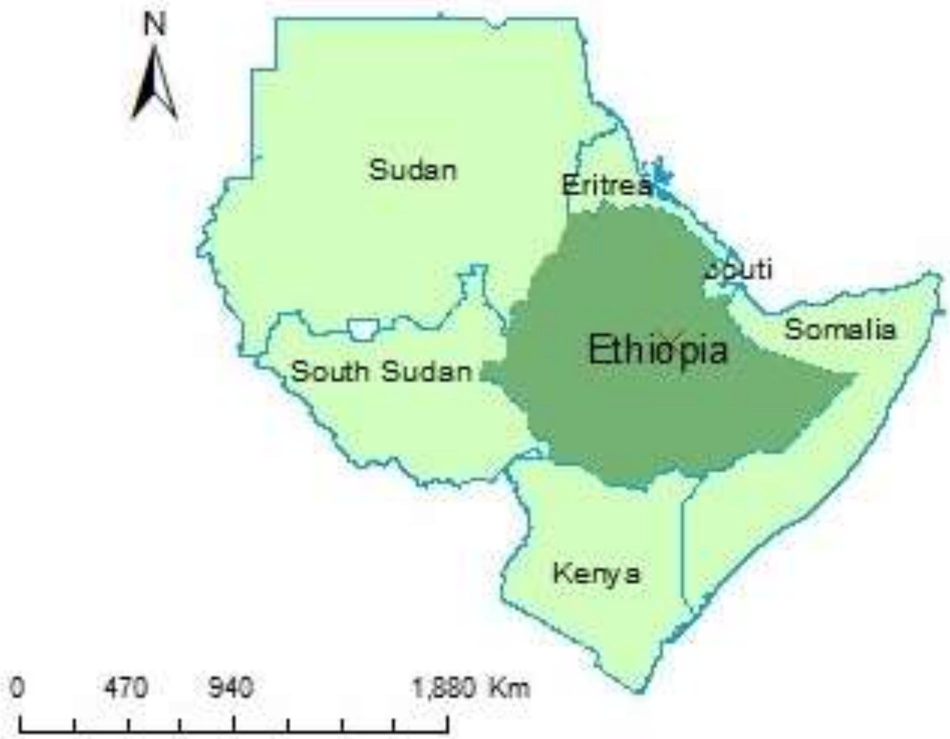
Exog. var.[a]	Long-term effect [+]			Long-term effect [-]		
	coef.	F-stat	P>F	coef.	F-stat	P>F
R	0.345*	3.455	0.077	0.060	0.100	0.755
T	-3.883**	5.888	0.024	-4.890***	11.900	0.002
K	-0.016	0.009	0.925	-0.157	0.009	0.927
L	0.155	0.134	0.718	0.000	IC	IC

a All variables have been converted to the natural logarithm

Table 3: Short-term NARDL model

Variable[a]	Coeff.	Std. Error	Variable[a]	Coeff.	Std. Error
$\Delta((y_{t-1})$	-0.054	0.128	$\Delta(K^{+})$	2.813***	0.735
$\Delta(R^{+})$	0.097	0.170	$\Delta((K^{+}_{t-1})$	0.881	1.005
$\Delta((R^{+}_{t-1})$	0.032	0.236	$\Delta((K^{+}_{t-2})$	1.534	0.998
$\Delta((R^{+}_{t-2})$	-0.436**	0.190	$\Delta((K^{+}_{t-3})$	1.848*	0.969
$\Delta((R^{+}_{t-3})$	-0.258	0.169	$\Delta(K-)$	11.159**	4.888
$\Delta(R^{-})$	0.071	0.134	$\Delta((K^{-}_{t-1})$	0.226	4.835
$\Delta((R^{-}_{t-1})$	0.259	0.180	$\Delta((K^{-}_{t-2})$	0.644	3.815
$\Delta((R^{-}_{t-2})$	0.581***	0.148	$\Delta((K^{-}_{t-3})$	-1.017	3.135
$\Delta((R^{-}_{t-3})$	0.527***	0.154	$\Delta(L^{+})$	1.627	1.129
$\Delta(T^{+})$	0.406	0.998	$\Delta((L^{+}_{t-1})$	3.075***	1.024
$\Delta((T^{+}_{t-})$	4.588***	1.467	$\Delta((L^{+}_{t-2})$	1.516	1.041
$\Delta((T^{+}_{t-2})$	4.262***	1.199	$\Delta((L^{+}_{t-3})$	-1.356	1.021
$\Delta((\square T^{+}_{t-3})$	3.011***	0.991	Dummy	0.038	0.033
$\Delta(T^{-})$	0.368	0.852	Trend	0.071***	0.020
$\Delta((T^{-}_{t-1})$	-4.089***	1.426	Cons	29.492***	5.374
$\Delta((T^{-}_{t-2})$	-2.614**	1.153	ECM_{t-1}	-1.280***	0.232
$\Delta((T^{-}_{t-3})$	-1.259	1.059			

**$\Delta(R^{-})$ and $\Delta(T^{-})$ and : the negative change in rainfall and temperature (down-warding)
$\Delta(R^{+})$ and $\Delta(T^{+})$ the positive change in rainfall and temperature (up-warding)



Map 1: GIS Map of Ethiopia and East African Countries: produced based on source shape file from The Humanitarian Data Exchange: https://data.humdata.org/

Figure 1: Cumulative effect of InR on InY

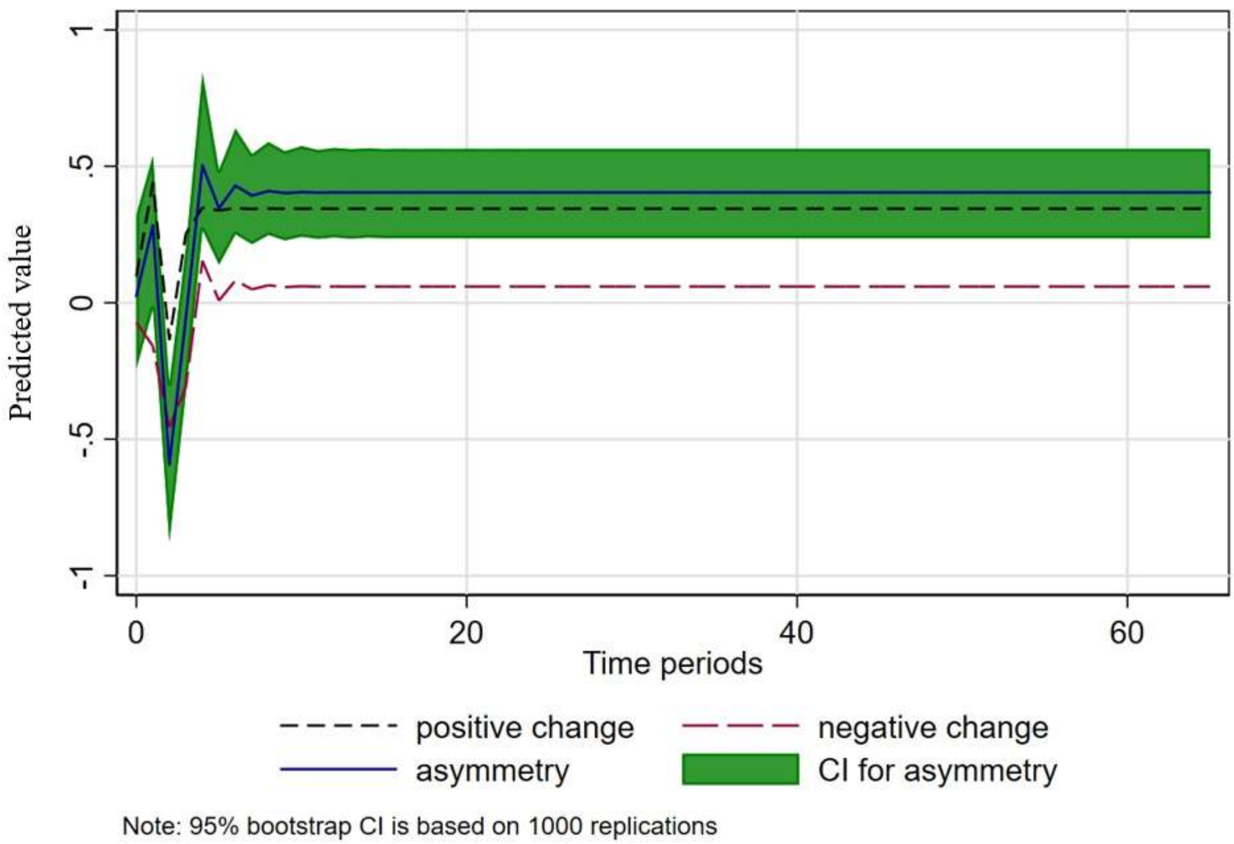
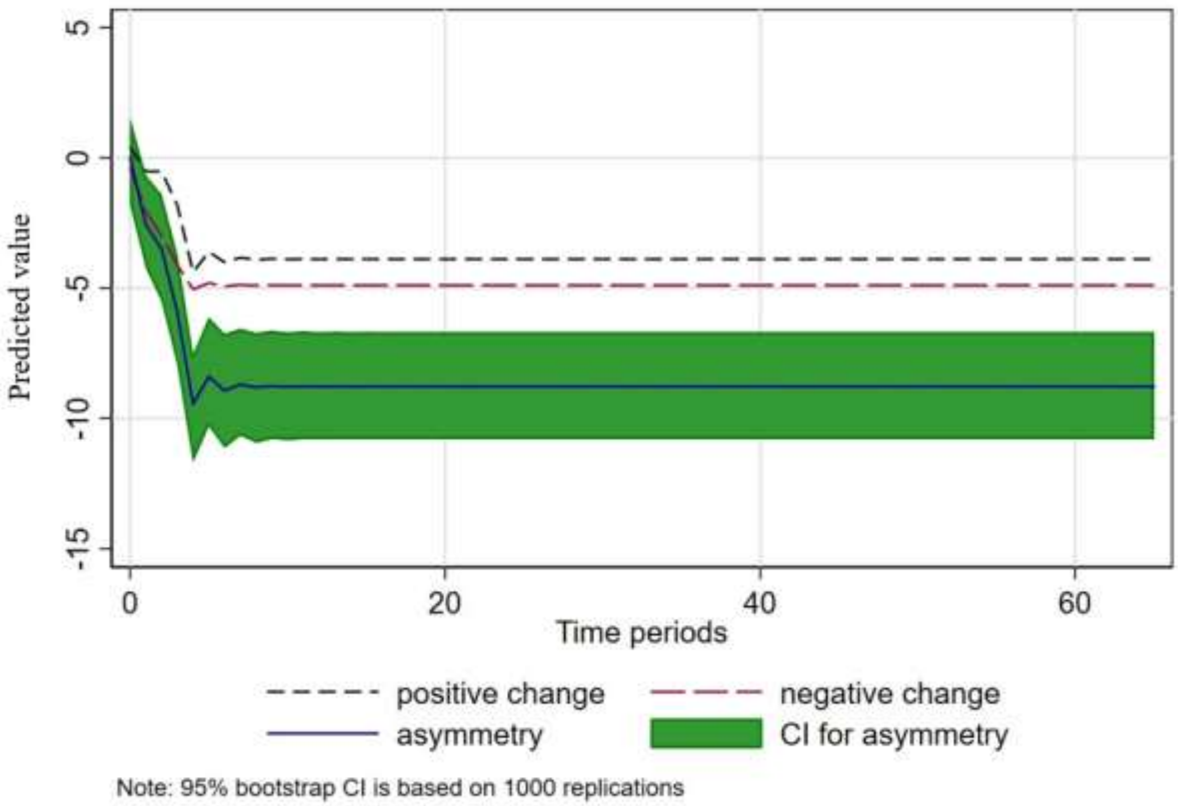


Figure 2: Cumulative effect of InT on InY



Appendix: Time series test result tables

Table A1: Unit Root Tests and Structural Breaks

Variables		Ng–Perron				ZA (Zivot-Andrews)	Clemente–Montanes–Reyes(CLEMA)						Final Decisions
		MZa	MZt	MSB	MPT		CLEMAO	CLEMAO1	CLEMAO2	CLEMIO	CLEMIO1	CLEMIO2	
lnY	Level	-1.41	-0.55	0.39	36.31	-3.42	-3.38	1988***	2006***	-2.63	1983**	2004***	I(1)
	First diff.	-9.44**	-2.17***	0.23**	2.59**	-6.31***	-6.95***	1990	2001**	-11.51***	1991	2002***	I(1)
	Integration	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
lnR	Level	-27.98***	-3.73***	0.131***	3.32***	-7.39***	-6.84***	1961**	1975**	-6.84***	1962**	1976***	I(0)
	First diff.	-23.89***	-3.45***	0.14**	1.05***	-7.69***	-10.89***	1961	1982	-10.71***	1962	1983	I(0)
	Integration	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)	I(0)
lnT	Level	-7.01	-1.77	0.25	13.14	-3.05	-5.45*	1974***	2006***	-3.59	1974**	2007***	I(1)
	First diff.	-3.09	-1.18	0.38	7.82	-10.32***	-12.20***	1954	2006	-12.07***	1955	2007***	I(1)
	Integration	ND	ND	ND	ND	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)
lnK	Level	-15.14	-2.27	0.15**	8.64	-1.65	-3.21	1975***	2007***	-1.78	1999***	2009***	I(1)
	First diff.	5.96*	2.72***	0.46	34.31	-1.41	-2.70	1983	2005***	-4.51	2002***	2009***	I(1)
	Integration	I(1)	I(1)	I(1)	I(1)	ND	I(1)	I(1)	ND	ND	ND	ND	I(1)
lnL	Level	-3.27	-1.05	0.32	23.47	-2.93	-2.51	1981***	2001***	-0.86	1969**	2003**	I(1)
	First diff.	-12.96**	-2.48**	0.19**	2.15**	-5.71***	-5.68**	1968***	1991	-5.56**	1969***	1992	I(1)
	Integration	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)

ND: Not defined

a All variables have been converted to the natural logarithm, their definition is specified in Table 1

Table A2: Cointegration test: bounds test with unrestricted intercept and unrestricted trend

NARDL bounds test
Sample: 1953–2014
Included observations: 61
K=4
Null hypothesis: No long-term relationships exist

Test Statistics	Calculated Value	Critical Value Bounds			Cointegration Outcome	Conclusion
		Significance (%)	Lower	Upper		
F_PSS [a]	5.45	2.5	3.89	5.07	Cointegration	
	5.45	1	4.40	5.72	Inconclusive	Cointegration
t_BDM [b]	-5.52	1	-3.96	-4.96	Cointegration	

[a, b]: F_PSS denotes the F-statistic proposed by. Pesaran et al. (2001) for testing the no cointegration hypothesis and "PSS" refers to "Pesaran, Shin, and Smith; while t_BDM is the t-statistic proposed by Banerjee et al.(1998), and the letters "BDM" refer to "Banerjee, Dolado, and Mestre"

dummy variable

Table A3: Results of short- and long-term asymmetry tests

Pairs	Long-term W_{LR} Ho: L-term symmetry H1: L-term asymmetry	Short-term W_{SR} Ho: S-term symmetry H1: S-term asymmetry	Conclusion
R–Y	7.80** [0.011]	15.01*** [0.001]	NARDL with long- and short-term asymmetry
T–Y	22.76*** [0.001]	19.99*** [0.001]	NARDL with long- and short-term asymmetry
K–Y	.001 [0.922]	0.51 [0.485]	Symmetric ARDL
L–Y	.013 [0.718]	3.92* [0.061]	NARDL with only short-term asymmetry

Table A4: Diagnostic test results

Model Diagnostic Tests	Stat.	p-value
Serial correlation: Portmanteau test up to lag 28 (χ^2)	18.36	0.917
Heteroskedasticity: Breusch–Pagan test (χ^2)	0.8527	0.356
Functional form and linearity: Ramsey RESET test (F version)	3.456	0.038**
Normality: Jarque–Bera test (χ^2)	2.151	0.341