Impact of Climate Change on Agricultural Output and Adaptation Measures in Ethiopia

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Abstract

Part of the literature informs that different regions of the world contribute to greenhouse gas emissions in varying degrees, in global warming. It also highlights that these regions influence different influences from the warming effects, ranging from extreme net loss to net gain. Importantly, it emphasizes that countries in the tropical regions, such as Ethiopia, are particularly vulnerable to these changes. This study utilized a production function approach that considers the physiology of plants and animals to assess the long-term economic impacts of rainfall variability on the agricultural output. The analysis is based on time-series data covering the period from 1961 to 2012. The results of the econometric analysis confirmed the existence of an optimal volume of rainfall. When this optimal threshold is exceeded, the benefits of rainfall diminish indicating that the country experiences short-lived and negligible gains from climate change, while enduring comparatively higher economic loses in the long run. Furthermore, there is a probable trend of excessive rainfall during the rainy seasons, surpassing the optimal amount. In order to delay the onset of diminishing benefits of rainfall, it is crucial to undertake mitigation and adaptation efforts promptly

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and resolutely. Among others, too much rainfall, which is catastrophic, can also be an opportunity to use rainwater harvesting to fill the moisture-stress gap that can be created due to the early stoppage of rainfall. Most importantly, since the adverse impacts are caused mainly by global negative externalities, the findings suggest a need to complement the global approach with the local adaptations of smallholder farmers to address the negative impact of climate change.

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JEL Classification: E23, Q15, Q54

1. Introduction

History tells us that climate change has been hitting this planet at irregular intervals of time since antiquity. Whenever it occurred, it caused great changes in life and socio-economic performances (for example, Acemoglu and Robinson, 2012, p. 152; World Bank, 2010:39). In recent years as well, our planet has been facing another climate change. According to the IPCC (2021), the global average surface temperature has been increasing since 1861 without moving back to its mid-nineteenth century level, rather increasing over the twentieth century by about 0.6°C, but taking a different trend since 1950, showing a 0.10°C rise per decade (IPCC, 2001:2), and continuing to increase (IPCC, 2021). The vast majority of scientists agree that the average surface temperature on the planet has already warmed by about 1°C since the mid-eighteenth century, and unless reductions in GHG emissions occur, the global warming of 1.5°C and 2°C will be exceeded during the 21st century (IPCC, 2021). The global concentration of carbon or emitted GHG in the atmosphere influences the natural climate (Althor et al., 2016; Weyant, 1993).

Just like the past climate changes, the present warming has several prolonged effects. Melting of snow and ice causing rising sea levels, increasing frequency of warmer days and nights and heavy-flood causing rainfalls are some major effects. IPCC (2021:5) puts the effects as increase in global average sea level by 0.20 (0.15 to 0.25) meters between 1901 and 2018, decrease in snow cover of about 10 percent since 1960s, twentieth century increase in precipitation by 0.5 to one percent per decade (IPCC, 2001:2).

With no doubt, agricultural outputs are mainly vulnerable to the indicated change. Some writers estimate the effect of such changes at a two to 50 percent yield decline in major cereal crops (Serdeczny et al., 2017; Rosenzweig et al., 2014) and a 20 to 30 percent reduction in grain production globally (Darwin et al., 1995). Burke et al. (2018) estimated a cumulative $20 trillion in global damages avoided by 2100 if global warming is limited to 1.5 degrees Celsius rather than two degrees Celsius. Reilly et al. (1994), assuming no adaptations, estimated the global welfare losses in the agricultural sector at US$61.2 billion and the likely welfare gains at US$0.1 billion. Many writers argue that the highest losses occur in tropical regions (Uribe et al., 2023; Mendelsohn et al., 2000), which may cause production to retreat from the tropics to temperate regions. Several studies projected that due to climate change, output agricultural reduction falls between 1.2 and 4.5 percent for Eastern Africa (Kahsay and Hansen, 2016) to 10 percent of GDP in Africa (Hernes et al., 1995). A large number of these studies conducted on the impact of climate change are, however, crop-specific rather than macro-level estimations (Carr et al., 2022; Pereira, 2017; Serdeczny et al., 2017; Schlenker and Lobell, 2010). Those studies estimated the yield fall due to climate change in specific crops by about 50 percent (for example, Serdeczny et al., 2017). Similarly, Thomas et al. (2019) assumed increasing rainfall and temperature in the future in Ethiopia and found a less than one percent yield decline of two major crops (sorghum and wheat) but a possible yield increase of maize by about 1.2 to 4.2 percent in 2035 and 2085. In the case of Ethiopia, Rettie et al. (2022) found a similar result of a limited decline in maize yield but a fall in wheat yield of 36 to 40 percent by 2050.

Reducing the adverse effects of the change and making optimal use of its likely gains requires an adequate and clear understanding of the relationship between climate change and a country's economic performance, however. This understanding may include knowledge of the magnitude of the changes in temperature and precipitation, the frequency and intensity of floods, a more precise functional relationship between climate variables and socio-economic variables like agricultural production and labour productivity, the feasibility and costs of factor reallocations offsetting adverse effects and reap optimally from available opportunities.

To reduce the vulnerability of its population, environment, and economy to the adverse effects of climate change, Ethiopia is undertaking adaptation and mitigation initiatives, following its Climate Resilient Green Economy Strategy/CRGE (FDRE, 2012), to at least sustain the encouraging performance of the agricultural sector since 2004. The sectoral GDP was growing with an average growth rate of seven percent annually between 2004/05 and 2013/14 (Schmidt and Thomas, 2018). The question is, despite the strategic approach to gradually addressing the issue of climate change, how far does climate change affect the agricultural output in Ethiopia? In line with the CRGE strategy, the study investigates agricultural water management in the context of climate change, aiming at assessing the impact of climate change on agricultural output. It could inform policymakers regarding policy measures that help overcome undesired effects and harness gains from the change.

To assess the impact of climate change on agricultural output, studies employ different models. They estimated a model focusing on assessing the effects of the change on the production of specific crops (Carr et al., 2022; De Salvo et al., 2013). Others employ non-crop-specific production functions (Rosenzweig et al., 2014), the Ricardian approach (Deressa et al., 2007; Mendelsohn et al., 1994), and the Integrated Assessment model (Peng and Guan, 2021; Nordhaus, 1993). Each approach has its own merits and limitations, however. This study employs a production function approach to look into the impact of climate change on agricultural output. The contribution of this study is that, among others, it estimated the optimal level of rainfall to understand the impact of deviation of the volume of rainfall from its optimal level, which is not attempted in many other studies (Solomon et al., 2021; Ketema and Negeso, 2020) rather than conventional estimations in time series analysis (Ketema and Negeso, 2020). In addition, the study used the quarterly dummies to check the impact of quarterly (crop-growing season) shocks on agricultural output. This study used more than 50 years of data, unlike similar studies (Ketema and Negeso, 2020), which is advantageous to adequately capture the long-run effects.

In the remaining part of the study, Section 2 reviews the literature on models employed and reported impacts. Section 3 presents the framework of the analysis. Empirical analysis employs alternative estimators and results and conclusions are presented in sections 4 and 5, respectively.

2. Literature Review

In the literature, various authors constructed several models to assess the impacts of climate change, very likely due to the multidisciplinary nature of the problem. De Salvo et al. (2013) listed crop simulation models, production function approaches, Rechardian models, mathematical programming, integrated assessment models and general equilibrium models (GEM). The crop simulation model concentrates on plant physiology and considers the biological and ecological consequences of climate change (Torriani et al., 2007), but criticised for ignoring the adaptive behaviour of producers and for its crop and site specificity. To improve its weakness, other authors prefer to employ a production function approach that considers producer behaviour (Rosenzweig et al., 2014). The approach is also praised for its suitability to both short and long-terms time-scale. However, its application to cross-section data is reproached for its likely biased results arising from omitting the possibility of farmers' adaptation. On this issue, Dell et al. (2014) underlines that the long-run effect estimate derived from cross-sectional data is larger in intensification or smaller in adaptation than the short-run. To address these issues, others employ Ricardian approach-developed by Mendelsohn et al. (1994) to capture farmers' adaptation in some sense. This approach specifies farmland prices as a function of climate and other variables. Unlike the production function approach the model aims at capturing the farmers' adaptation strategies based on land values or net revenues on normal climate situations and other control variables. Most often the normal situation is calculated as averages of long-term circumstances. This model is praised for it well assesses the effects climate change in the whole of agricultural, sub-sector or crop (Nguyen et al., 2022; De Salvo et al., 2013; Seo and Mendelsohn, 2008; Deressa, 2007), but difficult to apply when farmland prices are unavailable. Besides, it neglects irrigation except that Nguyen et al. (2022) took the proportion of irrigated land. All the above models assume agriculture is self-reliant while actually not. To bypass this limitation, other writers employ GEM, which considers the interdependence of economic sectors and provides information on the effect of climate change by regions and sectors. However, this model is criticised for it treats production factors, including irrigation water, undifferentiated inputs, and for the difficulty to analyse farmers' adaptation strategies (De salvo et al., 2013).

Peng and Guan (2021) and Nordhaus (1993) employed the integrated assessment model to address the limitations. However, the main obstacle to this model is the uncertainty about future economic growth and technological change that is associated with GHG emissions, the actual relationship between emitted GHG per unit of time and the accumulated GHG, the rate at which heat is transferred into the ocean, and the reverse causation from warming to atmospheric GHG concentrations (Allen and Frame, 2007). But, often, each difficulty could be improved as human understanding of the underlying mechanisms and relevant technology improves. Zerayehu et.al. (2020) applied a recursive dynamic computable general equilibrium (CGE) model to investigate CO2 emissions' impact on agricultural performance and household welfare.

Building upon these models and different types of datasets, several authors have assessed the impact of climate change and documented varying impacts depending on the relative global locations. Dell et al. (2012) employed a 1950-2003 panel dataset to examine how annual variation in temperature and precipitation affects per capita income throughout the world. They reported that being 1°C warmer annually reduces per capita income by 1.4 percent, but only in poor countries. Hsiang and Narita (2010) employed panel data (233 countries over 1950-2008) to examine the effect of windstorms on income and found higher wind speeds cause economic losses. Lobell et al. (2011) also conducted a global study focusing on the impact of weather on agricultural output and found a statistically significant and nonlinear effect. Though these studies are comprehensive, to the extent they are global, one expects to learn more about feedback effects. That is the extent of changes in warming due to the suppressed output, either through the impacted outputs exerted on GHG emissions or reflections of the sun's heat arising from the accumulation of GHG, which is beyond the scope of this paper.

The literature focusing on Africa reveals a similar effect. Emediegwu et al. (2022) developed a spatio-temporal model and estimated the effects of climate change on crop yield and found that the effect varies depending on whether the countries are poor or rich. Pickson and Boateng (2022) employed the pooled mean group technique and the Dumitrescu–Hurlin panel causality test to investigate the effect of climate change on food security in 15 African countries between 1970 and 2016 and found a significant role for rainfall and temperature. Bruckner and Ciccone (2011) and Exenberger and Pondorfer (2011), employing panel data on sub-Saharan Africa, examined the effects of climate change and observed that the effects are quite adverse. Following a similar technique, Schlenker and Lobell (2010) estimated the yield response in sub-Saharan Africa to weather changes. They found that higher temperatures reduce yields. Miguel et al. (2004) dealt differently, employing datasets of 41 African economies to examine the relationship of civil conflicts, income, and rainfall. They reported that the per capita income growth was positively predicted by the current and lagged rainfall growth. However, the researchers assumed a monotonic relationship between climate variables and economic variables. But one could ask whether the finding would remain unchanged had they relaxed their assumption about the possibility of non-monotonic relationship.

For Ethiopia, Solomon et al. (2021) employed the dynamic computable general equilibrium (CGE) model and simulated up to 2050 to see the impacts of climate change on the agriculture sector of Ethiopia, and their results suggest that crop production will be continuously adversely affected over time, suggesting the need for adaptation mechanisms. Also, Ketema and Negeso (2020) employed time series data from 1980-2016 to see the long-run and short-run effects of climate change on agricultural output in Ethiopia and found that climate changes have an important long-run effect on agricultural output and an estimated 73.8 percent annual adjustment towards long-run equilibrium. In the short run, mean annual rainfall has a significant effect, but the average temperature has an insignificant effect on output. However, the study does not consider, among others, the optimal level of rainfall and temperature in the analysis of the impacts of the variations.

Robinson et al. (2013) employed global circulation models and found that by 2050, climate change could cause GDP to be 8-10 percent smaller than under a no-climate change baseline. In identifying important elements of a climate-resilient development strategy, they recommend rapidly developing hydro-potential, upgrading road design, and gradually diversifying the economy. Wakeyo and Gardebroek (2013) found that growing perennial crops increases the probability of using rainwater irrigation to adapt to climate change, similar to the adaptation mechanisms of households in other developing countries (Williams et al., 2016). Tesso et al. (2012), employing time-series data, examined the effect on crop production. They documented that 90 percent of the variation in productivity was explained by area under irrigation, manure, improved variety, seasonal rains (Meher and Belg), and temperature. Demeke et al. (2011) investigated the effect of rainfall shocks on smallholders' food security. They found that the level and variability of rainfall determine persistent food insecurity. Shang et al. (2011) examined whether a long-term increase in extreme precipitation exists and reported no increasing trend in extreme precipitation. These studies clearly document the fact that Ethiopia's economy is influenced by climate change. But the issue of the non-monotonic relationship between climate variables and economic variables needs further investigation. From the reviewed models, cross-sectional studies may not capture the farmers' adaptive behaviour and hence bias the estimated marginal effects. According to Dell et al. (2014), panel data could also have limitations in reflecting medium- and long-run situations. This condition necessitates the use of time series to get clearer picture of the effects of climate change on Ethiopia's agriculture in the long run.

3. Empirical Methods and Data

3.1. Empirical Methods

To assess the impact of rainfall variation in the agricultural production function approach, one needs to know factors of production and the type of functional relationship that links them to the considered output. From the literature, one observes that the common factors used in production functions are capital, labour, and land. These factors can be modified into more suitable forms like substituting produced capital with livestock or splitting land into arable land, irrigated area, and investment like fertilizer.

Conventionally, it is assumed that maximizing behaviour of producers coupled with market forces leads to the stability of the product of the ratio of the marginal product of each factor to its unit price, and the share of output invested in the acquisition of that factor is constant, but this assumption may not hold true for rainfall since optimization is not so feasible.

This is because the decision on the amount of this 'factor' to enter the production is not in the hands of the producers. Besides, even one can assume that at the global level rainfall quantity depends on the extent to which people take environmental care, and hence, at the global level, human races can have some influence on the amount of rainfall. At the country level, the amount of this 'factor's supply seems exogenous. However, the implicit assumption in using rainfall as a factor of production could be that the cost of reducing GHG emissions that a country bears could represent the cost of getting the required amount of rainfall. In fact, the view is more plausible at the global level than at the country level or for a hypothetical closed economy. Bearing this in mind, the production function $f(.)$ that determine agricultural output, $Y(t)$ at time t is,

$$Y(t) = f\left(R(t), L(t), K(t), Z(t)\right) \quad \textbf{(1)}$$

Where $R(t)$, $L(t)$, $K(t)$ and $Z(t)$ represent the amount of rainfall, labour, capital and land, all registered and entered production at time point t, respectively. After taking total derivative of both sides of equation [1], and dividing both sides through by $Y(t)$ and then taking the integral of both sides one can switch to explicit function as

$$Y(t) = AR(t)^{\alpha_1} L(t)^{\alpha_2} K(t)^{\alpha_3} Z(t)^{\alpha_4} \quad \textbf{(2)}$$

Where $\alpha_1, \alpha_2, \alpha_3$ and α_4 are elasticities.

Usually, the Cobb-Douglas production function can be seen as the first-order Taylor's series expansion of the natural logarithm of the output in the natural logarithm of the factors. Under the expectation of interaction effects among the factors or non-unity elasticity of substitution, however, one may take the second-order Taylor's series expansion that results in the translog production function. Even if the interactions of agricultural inputs are very likely, as in, for example, Wakeyo and Gardebroek (2013), who reported the interaction effect of water-harvesting irrigation and fertilizer use, in our case we confined ourselves to first-order expansion since the estimation of the function demands much more observation than we have.

Expressing equation [2] in log form

$$lnY(t) = lnA + \alpha_1 lnR(t) + \alpha_2 lnL(t) + \alpha_3 lnK(t) + \alpha_4 lnZ(t) \quad \textbf{(3)}$$

Equation [3] helps to assess the effect of rainfall on the output of a hypothetically closed agricultural economy that avails no external economy to others or faces the same from others. For a country that fulfills such a scenario or is at least close to it, the equation may help to estimate parameters like the marginal effects of rainfall on output, the effect of a percent increase or decrease in rainfall on output, and the share of rainfall from total output as compared to other factors. As pointed out above, the equation may also serve to assess the global-level impacts of climate change, in which external economies are internalised, disregarding country-or regional-level impacts.

However, application of the model at country level, particularly to low-income economies, could give a misleading result. This is primarily because of the weak relationship between the assumed 'unit cost' and the amount of 'factor'. Under this condition, parameter estimates of the equation could be spurious, which as is clearly seen from the prediction of equation [3], which implies that for $\alpha_1 > 0$ there is persistent growth gain from a continuous increase in rainfall quantity, which is inconsistent with reality. From the physiology of plants and animals, one understands that scarcity and excessiveness of rainfall hamper their growth and reproduction, and at the extreme, threaten their lives. Despite this fact, the equation suggests that increases in rainfall at extremely high rainfall amounts, which are catastrophic, are associated with output growth just as they are associated with output growth at optimal rainfall levels. With a slight difference, the same is true for cases of scarcity. The equation implies that increases in rainfall from an extremely meager level are associated with output growth exactly the way they are associated with output growth at an optimal level. In real cases, a given amount of increase from an inadequate level is related to better performance than increases from an optimal level.

The interest of this paper is neither global-level assessment nor ignoring external economies, which is equivalent to assuming a closed economy since it is not realistic. As a result, even if equation [3] is a very common type, we need to modify it so that it serves our interests at best. To overcome the limitations of the equation, instead of treating rainfall as a factor of production, we treated it as a part of the general structure within which the production process takes place, just as the effects of the progress of industry on the progress of a firm are treated, that is, as a systematic deviation of the volume of rainfall from its optimal level that arises in the form of external economies.

In emphasizing that external economies play roles just like internal economies in determining the progress of production volume, Marshall (1890: 152) wrote, “We may divide the economies arising from an increase in the scale of production...into two classes: (1) those dependent on the general development of the industry; and (2) those dependent on the resources of the individual houses of business engaged in it, on their organization, and on the efficiency of their management. We may call the former external economies and the latter internal economies.” Regarding the size of the effects of external economies in comparison to internal economies, He (1890:255) wrote, “Those internal economies that each establishment has to arrange for itself are frequently very small compared to those external economies that result from the general progress of the industrial environment....”.

In our case, to express both forms of economies mathematically, we relied on the damage function, in which part of the output is damaged due to the external economies manifested in the deviation of rainfall from its optimal level. Before the introduction of the external economies, let’s first suppose that the economy gets an optimal volume of rainfall and employs traditional production factors. Following equation [1] and equation [2],

$Y(t) = A\mathrm{L}(t)^{\beta_1}\,\mathrm{K}(t)^{\beta_2}\,\mathrm{Z}(t)^{\beta_3}$ Where $\beta_1,\ \beta_2\ and\ \beta_3$ are elasticities. Now to introduce the external economy, let's suppose that at time t, some part of the output is damaged by some percent $D(t)$ as a result of scarcity, or excessiveness of rainfall, or deviation of rainfall from its optimal level. The actual output in this situation is that

$$Y(t) = A(1 - D(t))L(t)^{\beta_1}\,K(t)^{\beta_2}\,Z(t)^{\beta_3} \qquad \textbf{(4)}$$

Since the damage is assumed to be due to a deviation of rainfall from its optimal level, we set $ln(1-D(t))$ as an implicit function $H(R(t))$, where $H(.)$ is some function of the amount of rainfall. Using Taylor's polynomial approximation for $H(R(t))$ and substituting it in equation [4] and taking the natural logarithm,

$$lnY(t) = ln\,A + \sum_{i=0}^{\infty} \pi_i R(t)^i + \beta_1 lnL(t) + \beta_2 lnK(t) + \beta_3 lnZ(t) \qquad \textbf{(5)}$$

Where $\pi_i's$ are parameters.

Based on the physiology of plants and animals, which indicates the existence of some optimal level of moisture for their growth and reproduction and that both scarcity and excessiveness of rainfall hamper their growth and reproduction, one can truncate the Taylor series in second order. That is, using only quadratic approximation and setting the theoretically expected signs of the parameters as $\pi_2 \le 0$. Accordingly, the theoretical model that takes the physiology of plants and animals into account will be

$$\ln Y(t) = \ln A + \sum_{i=0}^{2} \pi_i R(t)^i + \beta_1 \ln \mathrm{L(t)} + \beta_2 \ln \mathrm{K(t)} + \beta_3 \ln \mathrm{Z(t)} \qquad \textbf{(6)}$$

Equation [6] suggests that the log of agricultural output is linearly related to the log of traditional factors of production and quadratically related to the amount of rainfall.

To compare the implications of equations [6] and [3], take the derivatives with respect to time. The result gives contribution of growth by rainfall amount plus other factors to the percent growth of agricultural output. After differentiating equation [6] and rearranging,

$$dY(t)/Y(t) = \left[(-2\pi_2 R(t))\left(-\pi_1/2\pi_2 - R(t)\right)\right] dR(t)/R(t) + \beta_1 \, \mathrm{dL(t)}/\mathrm{L(t)} + \beta_2 \, \mathrm{dK(t)}/\mathrm{K(t)} + \beta_3 \, \mathrm{dZ(t)}/\mathrm{Z(t)} \quad \textbf{[7]}$$

Under the secular amount of increase in rainfall, equation [3] implies that a percentage increase in rainfall is associated with a fixed percent increase or decrease in output growth depending on the sign of the parameter, α_1 irrespective of rainfall. This is a very unlikely prediction, for $\alpha_1 > 0$. It ignores the possibility that too much rainfall damages crops and the output in general, and in case of $\alpha_1 < 0$, it ignores the likely gains when the country is getting rainfall below optimal. Unlike equation [3], equation [7] suggests that a percent increase in rainfall depends on the previous time record of rainfall and the extent to which it deviated from the optimal level $\left(-\pi_1/2\pi_2\right)$. If $R(t)$ is below optimal level $-\pi_1/2\pi_2 - R(t) > 0$ and the coefficient of $dR(t)/R(t)$ will be positive since $-2\pi_2$ is expected to be positive based on the indicated physiology, and hence increase in the amount of rainfall contributes to the growth of output positively. A close look at the equation reveals that the contribution declines as the amount of rainfall approaches the optimal level. But, if the observed level is already above the optimal, the second term will be negative and the first term remains positive, i. e. $-\pi_1/2\pi_2 - R(t) < 0$ and $(-2\pi_2 R(t)) > 0$, implying the term in the big bracket will carry a negative sign, which suggests an increase in rainfall reduces the contributions of other factors of production to output growth. Thus, whether an increase in rainfall contributes to output growth depends on whether the nation is already getting below or above the optimal rainfall, and the size depends on the gap between the observed and the optimal, with a larger gap being associated with a bigger loss or gain and vice versa.

Following the same route of analysis, one can deduce that if rainfall follows a secular decline, it contributes to output growth adversely if the amount is below the optimal level. Similarly, under this context, one can conclude that it contributes favourably to output growth if the observed amount of rainfall is above the optimal level.

In the context of global warming, it is expected that a persistent increase in temperature will cause a persistent increase in rainfall, with some random fluctuations. Under this circumstance, the equation predicts that nations that are getting inadequate rainfall or are below the optimal level may enjoy some gains in their output growth up to the point when the optimal level is reached. Then after, they start to face suppressed output growth that may lead to stagnation or even economic crash if the warming continues to raise rainfall. Additionally, nations already getting above optimal would face suppressed output growth from the very beginning because of rising rainfall. In the long run, if warming is not mitigated and its effect on rainfall is unrelenting, nations depending on rain-fed agriculture may lose production. However, in the short and medium terms, whether the nation will be a net gainer or net loser will be the subject of empirical work.

From the perspective of reaping the likely gains and struggling against the likely losses arising from climate change, equation [7] has some additional information. In the context of the secular rise of rainfall, it implies that the nations already getting rainfall above optimal need to do their best on their own and with international cooperation to halt rising rainfall by limiting the forces that contribute to global warming. In terms of equation [7] this implies attempting to have lower $R(t)$ if possible, in the short run, otherwise in the medium or long run. This corresponds to mitigation activities related to stumbling rainfall from not exceeding the optimum level. At the same time, they need to alter the parametric optimal level in the direction of rainfall's secular trend. In terms of equation [7], this means rising $-\pi_1/2\pi_2$, which corresponds to adaptation -related to innovations associated with drought/wet resistant new varieties and other related activities.

From the set-up of equation [7], part of the inefficiencies in agricultural production could be attributed to the variations of rainfall around some optimal level. The next question is whether the deviation explains all of the inefficiencies involved or not. This question will be left to empirical analysis.

Turning back to the likely situation in Ethiopia, the three possibilities are: the country has been getting rainfall below the optimal level, exceeding its optimal level, and at about its optimal level. In the first case, one may expect some degree of economic benefit from the secular increase in rainfall, and in the later case, some degree of economic loss. However, as long as the increase in rainfall is continuous, it is likely that, soon or later, the economy will start to experience suppressed growth in its agricultural output. But if the second case is consistent with the country's reality (getting rainfall above the optimal level already), one can think that the diminishing benefit has already been set in the production system.

A look at Ethiopia's geographic location reveals that it lies within the tropical latitudes. From this location, living plants and animals have already adapted to tropical rainfall that suits their growth and reproduction. However, the increase in global warming may initially reduce rainfall to some degree, since it limits the process of condensation of water vapour to form rain drops. But after some degree of warming, when mountain glaciers, snowpack, and ice melt more and more, the country may experience more rainfall. Accordingly, keeping the effects of the annual erratic fluctuation of rainfall aside, the country has been getting rainfall below some optimal level, which may lead one to expect the first scenario to hold.

3.2. Data

The variables used for the empirical analysis include value added in agricultural output expressed in constant price in (million Birr[5]), annual rainfall (in millimetres), arable land (in hectares ha), area equipped for irrigation (in 1000 ha), fertilizer consumption (in kilograms per ha), livestock (in TLU) and labour[6] (in head counts). The time series constructed for them ranges from 1961 to2012.

Data for value added in agricultural output were taken from the Ministry of Finance and Economic Development (MoFED), whereas rainfall, arable land, and fertilizer consumption data were taken from the World Bank (2016). Similarly, data on land equipped for irrigation and livestock were taken from FAO (2017), and labour data from the World Penn Table.

4. Results and Discussion

4.1. Descriptive Statistics

The descriptive statistics is presented in Table 1. The table reports that the annual average temperature was 23^{o}C and 23.91^{o}C during 1981-1985 and 2006-2010 respectively. If we assume that the 5 year average can smooth out random

[5] One Ethiopian Birr was equivalent of 0.441 US$ on March 31, 2017.
[6] The variables series taken from Penn was adjusted for agricultural sector, using the fraction of rural population from the total.

fluctuations and that temperature follows a linear trend, we can think that the countries annual average has been rising by 0.37°C per decade over the past 25 years. However, there is no reason to rule out the possibility of a non-linear trend. The rising trend and the possibility of non-linearity can be seen in Figure 1. The figure indicates that if one fits a linear trend to the temperature 1961-2010 data, the fitted line shows that temperature exhibits a rising trend during the considered five decades. But if one allows the data to choose between a linear and non-linear trend by employing fractional polynomial-fit that gives the data both chances, there is a tendency toward non-linearity. The non-linearity and convexity to the origin are signs of rising marginal changes per unit of time, besides the rising trend. Thus, the temperature shows a tendency to rise with time.

Table 1: Descriptive statistics

Variables a	1981-1985		2006-2010	
	Mean	St. dev	Mean	St. dev
Annual rainfall (in mm)	673.17	83.80	745.51	44.02
Arable land (ha per person)	0.32	0.03	0.17	0.004
Arable land (ha per person) growth	-0.05	0.01	-0.001	0.03
Fertilizer in kg/ha	1.91	0.25	16.78	3.84
Fertilizer (in kg/ha) growth	0.07	0.01	0.17	0.16
Total irrigated area (1000ha)	180.97	5.19	304.86	10.43
Total irrigated area (1000ha) growth	0.02	0.001	0.02	0.00
Agriculture value-added per-person (birr)	669.51	105.37	743.43	59.58
Agriculture value-added per-person (birr) growth	-0.09	0.14	0.06	0.02
Rural labour growth	0.03	0.02	0.03	0.002
Rural population growth	0.03	0.004	0.02	0.002
Annual average temperature (°C)	23.00	0.12	23.72	0.53
TLU per-person	0.84	0.02	0.66	0.01
Livestock in TLU per-person growth	-0.001	0.03	0.02	0.04
Quarter-1 (December-February)	22.70	11.83	37.82	9.68
Quarter-2 (March-May)	211.76	38.53	183.50	32.28
Quarter-3 (June-August)	283.27	27.82	331.52	12.51
Quarter-4 (September-November)	155.44	29.72	192.67	11.38

Likewise, Table1 reports that the country's average annual rainfall was 673.172 mm during 1981-1985 which rose to 745.507mm during 2006-2010. Again, if there is reasonable ground to assume rainfall follows a linear secular trend, the statistics imply that during the study period, the country's rainfall was increasing by 2.893mm [(745.507-673.172)/25] per year, or 4 percent per decade. This general tendency is consistent with what the IPCC documented (2001:2) and is cited in section 1. But in a broader span (1961-2010), the linear trend suggests that annual rainfall was declining. However, if the restriction on linearity is relaxed, one can observe that the declining trend is limited to the period before the 1980s. Figure 2, which reports the fractional polynomial fit besides the linear prediction, indicates a clear tendency toward non-linearity in the rainfall. The non-linear curve indicates that the volume of rainfall was following a declining trend in the 1960s and 1970s but a rising trend 'after the 1990s'. Moreover, on average, the least amount of rainfall is during the first quarter (December to February) and the highest during the third (June to August), as shown in Table 1. Furthermore, Table 1 indicates a tendency to decrease in rainfall variability over time, with a coefficient of variation of 0.12 for 1981-1985 and 0.06 for 2006-2010. A similar situation is seen when the reference time is quarters of a year.

Figure 1: Trend of Temperature [1961-2010]

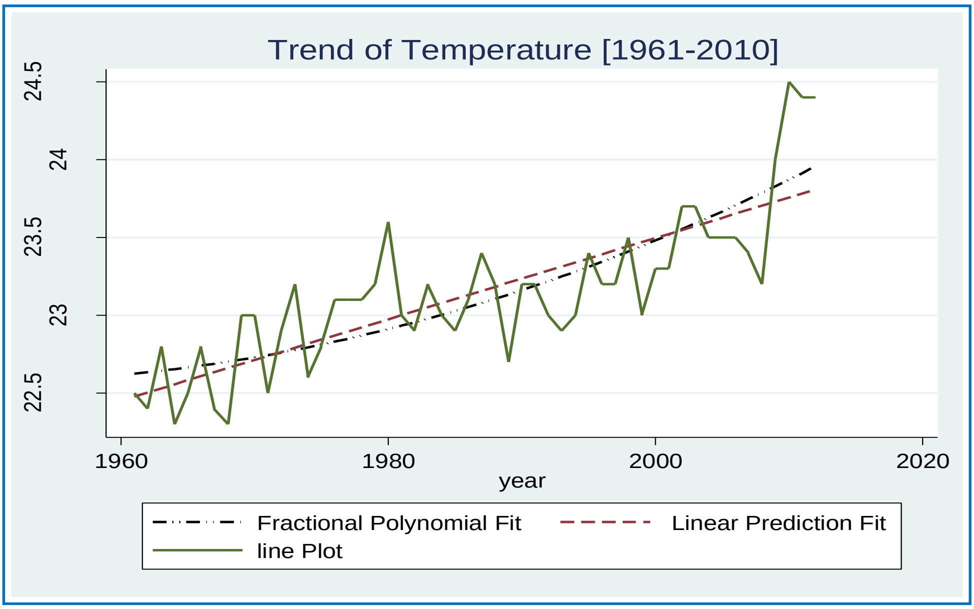
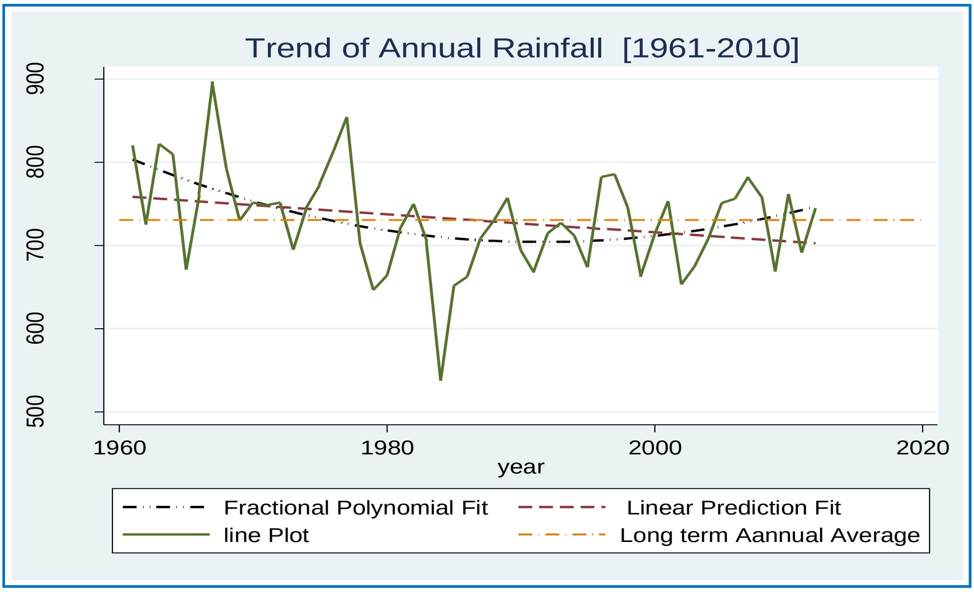


Figure 2: Trend of Rainfall [1961-2010]



In short, from the statistics of temperature and rainfall, we can understand that the variables are exhibiting some secular changes, be they in linear or non-linear form, instead of the common expectation of stable levels with some random variations. We can think that, besides the erratic fluctuations, such secular changes could have some effects on agricultural production. To see the temporal variations, rainfall anomalies were calculated as standardised rainfall units, the deviation of annual rainfall from its mean divided by its standard deviation. Table 1 reports that during the former period, the country was getting less rainfall than its long-term volume of 730.57mm, but during the latter, it was getting above its long-term average, with the difference getting higher over time. Figure 2 also confirms this point.

Besides, Table 1 indicates that during 1981-1985 the country was facing a decline in agricultural value-added per capita of -8.5 percent per year, a catastrophic decline. Most likely, it happened during a war and an extensive drought period. After 25 years, however, the economy exhibited swift progress as proxied by this variable. The table indicates that during 2006-2010 the average growth rate in agricultural value-added per capita was 5.7 percent.

Figure 3: Trend of agricultural value added per person growth

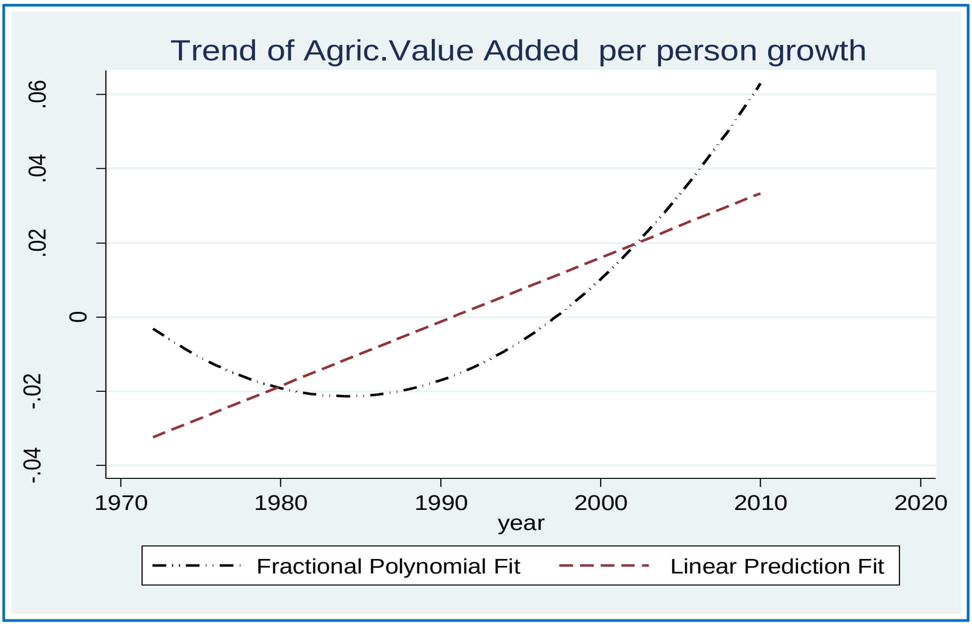
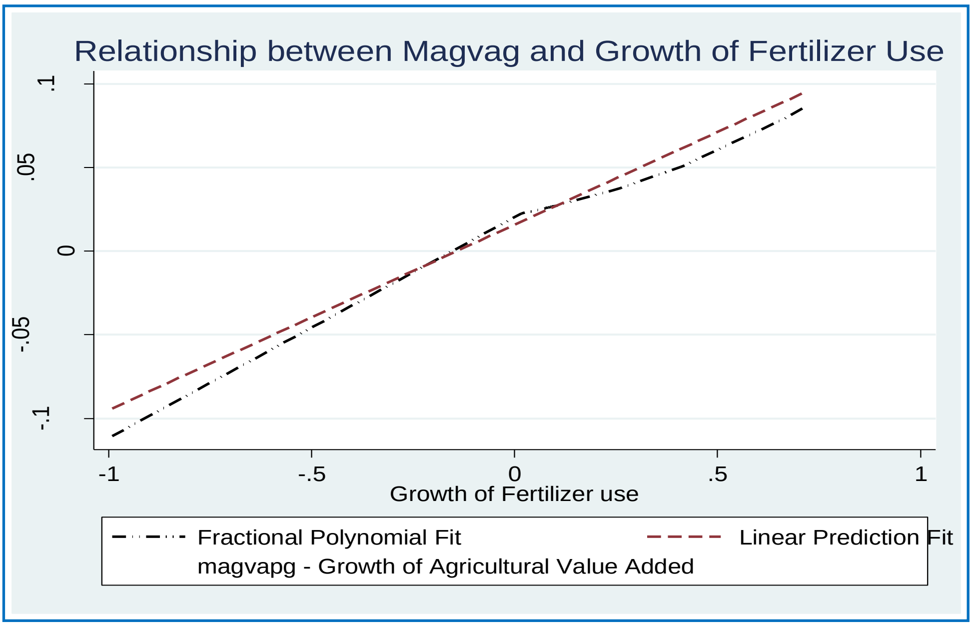


Figure 4: Relationship between agricultural value-added (magvag) and growth of fertilizer use



From the table, one can understand that the likely reasons behind such swift progress are improvements in the factor of production - fertiliser use that increased from 1.91 kg/ha in the first period to 20.12 kg/ha in the second, and land equipped for irrigation that increased from 180,965 to 311650 hectares. Figure 4 indicates a positive and nearly linear relationship between growth in agricultural value added and growth in fertiliser use, suggesting improvement in farm management could be among the likely factors behind the observed progress in the performance of the sector.

But these two factors alone may not bring such remarkable performances. Arable land per person has declined from 0.32 ha in the first period to 0.17 ha in the second, most likely due to rapid growth in rural population relative to the expansion of arable lands. Even if one cannot state this with certainty in our case, there is a possibility that land scarcity may induce technological progress. Besides, the growth of labour force has been close to stability, as the rate in both periods stood at 2.5 percent. Just like arable land, livestock per capita also declined from its level in the first period to the second. The scarcity of land and rapid growth of the rural population are likely reasons for the decline. However, the increase in aggregate livestock could be positively associated with aggregate-level output progress.

Figure 5: Relationship of rainfall and Temperature [1961-2010]

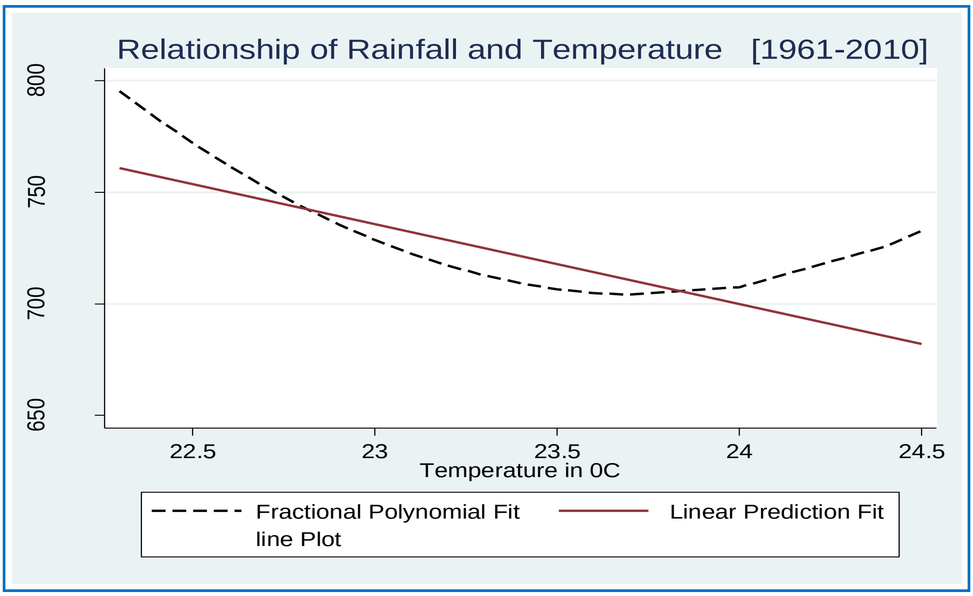
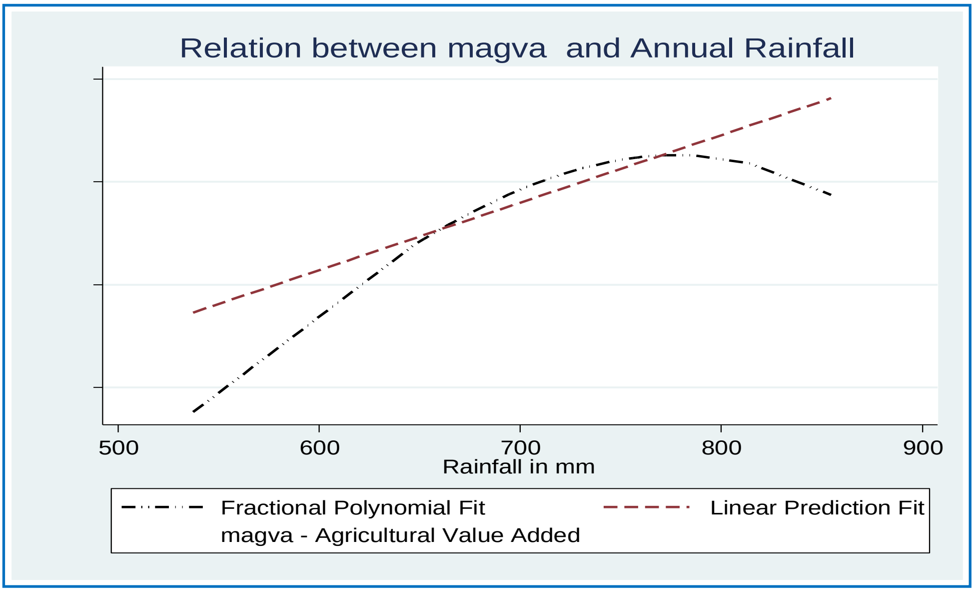


Figure 6: Relationship of agricultural value-added (magva) and annual rainfall



But the crucial point is how the secular change in temperature related to the secular volume of rainfall and how rainfall influenced the performance of the sector to bring about the results presented in Table 1 and Figure 2. Roughly one can imagine that if the secular trend in rainfall is below the optimal level, the rising secular trend might have been contributing favourably to the sectoral performance. This possibility can be observed in Figure 6. But if the trend has exceeded the optimal level, say at some point in time, it is likely that the rising trend has been adversely affecting the performance from that time on.

Figures 7 and 8 show curves with similar shapes. Roughly, Figure 7 suggests that for the growth of agricultural value-added per capita, there is an optimum temperature slightly below 24oC. Temperatures above or below such levels are associated with a lower rate of growth. Similarly, Figure 8 roughly suggests that the maximum growth of value-added in agriculture is associated with zero change in rainfall. In short, from the figures, it seems that the relationship between growth in agricultural value-added and temperature and growth in agricultural value-added and change in rainfall follows an inverted U-shape, which, if happed to be true, is compatible with plants and animals' physiology. To refine these points and related issues, we believe that econometric analysis is an indispensable tool.

Figure 7: Relationship between agricultural value added growth (magvapg) and annual temperature

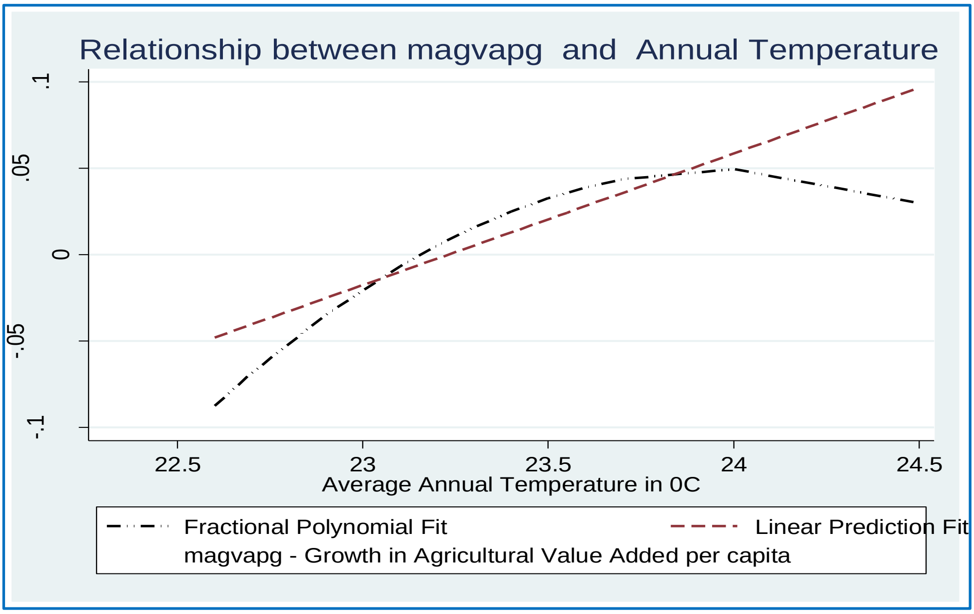
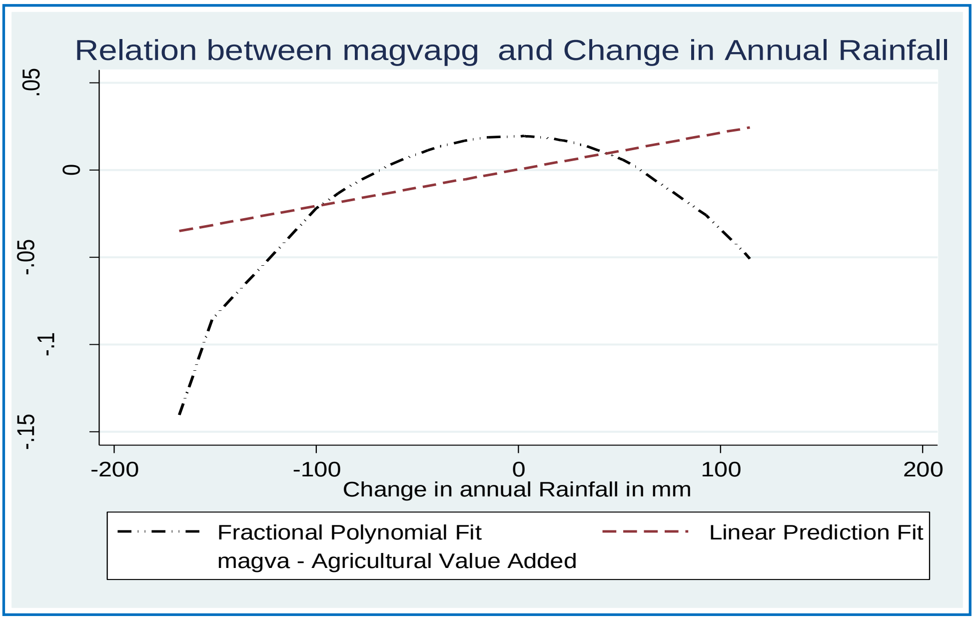


Figure 8: Relation between agricultural value added growth (magvapg) and change in annual rainfall



4.2. Econometric Analysis

To estimate equations [3] and [6], we used the national time series dataset described in Section 4.1. The analysis of agricultural time-series data requires taking care of the problems of non-stationarity (Granger, 1986) and technical inefficiency (Farrell, 1957; Aigner et al., 1977). Application of the Vector Error Correction Model (VECM from now onwards) to our dataset requires one to assume away the possibility of technical inefficiency while it is there in the actual case. Similarly, applicating the Frontier model to our dataset requires one to assume away the possibility of non-stationarity, while it is there too. Both assumptions are too costly to be the basis of our analysis. Rather, we followed an indirect approach that helps to avoid spurious regression.

Green (2003:852) notes that macroeconomic variables almost always exhibit non-stationarity or trending. Obviously, the application of traditional regression methods to such non-stationary variables leads to spurious results. To avoid spurious results, either one needs to have stationary variables or has to reduce them to stationary forms either through differencing or through the application of functional transformation. However, this could lead to the loss of some of the information needed for the analysis. On the problem associated with differencing the non-stationary but cointegrated variables with the aim of reducing them to stationary form, Green (2003: 852) notes, "...differencing would be counterproductive since it would obscure the long-run relationship....". The development of the concept of cointegration has simplified the problem to some extent. According to this approach, if some non-stationary variables are cointegrated even without transformation, the cointegrating parameters and t-tests and F-tests are not spurious, but they are economically meaningful (Gujarati, 2003: 822). This implies that to apply traditional regression methods, we need to undertake a cointegration test. On this point, Granger (1986) notes, 'a test for cointegration can be thought of as a pre-test to avoid spurious regression.' In the literature, one can find two approaches to testing for the cointegration of variables. The Engle and Granger (1987) method is based on assessing whether the equilibrium errors are stationary or not, and the Johansen (1988) and Stock and Watson (1988) approaches, which are indeed similar, are based on vector auto-regression. The second approach employed here tests the null hypothesis that there are r-number of linearly independent cointegrating vectors or fewer cointegrating vectors using the trace statistic.

Accordingly, to estimate equations [3] and [6], we first conducted cointegration test to confirm if the variables in our specified model are cointegrated or not. After confirming that the variables are cointegrated, the common step is to employ traditional regressions, or VECM, to get sample estimates of the cointegrating vectors. In our case here, proceeding with this step requires assuming the absence of technical inefficiency, while it could be there. Therefore, after fitting VECM, we tested the null hypothesis of no-technical inefficiency using the Frontier model before reporting the results from VECM. In the presence of technical inefficiency, since the cointegration test result legitimatises the application of traditional regression methods, we report the results from the Frontier model.

In the theoretical framework, it is indicated that two candidate models were suggested. To identify the model that fits the data better, both models were estimated using the VECM and Frontier, and their predicted values were compared with the actual. To start with equation [2], first, to employ VECM, we have to identify how many lags are to be included. The appropriate lag order was identified using Akaike's information criterion (AIC), final prediction error (FPE), Hannan and Quinn information criterion (HQIC), Schwarz's Bayesian information criterion (SBIC), and the sequence of likelihood ratio (LR) tests. Except for the statistic from SBIC that selects a model with lag(1), all the remaining three information criteria as well as LR tests suggest selecting a model with lag(2), not depicted here but found in the supplementary material.

Next, we conducted tests for cointegration based on the Johansen method. This test determines if the considered variables have a long-run relationship or not. After applying the method, we found that the trace statistic value (61.51) falls below the critical value (68.52) at the maximum rank of two, strongly rejecting the null hypothesis of one and failing to reject the null of at most two cointegrating equations. After determining variables are cointegrated, we estimated the parameters of our equation that can serve as estimates of parameters of a long-run relationship after making necessary rearrangements. The estimation results are presented in Table 2. However, bear in mind that these parameter estimates assume the absence of technical inefficiency and no physiological constraint on the rainfall-output relationship.

Table 2: Estimation Results of Equation [3] a

Estimator	Variable b	Coefficient	St. err	Z	P>|z|
VECM	Ln of agricultural value added	1.00	.	.	.
	Ln of annual rainfall	-0.46	0.12	-3.66***	0.000
	Ln of rural labour	0.75	0.26	2.84**	0.004
	Ln of TLU per person	-0.86	0.18	-4.81***	0.000
	Ln of arable land	-0.49	0.07	-6.70***	0.000
	Ln of total irrigated area (1000a)	-0.19	0.12	-1.62	0.106
	Ln of fertilizer in kg/ha	-0.36	0.11	-3.27***	0.001
	constant term	-6.68	.	.	.
	Number of obs=36; AIC = -21.03; HQIC= -19.98 , SBIC =-18.06				
	Cointegrating equations - chi2 = 1261.48 P>chi2=0.0000				
Frontier	Ln of Annual Rainfall	0.27	0.17	1.60	0.110
	Ln of labour	-0.36	0.19	-1.91	0.056
	Ln of TLU per person	0.29	0.15	1.90	0.057
	Ln of arable land	0.24	0.01	44.10***	0.000
	Ln of total irrigated area (1000a)	0.42	0.09	4.49***	0.000
	Ln of fertilizer in kg/ha	0.34	0.06	5.84***	0.000
	_constant term	9.52	.	.	.
	/lnsig2v	-26.45	47.19	-0.56	0.580
	/lnsig2u	-4.42	0.22	-19.76***	0.000
	sigma_v	0.000002	0.00004		
	sigma_u	0.110	0.012		
	sigma2	0.012	0.003		
	Lambda	60782.61	0.012		
Likelihood-ratio test of sigma_u = 0: chibar2(01) = 19.96 Prob>=chibar2 = 0.000					

*P <0.05, **P <0.01 and ***P <0.001.

TLU: Total livestock unit

The output from this estimator indicates that, under the considered assumption, the model robustly fits the data, P>chi2=0.000. The statistically significant coefficients of ln of annual rainfall suggest that the share of rain from the country's agricultural output is about 45.5 percent, or it suggests that a percent increase (decrease) in the volume of rainfall results in a 0.46 percent increase (decrease) in agricultural output. Likewise, the table reports that the coefficients of the natural logarithms of livestock in total TLU, irrigated land, fertilizer, and rural labour, the last variable with an unexpected sign, are also statistically significant.

As indicated above, these estimation results are based on the assumptions of the absences of technical inefficiency and the absence of no physiological constraint in rainfall-output relation. Keeping the issue for a while, next we dealt with the assumption of absence of technical inefficiency. In sober fact, the estimation results obtained from VECM and reported in Table 2 could be reliable only if the production system shows no technical inefficiency. That is the situation existing in the economic system is consistent with the assumption we made in applying the estimator.

However, since we are dealing with agricultural production, the issues of economic rigidity and uncertainty arising from imperfect foresight cannot be undermined. Therefore, after ensuring that the considered variables have a long-term relationship, the issue of technical inefficiency is examined.

The second half of Table 2 reports the estimation results from the Frontier model, which considered the issue of technical inefficiency. The table reports the parameter estimates together with their statistical tests. Besides, at the bottom of the table, it reports the test results of the null hypothesis of no technical inefficiency in the model. The output shows LR = 19.96 (p-value = 0.000), suggesting significant technical inefficiency existed.

Hence, we preferred the estimation results of Frontier instead of the ones obtained from VECM. Here, unlike the results of VECM, the coefficient of rural labour, with an unexpected sign, and annual rainfall are not statistically significant. Moreover, if the assumption that no physiological constraint is convincing, or at least the data were taken from the period when the actual secular trend of rain has not exceeded the optimal level, then one can estimate the share of rainfall from the entire agricultural output at about 27.1 percent. This shows a difference from the estimate obtained from VECM, which estimates the share of rainfall at 45.5 percent. Besides, the estimation results from Frontier suggest that the share of arable land, irrigation, and fertilizer is 24.4 percent, 41.7 percent, and 33.5 percent, respectively. Moreover, the results suggest that the share of livestock is 28.9 percent, which is weakly significant. There can be possible reasons for the wrong sign of the natural logarithm of labour, but besides the functional form under consideration, the negative marginal productivity of labour resulting from the abundance labour in rural areas is certainly a leading candidate among possible reasons.

In fact, the estimation results reported in Table 2 could be reliable as long as the dataset was taken from an environment with no secular trend in the rainfall or as long as the trend of rainfall did not exceed the optimal level. However, since the secular increase is underway, the inferences from the estimation results may not be reliable.

Equation [6] relaxes the assumption of the absence of physiological constraint. We estimated this equation following the procedure used for the estimation of equation [3]. To identify the number of lags, test results from AIC, FPE, HQIC, SBIC, and LR are used. Except for the statistics from SBIC and HQIC that select a model with lag(1), all the remaining three information criteria and LR tests suggest a model with lag(2) (Annex-3 test results depicted in the supplementary material). After identifying the lag order, we tested if the considered variables were cointegrated.

The trace statistics exceed the critical value at zero maximum rank, which implies no cointegrating equation, but the value 121.4 becomes less than the critical value 124.24 at a maximum rank or number of cointegrating equations of one (Annex-4 depicted in supplementary material). Hence, we rejected the null of no cointegrating equation and failed to reject the null of at most one cointegrating equation, showing the variables are cointegrated or have one cointegrating equation. Next, we estimated the parameters to get estimates of the long-run parameters (Table 3). Here again, we keep in mind that this estimation procedure is based on the assumption of no technical inefficiency.

Table 3 reports that the output from the VECM estimator indicates that under the no-technical inefficiency assumption, the model fits out time-series data well, chi2 = 2987 (P > chi2 = 0.0000). The coefficients of the natural logarithms of livestock in TLU (Total Livestock Unit), total irrigated land, arable land, and fertilizer in kg/ha carry the expected signs and are statistically significant. But the coefficient of the natural logarithm of labour carries wrong sign and is statistically significant (p>|z| = 0.011). The likely reason for the wrong sign could be excessive labour use, causing a negative marginal product.

Table 3: Estimation Results of Equation [6] a

Estimator	Variable	Coeff.	St.error	Z	P>|z|
VECM	Ln of agricultural value added	1.000	.	.	.
	Annual rainfall(mm)	-0.012	0.002	-6.18***	0.000
	ln of rainfall anomaly calculated as standardized rainfall	8.39e-06	1.41e-06	5.94***	0.000
	Ln of rural labour	0.49	0.193	2.53*	0.011
	Ln of TLU per person	-0.57	0.131	-4.40***	0.000
	Ln of arable land	-0.46	0.053	-8.66***	0.000
	Ln of irrigated land (1000ha)	-0.45	0.087	-5.16***	0.000
	Ln of fertilizer (kg/a)	-0.30	0.080	-3.72***	0.000
	_constant term	-2.84	.	.	.
	Number of observations = 38; AIC = 12.30; HQIC= 13.63 , 16.05				
	Cointegrating equations: chi2 = 2480.711 P > chi2 = 0.0000				
Frontier	Ln of annual rainfall(mm)	0.01	0.002	3.31**	0.001
	ln of rainfall anomaly calculated as standardized rainfall	-3.44E-06	1.25E-06	-2.75*	0.006
	Ln of rural labour	-0.37	0.002	-211.03***	0.000
	Ln of TLU per person	0.33	0.039	8.40***	0.000
	Ln of arable land	0.28	0.026	10.79***	0.000
	Ln of irrigation land	0.39	0.005	84.57***	0.000
	Ln of fertilizer (kg/a)	0.32	0.000	850.84***	0.000
	_constant term	9.31	.	.	.
	/lnsig2v	-24.91	33.403	-0.75	0.46
	/lnsig2u	-4.49	0.224	-20.08***	0.000
	sigma_v	0.00	0.000		
	sigma_u	0.11	0.012		
	sigma2	0.01	0.003		
	Lambda	27225.89	0.012		
Likelihood-ratio test of sigma_u=0: chibar2(01) = 22.79 Prob>=chibar2 = 0.000					

*P <0.05, **P <0.01 and ***P <0.001.

A shock to one of the variables, like rainfall, directly affects this variable. But it is expected that the effect is also transmitted to all other variables through the dynamic structure. An impulse response function traces the effect of a one-time shock to one of the innovations on current and future values (Figure 9).

Figure 9: Impulse-Response function

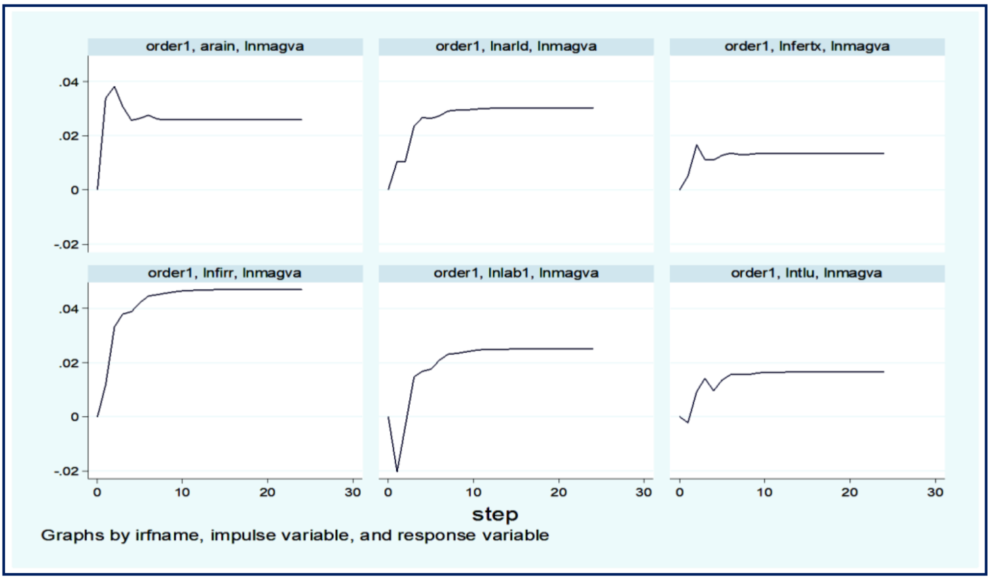
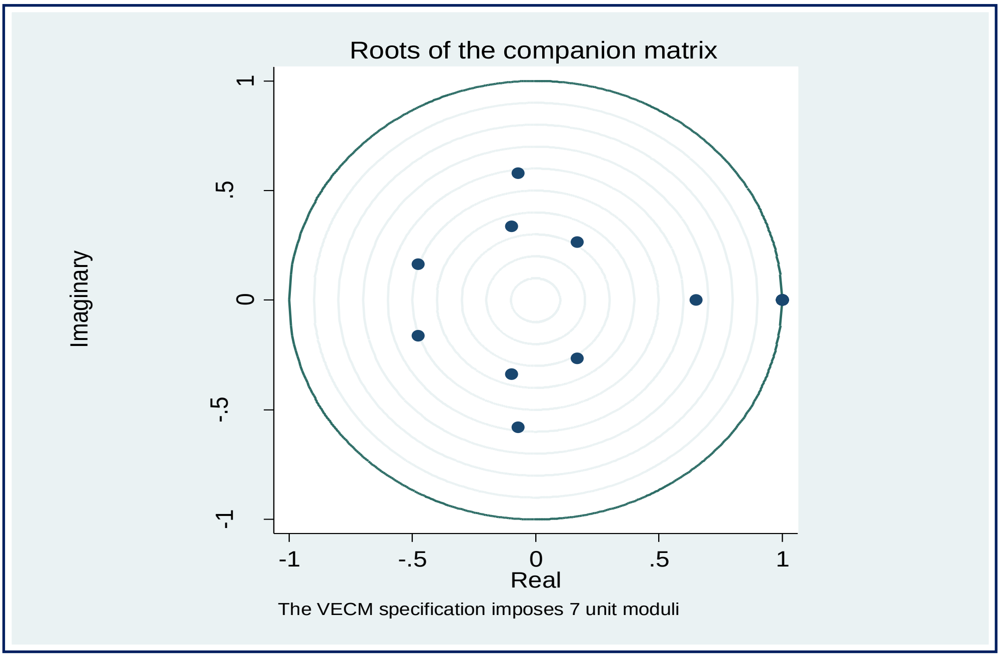


Figure 10: Roots of Companion Matrix



The trajectories of the impulse-response functions are almost similar, except for a shock to annual rainfall that shows an initial narrow, sharp point. The shocks to the rest variables cause temporary variations in the natural logarithm of agricultural value added (lnmagva) up to a period of 10 years and then end with a permanent effect on the natural logarithm of agricultural value added, which implies that the system exhibits long-memory processes. Making inferences after fitting VECM requires that the cointegrating equations be stationary. This requires a post-estimation test determine whether the cointegrating equations are stationary or not. Figure 10 presents the plots of the eigenvalues of the companion matrix, with the real component on the x-axis and the imaginary component on the y-axis. The graph shows that none of the remaining eigenvalues appear close to the unit circle, implying the stationarity of the cointegrating equation. In other words, the stability check does not indicate that our model is misspecified.

Turning back to the variables of interest, rainfall, the estimation results indicated that the coefficients of the natural logarithm of the annual rainfall (-0.012625) and of the rainfall anomaly calculated as standardized rainfall (8.39e-06) carry the expected signs and are statistically significant. These results confirm the hypothesis that the relationship between rainfall and output is not monotonic rather follows an inverted U-shape, indicating an optimal volume of annual average rainfall determined by the physiology of plants and animals. The parameter estimates suggest that this optimal level is about 752.4mm (-.0126252/(2 x 8.39e-06). From the shape of rainfall and output relation, the implication of this result is that when the rising trend of rainfall exceeds this optimal level, the diminishing benefit will set in the economy’s performance.

However, since this result assumes no technical inefficiency, having the estimate after relaxing the assumption would be more important. Based on the cointegration test results that confirm the variables are cointegrated, we employed the frontier model, considers the possibility of technical inefficiency. The test result is presented in the second half of Table 3.

Just like the results of VECM, the coefficient of the natural logarithm of rural labour lnrlab1 carries unexpected sign-negative and is statistically significant. This result suggests that an increase in labour would suppress the growth of agricultural output. Besides this, the remaining factors of production carry an expected sign, and estimates are statistically significant. Moreover, the coefficients of the natural log of annual rainfall and rainfall anomalies calculated as standardized rainfall carry the expected signs and have statistical significance. In agreement with the VECM estimate, this result also confirms the rainfall-output relationship has an inverted U-shape. This parabolic shape implies the existence of an optimal level of rainfall determined by the physiology of plants and animals. The coefficient estimates suggest this optimal level is about 742.15mm (0.005106/(2*-3.44e-06)), suggesting some economic gain from an increase in rainfall up to this optimal level and some economic loss from an increase beyond it. If an increase in temperature is associated with an increase in rainfall, as in recent times, then the result is consistent with Hope (2006) and Tol (2009), who inform initial benefits from a modest increase in temperature, followed by losses as temperatures increase further. The estimate of the optimal level is less than the estimate obtained from VECM by 10.25mm. We believe that the difference arises because VECM assumes the absence of inefficiency, and hence the level of rainfall and the time at which the diminishing benefits set in will be delayed. Putting it in other terms, had the production system been efficient, the time at which the economy starts facing the adverse effects of the secular increase in rainfall would have been delayed by some years until the indicated optimal level was reached. After considering physiological constraints and technical inefficiency, we were interested in seeing which quarter's rainfall is most important to production to examine the possibility of intra-annual water allocation.

Following the World Bank (2011), we divided and used from quarter 1 (December to February) to quarter 4 (September to November). We employed both the VECM and the Frontier model and presented the results in Table 4.

Table 4: Estimation Results of Equation [6] with Quarterly Rainfall a, b

Estimator	Variable	Coeff.	St.err	Za	P>|z|
VECM	Ln of agricultural value-added	1.00	. .	.	
	Quarter-1 (Dec-Feb)	-0.01	0.002	-7.74***	0.000
	Quarter-2 (Mar.-May)	-0.01	0.002	-7.11***	0.000
	Quarter-3 (Jun.-Aug.)	-0.01	0.002	-7.24***	0.000
	Quarter-4 (Sept.- Nov.)	-0.01	0.002	-6.59***	0.000
	Ln of rainfall anomaly calculated as standardized rainfall	7.79e-06	1.22e-06	6.39***	0.000
	Ln of rural labour	1.21	0.17	6.97***	0.000
	Ln of TLU	-0.78	0.11	-6.90***	0.000
	Ln of irrigated land (1000ha)	-0.37	0.06	-5.96***	0.000
	Ln of arable land (ha)	-0.17	0.08	-2.27*	0.024
	Ln of fertilizer (kg/ha)	-0.62	0.08	-8.05***	0.000
	_constant term	-10.59	.	. .	
	Number of obs=38; AIC = 38.10; HQIC= 40.45 , SBIC = 44.69				
	Cointegrating equations - chi2 = 4637.33 P>chi2=0.0000				
Frontier	Quarter-1 (Dec-Feb)	0.004	0.001	3.88***	0.000
	Quarter-2 (Mar.-May)	0.003	0.001	3.63***	0.000
	Quarter-3 (Jun.-Aug.)	0.003	0.001	3.99***	0.000
	Quarter-4 (Sept. - Nov.)	0.003	0.001	4.45***	0.000
	Ln of rainfall anomaly calculated as standardized rainfall	-1.92e-06	5.19e-07	-3.70***	0.000
	Ln of rural labour	-0.48	0.02	-33.02***	0.000
	Ln of TLU	0.37	0.01	80.03***	0.000
	Ln of irrigated land (1000ha)	0.26	0.06	4.22***	0.000
	Ln of arable land (ha)	0.36	0.02	21.02***	0.000
	Ln of fertilizer (kg/ha)	0.36	0.03	11.81***	0.000
	_constant term	11.00	.	.	.
	/lnsig2v	-26.30	44.603	-0.59	0.555
	/lnsig2u	-4.54	0.224	-20.29***	0.000
	sigma_v	1.95e-06	0.00004		
	sigma_u	0.10	0.012		
	sigma2	0.01	0.002		
	Lambda	53035.65	0.012		
Likelihood-ratio test sigma_u=0: chibar2(01) = 23.44Prob>= chibar2 = 0.000					

*P <0.05, **P <0.01 and ***P <0.001.

VECM, which assumes the absence of technical inefficiency, indicates that the marginal effects of the four quarters are more or less similar. But the marginal effects of quarter-1 (-0.014), that is, the marginal effect of the long dry season occurring from December to February, are slightly greater than those of the remaining quarters, with quarter 4 having the least marginal effects (-0.012).

Estimates of the marginal effects obtained from the Frontier estimator convey a similar message to that of VECM regarding the differences among the quarters. The parameter estimates of each quarter are more or less equal, though that of quarter 1 is slightly more important. The equality of the parameter estimates has some implications for the attempts made to adapt to climate change. For example, a nation can encourage rainwater harvesting practices at the individual household or community level as an adaptation strategy (Wakeyo and Gardebroek, 2017) of the third and fourth quarters (Korecha and Barnston, 2007), as it has been encouraged since the early 2000s (Wakeyo and Gardebroek, 2017). In the third and fourth quarters, the rainfall volume gets above the mean quarterly average (see Table 1) and can make use of the harvested water during the first and second quarters (the meagere-rainfall quarters). Since the marginal effects are more or less the same, it is possible to postpone the period at which the diminishing effect of rainfall sets in the production system. In other words. stepping on the observed empirical evidence, one can reduce the adverse impact of climate change on agricultural output through employing moisture stress gap filling technologies such as rainwater harvesting. From the literature, one can expect that technology gets additional benefit that come from inducing farmers to use fertilizers (Wakeyo and Gardebroek, 2013).

In general, the frontier estimation results presented in Tables 3 and4 indicate the likelihood that the country enjoys short-lived and negligible gains from climate change and suffers relatively higher economic losses in the long run. This result is consistent with Hope (2006) and Tol (2009), who documented initial gains from global warming and then economic losses. Tol (2009) indicated that the loss may go up to 25 percent of income in low-income countries. Thus, the effect of climate change on Ethiopian agriculture could not be different. Primarily, as the country exists closer to the equator, the region is expected to face more warming than the rest, and the effect may not be similar. Secondly, as a low income country, it may take time for policies designed to counter the effects. Thirdly, as in many low-income countries, measures to reduce the loss could be constrained by resource scarcity. Hence, the countermeasures need to be taken more determinedly on time and have to be supported financially and technically from the sources that generate the negative externalities.

5. Conclusion

The literature informs us that different parts of the world contribute quite differently to climate change. Also, they are affected differently, with effects ranging from extreme net economic losses to net gains. Different research results indicate that countries in tropical regions, like Ethiopia, are particularly vulnerable to the effect.

To investigate the impact of one form of climate change-rainfall variability-on agricultural output in Ethiopia, we compared two possible production functions. The first treats volume of rainfall as a production factor along with labour, capital, and land. The facts that it is an unpaid factor and that the amount of the factor that enters the production function is not under the control of the producers were considered. Besides these, the case that it implies the relationship between volume of rainfall and amount of output is monotonic, while the actual case could be non-monotonic, was considered critically. As an alternative approach, we employed a modified production function derived from a damage function where the damage is caused by a deviation of rainfall from its optimal level. Since the optimal is determined by the physiology of plants and animals, this approach takes into account a production function that considers physiology.

The empirical analysis is grounded in time-series data ranging from 1961-2012. Results from the econometric analysis indicate that it is very likely that the presently increasing trend of rainfall exceeds the optimal level of rainfall determined by the physiology of plants and animals in the near future. Such excess is associated with suppression of economic performance, which later, if left unchecked, leads to economic stagnation. In other terms, the analytic results indicate that the country enjoys very short-lived and negligible growth gains from climate change and the possibility that it may suffer relatively higher economic losses in the long run, unless satisfactory adaptation measures are taken. Among adaptation measures, the excessive rainfall that is very likely in the future can be an exploitable opportunity. The opportunity is that smallholder farmers can use rainwater harvesting to fill the moisture-stress gap created due to the early stoppage of rainfall in some areas. Most often, the winter rainfall in Ethiopia stops during mid- or early- September, when most of the crops of the major cropping season are in the critical ripening period. If a portion of the excess rainfall is harvested into ponds, shallow wells, and flood diversion structures, which require relatively low investment expenditure by households, the harvested water can be used to fill the moisture stress gap during the ripening period of crops. Note that under the increasing volume of rainfall that is expected, rainwater harvesting can be encouraged in rural areas and small towns to overcome the increasing shortage of potable water too, which is currently missing in several parts of Ethiopia. Because of this missing practice, we are losing this natural rainfall water in front of our eyes. Similarly, investment in conventional irrigation helps to overcome the effect of rainfall shortages in crop growing seasons. Also, dry-season irrigation can be cautiously encouraged, like in the case of irrigated wheat, in the production of food crops. In the dry season, wheat has the double advantage of increasing the supply of food crops while simultaneously reducing GHG emissions. These adaptations and transformative measures help to boost agricultural production and build climate-resilient agriculture.

In addition to the local measures, effective global-level mitigation measures could also help reduce the degree of economic loss. The paper concludes that, since the adverse impacts are caused mainly in the form of negative externality, the adaptation and mitigation efforts of the country need financial as well as technical support from the rest of the world.

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