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The Impact of Climate Change on Agricultural productivity in the Eastern African Community

Alexia Muhire Nshuti
Skidmore College, amuhiren@skidmore.edu

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By

Alexia Nshuti Muhire

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ABSTRACT

The impact of climate change is noticeable already affecting different sectors: health, social, economic and agriculture. Although climate change impacts countries differently, agriculture is expected to be the most vulnerable sector. The purpose of this thesis is to analyse the impact of extreme temperatures on agricultural productivity in the Eastern African Community. The Eastern African Region is chosen as a case study because of its dependence on agriculture. The study observes five countries with available data from 1991 to 2015. The result of the nonlinear temperature regression models shows a significant decrease on grain yields at extreme temperatures and rainfall measures.

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Introduction

What is climate change and why is it necessary that we understand its impact on the environment? To begin, it is important to understand that this major global event is, in the most part, a product of human activity. According to the European Environment Agency, the burning of fossil fuels is the largest contributor to climate change due to its significant release of carbon dioxide into the atmosphere. This causes a shift in the earth's natural balance of greenhouse gases, aerosols, and cloudiness (European Environment Agency, 2018). The thermal and solar radiation of the earth's energy balance is altered, causing either extreme warming and/or cooling of various areas of the globe (European Environment Agency, 2018). By disrupting the planet's natural processes, human activity is deteriorating the environment we live in, by encouraging terrifying natural disasters such as floods, droughts, cyclones and increase in soil acidity (European Environment Agency, 2018). According to Carleton and Hsiang (2016), climate change can no longer only be viewed in terms of environmental damages; it has surpassed its expectations and continues to negatively impact human and animal health, social and economic growth, and most importantly global food security. Food security is defined by the Food and Agricultural Organization of the United Nations as the sustained access to food that meets one's daily dietary needs in order to have a healthy life. Unfortunately, not everyone is included this is definition about 795 million people suffer from hunger (World Hunger, 2016). A number that is predicted to increase as climate change is negatively impacting agriculture, a vital sector to ensure food security.

It is worth noting that not all areas of the globe have been affected equally by climate change. Developing countries have been the most significant victims of climate change due to their lack of resources required to adapt to these drastic environmental changes. For instance, Eastern Africa is a region which relies heavily on agriculture, more specifically maize, rice and sorghum, for food security and economic survival and is thus an interesting case study to investigate. This has led me to develop my thesis question: What is the impact of climate change on agricultural activity in the East African Community?

The East African Community (EAC) was originally established in 1967 but fell apart in 1977 to then came back with a new treaty in 1999 with only three countries signatures: Kenya, Uganda, and the United republic of Tanzania (United Nations Economic Commission for Africa[UNECA], n.d.). Eight years later, Rwanda and Burundi joined the community, while South Sudan officially joined in 2016 (UNECA, n.d.). These countries have for common purpose to strengthen their economic sector through trade and market integration, while positively impacting their societies in order to reach a sustainable future for all (UNECA, n.d.). The major key to successfully achieve these goals is investing in the agricultural sector; a sector where approximately 80 percent of the population relies on, in terms of income and nutrition. With the progressive deterioration of the environment, it is essential to study the effect of these changes on countries that are more at risk, in order to create an early prevention plan.

Based on my previous research and literature review, I argue that extreme weathers will negatively impact agricultural productivity, namely very high or very low temperatures as well as heavy rains or complete lack thereof. I aim to prove this hypothesis by collecting data on temperature and precipitation variances from the World Bank's Climate Change Knowledge Portal (CCKP) and data on the agricultural productivity from the Food and Agricultural Organization of the United Nations. The methodology I use to determine whether a correlation exists between these variables is inspired by Deschênes & Greenstone (2011) study on the effect of extreme temperatures on human morality and residential energy consumption in the United States. Deschênes & Greenstone (2011) use a nonlinear temperature regression model, which allows the conservation of changes in temperatures. I used the same method and categorize the temperature and rainfall data to have a more accurate understanding on the impact of the two variables. Results show that, indeed, extreme weathers have a severe impact on agricultural productivity.

My thesis is split into multiple sections, the first section being the exploration of different literatures discussing the effects of climate change. In the second section, I will present my contribution to this existing literature. In the third section, I will outline my methodology used to test my hypothesis. In the fourth section, I will analyse the collected data and present the results in an orderly manner. Finally, the fifth section will discuss the impacts of my findings and open a platform for future research possibilities.

Section 1. Literature Review

This literature review is divided into six subsections. Part 1a explores the determinants of agricultural production and introduces the key topic: temperature extremes. Part 1b discusses the general burden climate change has on the African continent. Part 1c takes an in depth look at the implications of climate change on the Eastern African Community (EAC). Part 1d focuses on extremes temperatures and their role in crops production. Part 1e discusses this paper's relationship and additions to the literature. Finally, part 1f outlines the current study's hypothesis.

1.a- Determinants of agricultural production

Climate change has impacted and continues to impact multiple sectors including the health, social, economic and agriculture sectors (Carleton & Hsiang, 2016). Temperature change has a negative effect on human health, potentially deadly side effects (Gaffen & Ross, 1998). From 1949 to 1995, Gaffen and Ross (1998) show an increase in mean summertime temperature in the United States (US), leading to severe heat-stress events negatively impacting the population, especially elderlies. The combination of this increase in temperature and humidity show a positive correlation with mortality statistics (Gaffen & Ross, 1998). Curriero et al. (2002) study on the impact of extremely hot and cold temperatures on mortality in the US, estimate an increased risk of mortality increasing by 4 percent per 10°F decrease in temperature and a 4.3 percent per 10°F increase in temperature in the elderly population (65 years or more). Numerous studies (Meehl & Tebaldi, 2004; Curriero et al., 2002; Deschênes & Greenstone, 2011) support this correlation but also project economic losses as well as crucial environmental and social impacts in different parts of the world. Additionally, climatic variability has shown to weaken crops, exposing them to more diseases and affecting their overall growth (Rosenzweig, Iglesias, Yang, Epstein, & Chivian, 2001). The effect of these shifts in our ecosystem have distinctive (positive or negative) influences in different regions of the world (Rosenzweig et al., 2001). However, recent studies (Carleton & Hsiang, 2016; Tubiello & Fischer, 2007; Rosenzweig et al., 2001) prove that the change in climate have a severe impact on the global abundance of crops and food supply. Food security is considered the most pressing sector as humans require food for survival. However, about 795 million people suffer from hunger and about 98% of these people live in developing countries (World Hunger, 2016). Food security, which relies heavily on agricultural development also relies on the climate variability, which may positively or negatively impact global agriculture.

Many influential organizations in the environment debate, such as the National Aeronautics and Space Administration (NASA), National Geographic and the European Environment Agency (EEA) agree that human activity play a major role in today's environmental issues. The different factors leading up to the failure of our ecosystem and food production can be divided in two categories: physical and direct human factors. Physical factors are the changes in the ecosystem such as temperature change, rainfall, soil acidity and soil erosion (Fahey, Doherty, Hibbard, Romanou, & Taylor, 2017). Direct human factors, on the other hand, are the different direct actions humans take to maximize their production such as land tenure and investment in new technology (Fahey et al., 2017). Each of the factors often have an impact on the global agricultural productivity. Recent studies (Roberts & Schlenker, 2009; Parry & Rosenzweig, 1994; Chivian, Epstein, Iglesias, Rosenzweig & Yang, 2001) have pessimistic views on the future of agriculture, projecting a decrease in crops and food security with temperature change being one of the main causes of the decrease in agricultural productivity.

Various plants in the world, endemic to certain countries with different attributes, need special conditions and external additions to grow properly. Hatfield and Prueger (2015), using perennial fruits such as apples and cherries as examples, precise that climatic variations will have different impacts on plant development depending on the growth stage. The authors suggest that a rise in temperature in plants like maize, with an optimal temperature level of 29°C, will have a positive impact on the plant growth during the vegetative phase. However, Hatfield and Prueger (2015) also underline that a rise of 1°C to 4°C above the optimal temperature of certain plants has the potential to decrease the productivity between 2.5% and 10%. A rise in temperature above the common optimum level of 22°C for perennial fruits would disturb the pollination phase, causing a reduction in glucose, which would negatively affect the overall plant growth.

Previous research also state that grain fertilization is sensitive to extreme temperature (Ferris, Ellis, Wheeler & Hadley, 1998; Hatfield & Prueger, 2015). Ferris et al. (1998) analyse the effect of temperature change on spring wheat growth, from the sowing, to the flowering and post-flowering development phases. The wheat crop is planted under a controlled environment with ambient temperature. A heat stress was applied 12 days before the anthesis (flowering) phase, which is anticipated at around the 80th day after planting the grain. Before the increase in temperature no abnormal changes are detected within the growth of the crop.

However, the study reports differences in the grain yield on the 4th day of the heat treatment. The authors find a negative response of the grain yield on the heat treatment at 50% of the flowering stage. This indicates that an increase in temperature close to the flowering stage reduces wheat development. Ferris et al. (1998) show significant results on the impact of high temperature on crops. Under a natural environment other factors, such as wind, water erosion, and drought, which may have a critical effect on pre-anthesis, post-anthesis and on overall crop development would need to be taken into consideration.

Wheeler and Von Braun (2013) believe that the increase in temperature is mainly due to the rise of carbon dioxide (CO_2) in the atmosphere. The authors state that global warming will increase sea levels having a severe impact on agricultural productivity due to potential flooding in different regions around the world. Some countries with advanced technologies and current adaptation methods may be able to overcome the climate change stress for the next few years. Wheeler and Von Braun (2013) present concerns about the effects climate change will have on the developing world, especially on African and South Asian countries, which already face food security issues. Developing countries in this environmental debate, should be the main focus of discussion as they are the most vulnerable to extreme climatic conditions. Mirza (2003) state that developing countries have taken up to 'US$35 billion a year in damage from natural disasters'. An unsustainable yearly amount of money, which only worsen these countries by putting them into long lasting debt. An example of the gravity these countries face is the floods events in Mozambique. Due to heavy rains, in the beginning of 2000, Mozambique faced devastating floods that killed on their way 700 people (Mirza, 2003). The following year more destructive floods impacted the so-economic status of the country, creating 77.000 homeless and destroying 27.000ha of crops (Mirza, 2003). With 40% of the population leaving under the poverty line, Mozambique is expected to pay an annual amount of US$71 million as debt repayment when it can barely afford investment into health care and primary education (Mirza, 2003). This creates a vicious circle where the most vulnerable countries stay vulnerable because of their pre-determined conditions and because of an interruption in their economic growth plans due to environmental disruptions (Mirza, 2003).

Agricultural, as mentioned previously, is an important sector for economic growth. Many developing countries in Sub-Saharan Africa (Ethiopia, Central African Republic, Liberia, Benin etc.), which heavily rely on agricultural will see this sector decline as a result of climatic variability (CIA, 2016). Campbell et al. (2016) state that a one-degree increase in temperature is estimated to decrease variety of crops, including rice and maize, by 3 to 10 percent production. Wheeler and Von Braun (2013) predict climate change to have a negative impact on the continents' most popular crops: wheat, maize and sorghum. By 2050, Wheeler and Von Braun (2013) predict an overall decrease of 17% (wheat), 5% (maize) and 15% (sorghum) in Africa and a decrease of 16% (maize) and 11% (sorghum) in South Asia. Climate change is predicted to not only have an impact on food security, but spark different humanitarian crisis, including refugee crisis, civil wars, and financial shortfall.

1.b- Impact of Climate Change in Africa

Carleton and Hsiang (2016) analyse the past and present changes within the global economies and societies, as well as problems the future displays. In the 2016 paper, the authors report empirical studies on the impact of temperature change and rainfall over various sectors such as health, agriculture, mortality, electricity consumption and migration.

In the health sector, climate change has an impact on everyone through different ways. Carleton and Hsiang (2016) report that a change in temperature increases the risk of diseases, like cardiovascular or vector-borne maladies. An example given is the increase in the infectious disease, malaria, which migrates widely during extreme temperatures. High temperatures also have negative impacts on the early life of a human, impacting the foetus to the point of miscarriage. Within the economic sector, agricultural production has been affected the most, damaging people's nutrition and source of income. A decrease in yields production can slow down the economy in terms of trade and consequently affect the Gross Domestic Product (GDP) of a country. However, the same study also reports that the change in climate increases the demand for energy supplies, hence stimulating the economy. On the social level, climate variability affects humans on different scales, from the creation of intergroup violence to the migration of people risking death because of the deterioration of their homes and resources.

Carleton and Hsiang (2016) prove the need to worry about climate change as it impacts human beings on every aspect of a society. Agriculture, being a fundamental practice for survival, depends heavily on weather changes. The production of crops as well as the human efficiency to produce are drastically decreasing because of the negative environmental transformations. According to the Food and Agricultural Organization of the United Nations (FAO), the amount of undernourished people increased by about 38 million from 2015 to 2016.

Brown, Hammill, and McLeman (2007) share the same concerns as Carleton and Hsiang (2016) about the threat of climate change to the world, but more specifically in Africa. The authors point out the irony of climate change impacting countries the least responsible for the transformation of our ecosystem. With less advanced technology and resources for adaptations, African nations are expected to face multidimensional social and economic consequences repercussions. Brown et al. (2007) emphasize the link between climate change and the security the African continent is facing. The authors suggest that climate change creates a shortage in resources, which will most likely increase competition leading to conflicts between opponents. Africa, being the major continent at risk of the negative impact climate change engender, adaptation is an important focus for the different nations. Adapting to the new changes within the climate is the key to avoid conflicts and reach a fair agreement.

Past literature indicates that Africa is the most vulnerable continent to face the negative impacts of climate change, specifically in the agriculture sector (Brown et. al, 2007; Kotir, 2011). Kotir (2011) reports that a change in events such as precipitation, temperature and extreme weather have a significant impact on agricultural productivity with Sub-Saharan African (SSA). The study, supported by the general circulation models (GCMs), projects an increase in heat on the continent affecting mostly equatorial countries such as; Cameroon, Uganda and Kenya. Another climatic variable to consider when talking about agriculture production is rainfall. An increase in rainfall may hinder productivity but a decrease in rainfall leading to drought is most likely to have a severe negative impact on agriculture. On top of this climatic variability, natural disasters such as cyclones and floods are also common occurrences on the African continent. Overall, these authors underline that the negative effect of climate change on crop production in Sub-Saharan Africa is worrisome. Kotir (2011) states that a 2.5°C increase in temperature would decrease Cameroon's net revenue by US$0.79 billion and the greater the increase in temperature, the greater the decrease in revenue will be. In the near future, SSA faces terrible challenges in regard to food security.

Although, Kotir (2011) presents interesting predictions, they are not entirely reliable. GCMs are very efficient tools to analyse the past and the future impacts of climate change but they have limitations. One common limitation is omitting important country specific effects, such as droughts, floods and cyclones, into the analysis. Not all aspects of the environment are taken into consideration, which may lead to flawed results. However, GCMs have been improved for more accurate results since the paper was published in 2011. The rapid increase in climatic changes require more performing models that will be able to capture detailed estimates.

1.c- The impact of climate change on agricultural productivity in East Africa

The East African Community is an association composed of six countries: Burundi, Kenya, Rwanda, South Sudan, Tanzania and Uganda. Officially established in 1967 and expanded throughout the years, the community's principal mission is to reinforce its economy, political and social standings in Africa as well as internationally (East African Community, n.d.). In addition, the Community plans on creating further opportunities for the people of East Africa, increasing investments and improving its markets, while being the role model to surrounding countries ("Pillars of EAC Regional Integration," n.d.). Being the fastest growing region in Africa, the EAC still has a long list of objectives to achieve, especially concerning the agricultural sector. The EAC report of 2006 specifies these objectives: the improvement of food security within the region, improvement on crops adaptation for a sustainable future, investment into new technologies helping the efficiency of agriculture production, and an increase in foreign exchange through agriculture.

The EAC is an interesting case study for determining the impact of climate change on crops as agriculture takes a large portion of the region's economy. According to the Central Intelligence Agency (CIA) world factbook (2018), the agriculture sector accounts for 40% of the total GDP of Burundi, 35% of Kenya, 31% of Rwanda, 23.5% for Tanzania and 24.5% of Uganda. Another reason why the EA region is a good case study is because of the weather patterns it presents. From floods to droughts, high heat to high precipitation, the region's tropical weather can possibly have different significant impacts on agriculture development. Although agriculture is an important field and the main source of nutrition for a large part of the population, food insecurity is still present. The main causes of this insecurity, emphasised by the EAC report of 2006, is the climatic variations decreasing food availability, infrastructure and the overall poverty that dominates the region. The potential negative effect of climatic variations can lead to a decline in crop production affecting the agro-business of the EA region and therefore keeping a major part of the population unnourished.

Kahsay and Hansen (2016) agree with the significance of studying a region highly dependent on agriculture and therefore choose East Africa as their case study. The paper focuses on Burundi, Djibouti, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda. The authors use a United Nations food and agricultural organization dataset from 1980 to 2006 to analyse the impact change in temperature has on agricultural production and livelihoods in the Eastern African (EA) countries. More specifically, the climate variables are analysed within different growing seasons: fall, summer, and spring. Using a dataset from 1980 to 2006 from the Food and Agriculture Organization of the United Nations, Kahsay and Hansen (2016) construct the following standard model that shows the relationship between output and input:

$$\ln(Output_{it}) = \beta_0 + \beta_1 \ln(Labor_{it}) + \beta_2 \ln(Land_{it}) + \beta_3 \ln(Machinery_{it}) + \beta_4 \ln(Livestock_{it}) \beta_5 \ln(Fertilizer_{it}) \beta_6 \ln(Irrigation_{it}) + pTT_{it} + \mu_i + u_{it}$$

where represents total agricultural output of country *i,* in year *t*. The model is composed of various inputs: land, machinery, livestock, labor, fertilizer and TT_{it} irrigation represents country time trend. Kahsay and Hansen (2016) continue the equation by adding the climate change variables, temperature and precipitation, to evaluate changes within crops production. The equation is as follow:

$$\ln(Output_{it}) = \beta_0 + \beta_1 \ln(Labor_{it}) + \beta_2 \ln(Land_{it}) + \beta_3 \ln(Machinery_{it}) + \beta_4 \ln(Livestock_{it}) + \beta_5 \ln(Fertilizer_{it}) + \beta_6 \ln(Irrigation_{it}) + \sum_{s=1}^{3} \alpha_{1s} \ln(Temp_{ist}) + \sum_{s=1}^{3} \alpha_{2s} \ln(Precip_{ist}) + \sum_{s=1}^{3} \alpha_{1s} \ln(variability_{ist}^{Temp}) + \sum_{s=1}^{3} \lambda_{2s} \ln(variability_{ist}^{Precip}) + pTT_{it} + \mu_i + u_{it}$$

where $Temp_{ist}$ and $Precip_{ist}$are the average temperature and precipitation of country i in season of year t. $variability_{ist}^{Temp}$ and $variability_{ist}^{Precip}$ are measures within growing season temperature and precipitation. Kahsay & Hansen (2016) results overall show negative impact on agricultural production due to strong increase in heat and precipitation within growing season. The spring and fall temperature seasons may have increase agricultural output but have no significant impact. The summer temperature season on the other hand has an insignificant effect on the output. Interestingly, the within growing season under precipitation have more significant results but with negative coefficient. The precipitation during the spring and fall seasons are significant with p-value < 0.10.

The results drastically change when evaluating with the mean temperature and the mean precipitation. The mean temperature during the spring season has a positive coefficient of 0.871, with a very significant p-value <0.001. The summer and the fall mean temperature however, have a negative impact on agricultural output. Finally, the fall and spring seasons mean precipitation increase production significantly with p-value <0.05, while the summer season has a positive effect but it is not statistically significant.

Linderman, Lobell, Rowhani & Ramankutty (2011) also test to see if climate change has an impact on crop yields, specifically analysing maize, rice and sorghum productivity in Tanzania. All the data comes from Tanzanian Ministry of Agriculture including 19 regions of the country and looking at a period from 1992 to 2005. Like Kahsay & Hansen (2016), Rowhani et.,al (2011) use a simple linear regression model and also include the inter-seasonal variability of each climate variable into the following equation:

$$y_{ij} = \beta_0 + \beta_1 T_{ij} + \beta_2 P_{ij} + \beta_2 P_{ij}^2 + \beta_4 CW_{T-ij}{}^1 + \beta_5 CV_{p-ij} + a_i + \varepsilon_{ij}$$

[1] $CWT{-}ij*$ is most likely a typo from the authors who meant to write $CVT{-}ij$, according the previous information in the paper.

where y is yields, of the regions i, the observations within a region j, P represents precipitation, T for temperature, P_{ij}^2 for precipitation squared, CW_{T-ij} represents the inter-seasonal temperature variability, CV_{p-ij} represents the inter-seasonal precipitation variability, a country fixed effect term is also added to the equation a_i, and an error term ε.

Later on, the authors added the different regions as a dummy variable and a time variable to account for different changes within the agriculture:

$$y_{ij} = \beta_0 + \beta_1 T_{ij} + \beta_2 P_{ij} + \beta_2 P_{ij}^2 + \beta_4 CV_{T-j} + \beta_5 CV_{p-j} + \beta_6 Region_j + \beta_6 Year_j + \varepsilon_j$$

The results from Rowhani et al. (2011) study proves that climate change has, indeed, a significant effect on maize, sorghum, and rice in Tanzania. However, each climatic variable has a different impact on each crop. Results show that maize growth is favourable when there is an increase in precipitation but up to 120mm. A slight increase above that measure in precipitation would hurt the growth of maize. Sorghum shows similar responses to maize on precipitation effect but a stronger negative relationship on temperature change. In rice, temperature and precipitation change have a notable impact but the impact differs within seasons. Results show that during the first six months an increase in precipitation negatively impact the growth of the crop: however, an increase in heat over the same stage has a positive effect on rice. After presenting the model results for each crop, Rowhani et al. (2011) go further into the analysis and present concerning evidence about the future impacts of climate change on agricultural productivity in 2050 in Tanzania. Using a GCM, the study predicts that an increase of 2°C in temperature will decrease maize production by 5.2%, sorghum by 5.3% and rice by 6.0%. Although it is evident that climatic variations will have an overall negative impact on crop production, Rowhani et al. (2011) did not take into consideration other aspects of the environment that may reduce the production of these crops. For instance, it is possible that new findings about rice, maize or sorghum may abstain people from buying these crops, which will therefore decrease the demand. It is important to analyse the demand of a product as taste and preferences change. Kahsay & Hansen (2016) and Rowhani et al. (2011) articles both present evidence of agricultural challenges countries in East Africa are facing and will face in a near future. Challenges that need to be managed through policies, investment in sustainable agriculture is needed soon to avoid a famine crisis within the region.

1.e- Inspired Literature

As shown in the previous section, a lot of studies generally use a linear regression approach for modelling the effect of temperature changes, precipitation and other variables on crops. A model that does not take into account the different changes within climatic variables. Kahsay & Hansen (2016) and Rowhani et al. (2011) show unreliable results by using the linear regression. The question that arises is, how effective is this method and is there a better one? The critical aspect of this method is that it does not take into consideration nonlinear temperature patterns, which can trouble the accuracy of the study. The change in temperature and other climatic variables such as precipitation needs to be well taken into consideration for rigorous predictions.

Deschênes & Greenstone (2011) study the effect of extreme temperatures on human morality. They also examine the effect of these temperatures on residential energy consumption in the United States (US) by using a nonlinear temperature regression model that captures the changes in temperature. The authors defined the climate change's main variables by the daily maximum and minimum temperature and precipitation pulled from the National Climatic Data Center (NCDC). In order to determine the relationship between these climatic variables, morality and residential energy consumption, Deschênes & Greenstone (2011) construct the following equation model:

$$Y_{cta} = \sum_{j} \theta_{aj}^{TMEAN} \, TMEAN_{ctj} + \sum_{j} \delta_{al}^{PREC} \, PREC_{ctl} + \alpha_{ca} + \gamma_{sta} + \varepsilon_{cta}$$

where Y_{cta}represents the mortality rate for age group a in county *c* in year *t*. As people live things differently according to their age, the authors separate the age data into four distinct groups. Now, here is where this paper differs from other studies. $TMEAN$ represents the number of days in county c and year t and where daily mean temperature is in the jth of the bins created through data processing. To assure an accurate integration of the changes in temperature, Deschênes & Greenstone (2011) use a nonlinear temperature regression model, where the daily mean temperature is categorized within 10°F wide bins intervals. Starting from the lowest temperature 0°F, up to 90°F and higher, ten bins are created. This 10°F interval choice is set because of the vast range of temperatures the US presents within 35 years of data. The other climatic variable $PREC$ represents annual rainfall in county c and year t also categorized in different bins with 5-inch interval. 0-inch being the lowest length, up to 60-inches and above, categorizing the rainfall data into 11 bins. The authors also add a full set of county-by-age group fixed represented by α into the equation as well as state by year effects represented by γ_{sta} and to finalize the equation an error term is included, represented by ε. This nonlinear temperature regression model allows for more precision on the impact of extreme temperature and precipitation within the study.

1.f- Contributions

Due to Deschênes and Greenstone's (2011) empirical model allowing the conservation changes in temperature, the current study opt to use this method as well. Similarly, to Deschênes & Greenstones (2011) study, which looks at temperature data from 1968 to 2002, the current study focuses on more recent temperature data from 1991 to 2015. However, unlike Deschênes and Greenstone (2011), the lowest average monthly temperature in the current data sample is 17°C and the highest is 27°C and above. Temperatures extremes differ from country to country. In this case, countries within the EAC do not experience the same weather extremes found in the US, which can vary from -40°C to 30°C. That being the case, 2°C wide bins between the minimum and maximum temperature, with six bins, seems to be the appropriate interval to capture climatic changes. The current study's rainfall data ranges from 0 mm to 300mm as the maximum value is 299,674. The interval between bins is set at 50mm, creating six distinct bins as well. Different variables, such as GDP and population are added in order to look at the impact of human factors on maize production. The above arrangements are made in order to accurately estimate the link between climatic variability and yield for maize, the most cultivated crop in East Africa. Furthermore, this study contributes to the overall climate change literature and current debate on its existence and impact. The existing literatures use linear models (Rowhani et al., 2011; Kahsay & Hansen, 2016) to assess the impact of climate on agriculture, which does not fully capture the change in temperature. These literatures do not take into consideration the different impacts a one-degree increase has on agricultural productivity. A one-degree increase from 20°C to 21°C, for instance, will not have the same impact as a one-degree increase from 21°C to 22°C. The nonlinear temperature regression model inspired by Deschênes and Greenstone (2011) helps collect more quantitative estimates, giving us a better insight on the impacts of a degree change in temperature.

Following the decision of the current President of the United States, Donald J. Trump on the 1st of June, 2017 to withdraw the U.S. from the Paris Agreement, aiming to "strengthen the global response to the threat of climate change", takes us a step backward from improving our ecosystem (Dai, Lai, Wang & Zhang, 2017). This withdrawal of the world's most powerful country could influence other nations to rethink their stance on climate change and may lead to gaps in funding opportunities as countries decide to reduce the climate aid they assured to developing nations or even to defund important researches on climate change (Dai et.al, 2017). This study, therefore, contributes to the present discussion on climate change and to future policy recommendations specifically targeting developing countries.

Given the different studies analysed previously on climatic variations, it is fair to assume that extreme temperatures will have a negative impact on maize production. This hypothesis will be tested through statistical analysis in the next sections of this paper.

Section 2. Data and Methodology

This section of the paper is divided into three parts. Part 2a outlines the data for maize production, temperature, rainfall, GDP and population, variables used to implement the analysis of this study. Part 2b reports the summary statistics. Part 2c describes the models of the study and few prior steps taken before the empirical results.

2.a- Data

The maize production data comes from the Food and Agriculture Organization of the United Nations (FAO). The FAO compiles information on food, water, and agriculture related data for different region of the world from 1961 to the latest updated year. For this study, I collected data for the maize production quantity, measured in tonnes, from 1991 to 2015 for the five countries of focus in the EAC (Burundi, Kenya, Rwanda, Tanzania, and Uganda). This study could be conducted on a longer period of time, however the lack of data from the temperature and rainfall variables prevent further exploration.

The temperature and rainfall data, respectively noted in Celsius and in millimetres, is taken from the Climate Change Knowledge Portal (CCKP), a platform created by the World Bank Group (WBG) to record any global environmental changes. I obtain the temperature and rainfall monthly average for the same time period as the maize production. In order to create a comparable nonlinear temperature regression model to Deschênes & Greenstone (2011), the climate variables are categorized. The temperature data ranges between 17°C and 27°C and above. Creating a 2°C temperature bin interval seemed the most appropriate strategy to analyse the data. The first temperature bin range from 17 to19°C, the second bin from 19-21°C, third bin from 21-23°C, fourth bin 23-25°C, the fifth bin from 25-27°C and the last bin from 27°C and above. I use the same concept for the rainfall interval ranging between 0 and

300mm. For this variable 50mm interval bins are created. The first rainfall bin range from 0-50mm, the second bin from 50-100mm, third bin from 100-150mm, fourth bin 150-200mm, the fifth bin from 200-250mm and the last bin from 250-300mm. The GDP measured in US$ and total population data is directly collected on an annual basis from the WBG website.

Furthermore, as the analysis is based on a panel data, all the variables of the study need to be converted on a yearly basis. In this data collection only the temperature and rainfall variables need to be adapted to a yearly analysis. I added the number of months appearing in each bin within a year for each country. For instance, the average temperature of eleven out of twelve months, in 1991 in Burundi, appear to fall under the second temperature bin ranging from 19-21°C and one month falls under the third bin ranging from 21-23°C. Proceeding with the same year and country, the average rainfall of three months out of twelve fall under the first rainfall bin ranging from 0-50mm, one month falls under the second bin ranging from 50-100mm, seven months fall under the third bin ranging from 100 to 1500mm and one month falls under the fourth rainfall bin ranging from 150-200mm. Some bins are empty, which simply means that no monthly temperature or rainfall average appear to have reached the numbers in the respective bins. This arrangement of the monthly averages of the climatic variables into a yearly basis is expected for all the five countries of the data set.

2.b- Summary Statistics

Table 1, below, outlines the summary statistics of all variables. The analysis is based on the five previously mentioned EAC countries observing 25 years (1991-2015) of changes in temperature, rainfall and maize production. This makes a total of 125 observations.

Table 1: Summary Statistics for All Variables

Variable	Mean	Std. Dev.	Min	Max
Maize	1632715	1563697	54912	6737197
bin1 (17-19)	0.2	0.683917	0	4
bin2 (19-21)	3.52	4.143787	0	12
bin3 (21-23)	2.992	2.547915	0	10
bin4 (23-25)	3.664	3.282269	0	11
bin5 (25-27)	1.544	2.45772	0	8
bin6 (>27)	0.08	0.300537	0	2
bin1 (0-50)	4.072	2.008755	0	9
bin2 (50-100)	2.936	1.707403	0	7
bin3 (100-150)	2.912	1.844853	0	8
bin4 (150-200)	1.648	1.232987	0	4
bin5 (200-250)	0.296	0.609389	0	3
bin6 (250-300)	0.136	0.388213	0	2
GDP	1.20E10	1.41E10	7.54E08	6.38E10
Population	2.55E07	1.57E07	5542048	5.39E07
Observations	125			

Unsurprisingly, there is a fairly large difference between the mean of maize production 1632715 tonnes (s= 1563697 tonnes), GDP 1.2 billion (s= 1.41 billion) and population 2.55 million (s=1.57 million) and their respective standard deviation. A simple explanation of this dispersion is due to the time series analysis (1991-2015) as well as the difference in land and resources of the various countries of analysis. Tanzania being the biggest country with 947,300 sq km, within the community, Rwanda being the smallest with 26,338 sq km and with Kenya having the highest GDP, the dispersion is therefore evident (CIA). Since 1991, the population and GDP of the EAC has increased and continue on increasing, with the maximum values coming from 2015. The GDP and population are important variables to have in this study as they will help determine the impact maize production has on the overall economic performance as well as on the individual level.

Based on the mean values of the different temperature bins a significant difference can be noted. As mentioned previously, the first bins represent the monthly average temperature from 1991 to 2015. Between the minimum of 17°C and the maximum of 27°C and above temperature, there are six bins of 2°C interval. Four months within a year is the maximum time temperature ranged between 17-19°C. In other words, these countries rarely face temperatures below 19°C. On the other hand, bin 2, 3 and 4 have high mean values because temperatures between 21°C and 25°C are more apparent throughout the 24 years' analysis. Bin 7 has the lowest mean 0.08, the temperature in the EAC rarely goes above 27°C. The standard deviation between the temperature bins varies from 0.38 (bin 6) to 4.1 (bin 2). There is a notable difference in dispersion between the bins, bin 2 having the highest variation.

The same analysis can be used for the rainfall bins. The rainfall bins are arranged into six bins with 50mm interval. According to the summary statistics, the precipitation between 250-300 mm occurs the least throughout the years. The rainfall distribution seems to be higher within bin 1 with 0-50 mm, which can be considered as heavy rain. The rainfall measures between bins 1, 2 and 3 appear to be the most current within our time-series analysis. As Deschênes & Greenstone (2011) mention, the categorization of temperature and rainfall into distinct bins helps conserve the variation of temperature most studies keep linear.

2.c- Methodology

1- Regression analysis

This study's principal objective is to determine whether a change climate has a negative impact on maize production in the EAC. For this analysis, the following regression is used:

$$\log(Y_{it}) = \sum_a \theta_a^{TMEAN}\, TMEAN_{ita} + \sum_c \delta_c^{RAINF}\, TRAINF_{itc} + \gamma_i + \tau_t + \varepsilon_{it} \qquad (1)$$

Where Y_{it} represents the maize production in country *i* and in year *t*. Maize is chosen as the dependent variable because it is seen by the EAC as a value chain that could enhance GDP and lower food insecurity (Daly et. al., 2016). Maize is one of the few common crop in the EA region that had multiple positive growth periods but also face a decline in production due to different environmental conditions (Karugia et. al., 2013). Each country in the EAC face different environmental events that may happen at distinct or similar periods. It is therefore important to add variables for specific unobserved characteristics to a country and to a period. γ_i is found in the equation for country i's specific fixed effects and τ_t for a year specific fixed effects. Similar to Deschênes & Greenstone (2011), the variable $TMEAN_{ita}$ is present in the regression, representing in year *t* for country *i* the number of months in yearly average temperature in the ath of the six temperature bins with 2°C interval shown earlier in Table 1. The $TRAINF_{itc}$ variable lays on the same categorization concept as the $TMEAN_{ita}$ variable. $TRAINF_{itc}$ represents in year *t* for country *i* the number of months in yearly average rainfall in the *cth* of the six rainfall bins with 50mm interval. θ_a^{TMEAN} and δ_c^{RAINF} are unknown parameters. The equation end with the error term ε_{it}.

The second regression of this study includes two new logged variables: GDP and population. The equation is written as follow:

$$\log(Y_{it}) = \sum_a \theta_a^{TMEAN}\, TMEAN_{ita} + \sum_c \delta_c^{RAINF}\, RAINF_{itc} + \beta_1 \log(GDP_{it}) + \beta_2 \log(POP_{it}) + \gamma_i + \tau_t + \varepsilon_{it} \quad (2)$$

Where GDP_{it}represents the control variable for annual average rate of GDP of country *i* in year *t*. POP_{it} denotes the last added variable of the equation for the annual average of population of country *i* in year *t*. The temperature and rainfall variables measures and categorization in this equation are no different than in the previous equation. As mentioned previously this categorization helps keeping the natural variation within the climatic variables. The prediction of equation (2) will present negative estimates of the θ_a^{TMEAN} and δ_c^{RAINF} parameters. It is important to note that in both regressions maize production, GDP and population are logged as a way to scale the variation across countries there is between the dependent and the two independent variables.

2- The Hausman Test

In a panel model, the analysis can be modeled either by the random effects or the fixed effects. It is therefore essential to run the Hausman Test to help deciding between the two models. It is assumed that the

-Null Hypothesis: The Random Effects Model is suitable

-Alternative Hypothesis: The Fixed Effects Model is suitable

The resulting p-value of the test is high 0.9794, which mean the results are not significant therefore the random effects is chosen as the analysis model.

Section 3. Results

This section is divided into two section. Part 3a provides the estimates change in temperature and rainfall have on maize production. Part 3b discusses the estimate of the added variables to the equation, GDP and population.

3.a- Temperature and rainfall effect

Table 2 below reports the results of the first regression.

Table 2: Impact of climate on maize production

VARIABLES	(1) Maizeln
bin1 (17-19)	-0.144
	(0.0899)
bin2 (19-21)	-0.0734**
	(0.0286)
bin4 (23-25)	0.274***
	(0.0343)
bin5 (25-27)	0.0381
	(0.0429)
bin6 (>27)	0.256
	(0.228)
bin1 (0-50)	0.130***

	(0.0452)
bin2 (50-100)	-0.0318
	(0.0486)
bin4 (150-200)	-0.0207
	(0.0620)
bin5 (200-250)	-0.194*
	(0.102)
bin6 (250-300)	0.00226
	(0.161)
Constant	12.47***
	(0.471)
Observations	125
Number of Countries	5

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The basic step to avoid unreliable results was to control for multicollinearity and drop variables. In this analysis, the third temperature and rainfall bins were chosen as baseline variable. The results from the first equation show interesting coefficients supporting the hypothesis stated earlier. Every one-month increase in the first temperature bin, 17- 19-degree interval, will lead to a decrease of 14.4% annual maize production. Although the results from the first temperature bin is not significant, a 14.4% decrease may have major impacts on the long-term. Using the same analysis, for every one-month increase in the second temperature bin, 19-21-degree interval, will lead to a decrease of 7.34% annual maize production, with a p-value of 0.0, which is very significant. Oppositely, an increase of 0.274 in annual maize production is recorded when the monthly average temperature is between 23-25°C, the p-value equating 0, the result is extremely significant. For every on-month with an average temperature above 25°C, the fifth bin (25-27°C) and above 27°C, the sixth bin, there is an increase in annual maize production respectively by 0.038 and by 0.256. A slight increase with no significance compared to the second and fourth bin. With these values it is fair to assume that an increase in temperature can be beneficial for maize production.

Interestingly, the significant results in temperature appear to be 2°C below or above the 22°C median. Contrary, the rainfall significant results are found at the lowest and highest extreme rainfall values. The first bin of the rainfall measures has the most significant value with 0.004 p-value. For every one-month increase in the 0-50 mm interval, would lead to a 13% increase in annual maize production. However, once the rainfall exceeds 50 mm, the maize production is negatively affected. Rainfall between 50-100 mm and 150-200 mm, respectively decrease maize production by 3.18% and by 2%. The fifth bin between 200 and 250 mm is statistically significant with a p-value of 0.0.56. For every one-month increase in this previous bin would decrease the annual maize production by 19%4. Finally, rainfall between 250 and 300 leads to a slight and insignificant increase of 0.2% on annual maize production.

3.b- GDP and population contribution

Table 3 below reports the results of the second regression

Table 3: Impact of GDP and population on maize production

VARIABLES	(1) Maizeln
bin1 (17-19)	-0.159**
	(0.0708)
bin2 (19-21)	-0.0108
	(0.0282)
bin4 (23-25)	0.0609*
	(0.0313)
bin5 (25-27)	-0.0188
	(0.0301)
bin6 (>27)	-0.0261
	(0.158)
bin1 (0-50)	0.0968***
	(0.0367)
bin2 (50-100)	-0.0301
	(0.0329)
bin4 (150-200)	0.00317
	(0.0443)
bin5 (200-250)	0.0640
	(0.0749)
bin6 (250-300)	0.263**
	(0.112)

GDPln	0.584***
	(0.185)
Populationln	0.728**
	(0.328)
Constant	-11.84***
	(2.824)
Observations	125
Number of Countries	5

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To increase the explanatory power of the model, GDP and population are added to the equation as independent variables. The addition of these variables lead to a modest change on the coefficients from the first equation. In this second equation, for every one-month increase in the first temperature bin, 17-19-degree interval, continues to decrease the annual maize production by15.9% but the result is, currently, significant with a p-value of 0.025. On the other hand, the second bin, with a previous significant coefficient became insignificant. The addition of GDP and population variables to equation reduces the annual maize production by only 1.08% for the same temperature bin. The fourth bin with temperatures between 23-25°C continue to have a positive impact on annual maize production but with only a p-value of 0.052, less significant than before. For every one-month increase in this previous bin, will lead to a 6% increase in annual maize production. The last two temperature bins shift from positive to negative coefficients indicating a non-significant decrease in maize production. For every one-month increase in the fifth and sixth bin, will respectively lead to a decrease of annual maize production by 0.188% and by 0.26%.

For every one-month increase in the first rainfall bin, with 0-50mm interval, increases annual maize production by 9.68%. The coefficient form this previous bin has the greatest impact on maize production and continues to be very significant with a p-value of 0.08. Every additional month in the second rainfall bin negatively impact the maize production, decreasing it by 3%. The fourth and fifth rainfall bins lead to a slight, however, insignificant increase in maize production. For every one-month increase in the fourth and fifth bin will respectively lead to an increase of annual maize production by 0.3% and 6.4%. An additional month in the last bin will significantly increase the annual maize production by 26.3% with a p-value of 0.019. Finally, a 1% increase in GDP and population respectively leads to a 0.584 (p-value=0.002) and 0.728 (p-value=0.026) increase in annual maize production, both coefficient being very significant. The inclusion of GDP and population show that an increase and decrease in maize production is not only determined by nature but also by human activity. A substantial growth in economy and investment into the people would actively increase the production of crops. The addition of these two variable helps with the accuracy of the model.

Section 4- A comparison of models

In this section, I make a comparison between the nonlinear temperature regression model results and the linear temperature regression model (see: Kahsay & Hansen, 2016) using the averages of the climatic variables with no categorization. Part 4a provides the linear regression analysis. Pat 4b presents the results for the first equation of this model. Part 4c presents results from the second equation.

4.a- Regression analysis

The following linear equation is used as a comparison:

$$\log(Y_{it}) = \beta_0 + \beta_1 Temp_{it} + \beta_2 Rain_{it} + \gamma_i + \tau_t + \varepsilon_{it} \qquad (1)$$

Where Y_{it} represents the maize production in country *i* and in year *t*. $Temp_{it}$ represents the annual temperature average of country *i* in year *t*. $Rain_{it}$ using the same reasoning, represents the annual rainfall average of country *i* in year *t*. As mentioned previously each country in the EAC face different ecological events that may happen at distinct or similar periods. Similar to the equations in the non-linear temperature regression model variables for specific unobserved characteristics to a country and to a period are also added in this linear model. γ_i

represents country i's specific fixed effects and τ_t for a year specific fixed effects. The equation ends with the error term ε_{it}.

The second regression of this comparison also includes GDP and population as logged variables. The equation is written as follow:

$$\log(Y_{it}) = \beta_0 + \beta_1 Temp_{it} + \beta_2 Rain_{it} + \beta_3\, log(GDP_{it}) + \beta_4\, log(POP_{it})\ + \gamma_i +\ \tau_t + \varepsilon_{it}\ (2)$$

Where GDP_{it} similar to the nonlinear temperature regression model, represents the control variable for annual average rate of GDP of country *i* in year *t*. POP_{it} represents the annual average of population of country *i* in year *t*. The temperature and rainfall variables averages in this equation are no different than in the previous equation (1). The variables for specific unobserved characteristics stay the same in this equation and ε_{it} is the error term.

4.b- Results of the linear model

Table 4: Impact of climate on maize production (a linear observation)

VARIABLES	(1) Maizeln
Temperature	0.289
	(0.208)
Rainfall	0.00443
	(0.00514)
Constant	6.524
	(4.570)
Observations	125
Number of Countries	5
R-squared	0.553

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In this linear model climatic variables seem to only have a positive impact on the annual maize production. The yearly mean temperature increases the annual maize production by 28.9%. This model as mentioned earlier, assumes that a one-degree increase from, for instance, 20°C to 21°C will have the same impact on maize production as an increase in temperature from 23°C to 24°C. In this case, the impact is only a positive maize production. The nonlinear temperature regression model presented earlier disproves this notion. Proving that an additional month under the 19-21°C temperature interval actually has a negative impact on maize production rather than a positive one. Similar to the temperature variable, the yearly mean rainfall in this model only shows a positive impact, increasing the annual maize production by 0.4%. Whereas in the nonlinear temperature regression model, rainfall between 50 and 250mm had a negative impact on the annual maize production. Although the climatic variables in this model have a positive impact on the annual maize production, none of the coefficient are significant.

4.c- GDP and population contribution

Table 5: Impact of GDP and population on maize production (a linear observation)

VARIABLES	(1) Maizeln
Temperature	0.317*
	(0.191)
Rainfall	0.00589
	(0.00472)
GDPln	0.730***
	(0.184)
Populationln	-0.211
	(1.228)
Observations	125
Number of Countries	5
R-squared	0.634

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The addition of GDP and population in the equation significantly change some of the coefficient. The annual mean temperature increases the annual maize production by 31.7% and is currently significant with $p<0.1$. This previous annual mean rainfall continues to be positive and non-significant. The following climatic variable increases the annual maize production by 0.58%. Similar to the nonlinear temperature regression model, the GDP in this linear model continues to be very significant with $p<0.01$. In this model a 1% increase in

GDP will lead to a 0.73 increase in annual maize production. A 1% increase in population, on the other hand, will lead to a 0.21 decrease in annual maize production, conflicting results from the first analysis. In the nonlinear temperature regression model a 1% increase in population actually benefit the annual maize production increasing it by 0.728.

Section 4. Discussion

This section of the study is divided into three parts. Part 4a looks at the relationship between extreme temperatures and maize production. Part 4b outlines the limitations.

4.a- The relationship between extreme temperatures and maize production

As mentioned earlier, this study hypothesized that extreme temperatures have a negative impact on maize production. When testing this hypothesis, the results indicated that for every one-month increase in extreme temperature values between 1991 to 2015 negatively impact the annual maize production. According to the results of the first equation of the nonlinear temperature regression model, a one-month increase in extreme cold temperatures, in this case being between 17-21°C show a significant decrease in the annual maize production. Similarly, in the same model with the accuracy the GDP and population variables bring to the study, it is notable that for every one-month increase in extreme heat temperatures, ranging from 23°C and above (>27°C), also have a negative impact on annual maize production. Although these results support the hypothesis, they differ from the literature mentioned previously. Hatfield and Prueger (2015), for instance, predict that a rise of 1°C to 4°C above the optimal temperature of certain plants will potentially decrease the productivity between 2.5% and 10%. Hatfield and Prueger (2015) assert 29°C as being the optimal temperature level for maize production. In this study, an additional one-month increase above 27°C will lead to a 2.6% decrease in annual maize production. It seems that in the eastern African region, maize start being negatively affected 2°C below its optimal temperature. This may be influenced by different other aspects of the environment such as the humidity. The interpretation of the results the temperature variable has on maize production using the linear model are not reasonable. Compared to other linear models, Kahsay & Hansen (2016) and Rowhani et al. (2011) present an overall negative impact on agricultural production, the results of this study using the linear model instead show a positive impact on maize production.

The distribution of results of the rainfall variables in the nonlinear temperature regression model also support the hypothesis. The lowest extreme precipitation ranging between 0-50mm has a positive significant impact on the annual maize production. While precipitation, as previously mentioned, between 50mm and 250mm has a negative impact on maize production. The highest extreme precipitation between 250-300mm is positively and statistically significant. This last result is interesting as high level of rain tend to cause flooding negatively impacting crops. The results of the rainfall variable using the linear method, once again, are unreliable as it only presents a positive impact on the maize production. These results do not align with Rowhani et al. (2011) who state that an increase above 120mm will negatively impact the maize growth.

The inclusion of the GDP and population influence the magnitude, which increase the accuracy of the study as human factors are then included in the analysis. Accounting for other variables such as wind and soil acidity would also have an impact on the overall results. These results prove the sensitivity the EA countries have to extreme temperatures. Continuing towards these extreme temperatures risk to cause a significant decrease in maize production in the nearest years. Using a more basic reasoning inspired by Lewis & King (2017) who project the future temperatures years 2036-2065. Assuming there is an increase of 2°C in temperature, this would lead the first bin, in this study, to shift to the second bin, the second bin would take the third bin's position and so on until the last bin. Following this assumption, in order to predict the future impact on maize production the coefficients of the nonlinear temperature regression model are added together. This method predicts an overall decrease in maize production of 2% in the future years of 2036-2065.

It is important to understand the difference between climate change and global warming. Climate change, as mentioned previously, is referred as “a statistically defined change in the average and/or variability of the climate system, this includes the atmosphere, the water cycle, the land surface, ice and the living components of Earth” (“Climate Change”, n.d). While global warming is defined as “the usually rapid increase in Earth’s average surface temperature over the past century primarily due to the greenhouse gases released as people burn fossil” (Global Warming, n.d). These two concepts are often misinterpreted. Controversially, the results of my study show that global warming is actually beneficial for maize growth. This study calls for an awareness on the global climate change. The variation of climate from low to high extreme temperatures is what we need to worry about when analysing the future of agriculture productivity.

4.b- Limitations

Crops diversity - A limitation of this study is the lack of crop diversity. The analysis only focuses on maize, when it could include more popular crops that grow in the eastern African region. Including more crops may change the results of the study as different crops need different climatic conditions to grow. The next ideal crops to include in this study would be rice, wheat and sorghum. These crops are the most cultivated after maize in the EAC.

Climate variables - Another limitation of this study is the climate variables values. Unlike Deschênes & Greenstone (2011) I was only able to find the monthly average of the rainfall and temperature variables. Obtaining daily averages of temperature and rainfall would have taken the analysis of the impact of climate change on an advance and accurate level. Results, potentially, could have inspired a day-to-day policy on how to avoid an increase in temperatures leading to a decrease in maize production.

Natural disasters- This study only accounts for the change in climate, specifically, looking at temperature and rainfall. As discussed earlier, agricultural productivity is not only affected by the change in the environment but also by other natural disasters including floods, cyclones and droughts. Including the impact of these natural disasters is important for the accuracy of the results.

Human activity- Similar natural disasters on a different scope, human activity also impact agricultural productivity. This study does not account for the newest technology or traditional ways used to enhance productivity. This is an important aspect to incorporate as it has a direct effect on production.

Data set - The data was also limiting in terms of temporal statistical analysis. The latest year found for the temperature and rainfall variables of the study was 1991. Although the data runs over a 24 year's time-series analysis, having data prior to 1991 would increase the credibility of my findings. Because of the lack of extensive data collected, I fear that the correlation between the climatic variables and maize production might not be as detailed as it could be. Moreover, ideally having more granular level of maize production data would help with the precision of the study.

Sample size- This study only looks at five eastern African countries, while the east coast region of the continent is composed of more nations. A larger sample size with greater extreme temperature variations may present more significant relationships from the data. For instance, Ethiopia could be added to the study, with an average temperature minimum of 9°C and maximum of 28°C, the addition of this country would could provide with even more interesting results.

Section 5. Conclusion and Policy implications

Using data from the FAO, the WBG and the CCKP, and implementing a nonlinear temperature regression model I was able to study the impact of climate change on agricultural productivity in the Eastern African community. I specifically observed the agricultural development of five countries: Burundi, Kenya, Rwanda, Tanzania and Uganda during the 1991 to 2015 years. The use of the nonlinear temperature regression model allowed for more accurate results, as it took into consideration the different impacts the numerous variations climatic variables may have have on cultivation. The final results show that extreme temperatures have a negative impact on maize production in the EAC. Continuing towards these extreme temperatures risk to cause a significant loophole no only in the agricultural sector, but also into the food security and economic development plan of these countries. The countries of study are more vulnerable than others as the agriculture sector accounts for more than 20% of their GDP. Hence, more innovative policies need to tackle agriculture in the EAC to ensure a sustainable future.

The first policy that could be implemented is the control on crops. Examining the ideal seasons for the different crops would help controlling the loss of production. This policy would help addressing the climatic variability negative effects on agriculture in order to ensure the maximum abundance of crops. A second policy is the investment in new technologies. Between 2008-2014 the agricultural GDP per worker, in the African continent, equated to an annual total average of $US832.45 (Africa Agriculture Status Report, 2016). With such low revenue it is rarely possible for farmers to buy the newest machineries. In this regard, the EAC governments should increase the exposure to microfinance allowing smallholders to borrow more money in order to further invest into their agribusinesses. In addition, the EAC governments could donate land to the population to enhance agriculture practices leading to more crop production. Finally, investing into research institutions that can further study the impacts of climate change by building efficient adaptation strategies, in order to reduce the vulnerability of plants could be essential for the future of agriculture.

Overall this study makes important contributions to existing literature because it presents significant results, which provide a natural guide to future research. For instance, the use of at least a 30-year spam data on climate change and agricultural production. The use of a larger scale data would provide interesting results with a better understanding the change in climate had and will have on crops production. Future research could also include solar radiation as a variable as the sun is an important element in the ecosystem cycle. Climate change is a broad concept, for some a new one. Much research remains to be done with careful analysis as it has been proven that climate change has a global impact, especially, in developing countries. As the EAC follow its economic plan to grow and become the leading region of the African continent, the leaders must start having a conversation on climate change, evaluating the risks to find suitable solutions for the future of agriculture. Climate change is happening and the worst is yet to come.

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