ACE529 - Data Science

Deforestation and Climate Change: The Case of Zambia

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I. Introduction

Deforestation, particularly in Sub-Saharan Africa (SSA) has been on the rise, which threatens the global climate and also biodiversity (Sparovek et al., 2012). In SSA, trees are integral for food, fuel, medicinal products, building materials, and as a commodity to generate income (Boffa, 1999). Rural smallholder farmers in Zambia rely on trees as an important source of income from charcoal production (Mulenga, Hadunka, and Richardson, 2017). Charcoal production is important both as a source of income and because it is the main fuel used for cooking in Zambia. There is a strong correlation between deforestation and temperature increases (climate change) in Zambia, especially when considering charcoal production. Trees are cut down to produce charcoal, and the production of charcoal releases greenhouse gases into the air, contributing to climate change. Climate change disrupts weather conditions in Zambia, affecting livelihoods and causing people to resort to charcoal production as a way to get income. This is just one example of the interconnectedness of deforestation and climate change.

Climate change and deforestation have impacts not only for the local people and small farmers in SSA, but also for the entire world. There has also been increased focus on the policy issues between climate change and deforestation due to the potential synergies and policy conflicts between forest conservation and climate change mitigation (Buizer, Humphreys, and de Jong, 2014). The goal of this paper is to investigate whether there is a relationship between the deforestation rate and temperature increases (climate change) in SSA. We focus specifically on Zambia due to the availability of data and the ability to extrapolate results to the rest of SSA. The relationship between deforestation and climate change in this area has typically been understudied, so our results shed new light on the discussions about climate change. Our results also have practical implications for the development of policies related to deforestation and climate change in Zambia.

II. Background

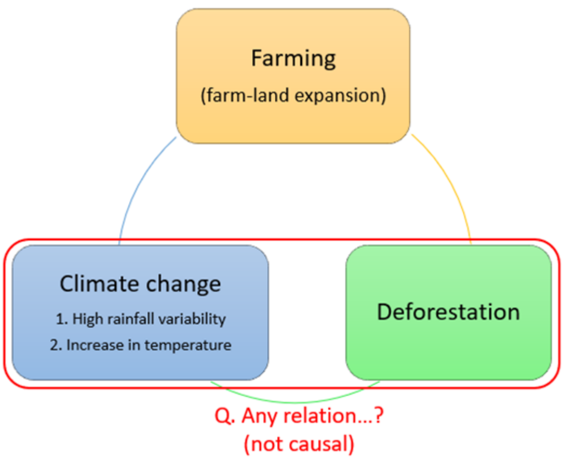
In Zambia, about 60% of the forests lost per year, on average, is caused by cropland expansion by smallholder farmers (Ngoma et al., 2021). The high proportion of forest loss caused by smallholders motivates us to investigate the relationships between deforestation due to smallholders' behavior and the year to year climate variations such as temperature in the smallholder's living zones. Previous studies have found that land cover changes can change the surface energy and water balance, thus affecting the regional climates (Kalnay & Cai, 2003; Pielke et al. 2002). Kalnay and Cai (2003) used the observed surface temperature data in the United States to estimate the impact of land use changes on surface warming, and they found that agricultural development tends to increase the minimum temperature. In addition to the effect of deforestation on temperature, rainfall is found to be highly correlated with temperature (Pumo et al., 2019). Besides, Phiri et al. (2019) found that deforestation can be influenced by cultivated areas. Therefore, rainfall and cultivated land area are included as controls to improve the estimation accuracy.

III. Conceptual Framework

The mechanisms through which deforestation can lead to increased climate change risk appear complex and contextual, and remain an important research need. This short report tries to investigate if a higher deforestation rate affects the climate change proxied by higher temperatures by using simple visualization and regressions.

Expanding area cultivated into forests has been taken by small-scale farmers, especially in developing countries, as an important risk coping strategy in response to recent climate change. Thus, in this report, we assume that the mechanism would be that: first, climate change/extreme weather (e.g., drought) serves as a negative weather shock for small-scale farmers. Then, climate change encourages farmers to cut down trees to expand farmlands to cope with risks. This results in a higher deforestation rate in a certain area. This deforestation and climate change chain is also explained in Fig 1. We take Zambia as a field of case study. We believe it has a strong external validity to other countries of SSA as they share the similar climate and are heavily dependent on agriculture. Zambia being one of the countries in the central parts of Africa and has no influence on changes in climate or temperature from the ocean, would be a great representation of the direct influence of deforestation on changes in temperature.

Figure 1. Project Framework

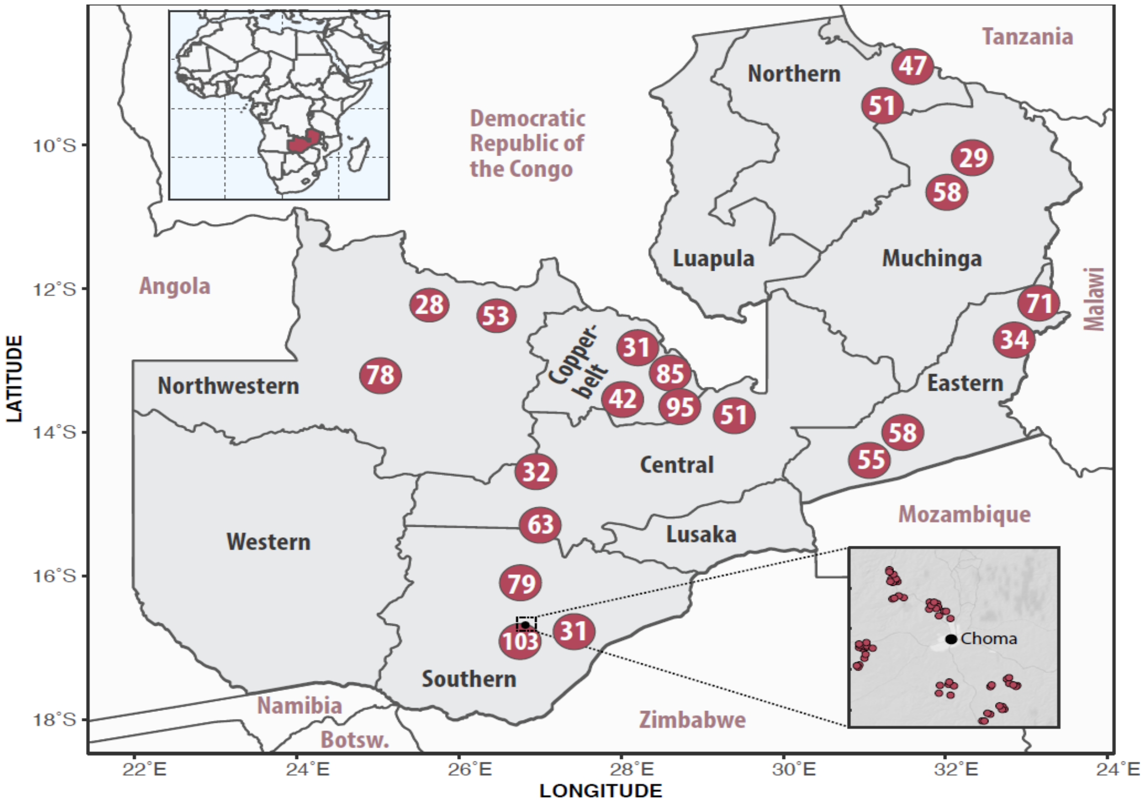


Finally, because of the fact that both climate change and deforestation could influence one another simultaneously, our results are not going to be causal. What we are going to show in the results section are correlations between deforestation and climate change.

IV. Study site

The study sites include 12 districts in Zambia which were randomly selected shaded (see Figure 2). These districts are Mkushi, Mumbwa, Mpongwe, Masaiti, Lundazi, Petauke, Mbala, Mungwi, Chinsali, Mufumbwe, Solwezi, Choma and Namwala. Respondents were randomly selected across all the districts and on average the number households were the same across the districts. The districts were randomly sampled from within each of the three dominant rainfall regions in Zambia, and then we further randomly selected the agricultural camps within the districts. An agricultural camp is defined as a small unit within the agricultural sector where farmers are grouped around agricultural extension service provision in groups called cooperatives (Alamu et al., 2019). Finally, we randomly selected households within the agricultural camps and villages.

Figure 2. The numbers in red circles represent the number of households interviewed in every camp in a district.



Source: Author's work from the HICPS data

V. Data

The data used to extract are from a large panel household survey of smallholder farmers across Zambia conducted in June and July of 2016, 2017, 2018 and 2019 covering the 2015/16, 2016/17, 2017/18 and 2018/19 agricultural seasons. The survey sampled about 1,200 smallholder households in 12 districts of Zambia and collected data on socioeconomic, demographics and agricultural productivity such as land holding size and land cultivated area. This survey is a rich survey that has the household geographic locations. We then use the household geographic location to obtain the rainfall variable from the Climate Hazards center InfraRed Precipitation with Station data (CHIRPS). To extract the rainfall we create a buffer of 5 km around the households coordinates which is on the average furthest distance of their landholdings. We then overlay the rainfall raster layer to extract the rainfall around the farmer's landholdings (where the farmers are likely to produce charcoal or cut down trees for agriculture production). We then extract the temperature data from the Moderate Resolution Imaging Spectroradiometer (MODIS). We equally create a 5 km buffer around the households and overlay it with the temperature raster file.

To extract the deforestation data we create a buffer of 4 km around the households coordinates which is on the average furthest distance of their landholdings . For the robustness checks, we additionally extract 10 km and 15 km buffers to see the effect of varying the buffers on the accuracy of our results. We then overlay the deforestation raster layer to extract the deforestation with the various buffers to extract the deforestation rates around the households.

Figure 3 provides an overview of the weather data and Figure 4 provides an overview of the deforestation data for Zambia. One observation about these graphs that summarize the data is that the year with the highest rainfall and lowest average temperature, 2017, is also the year with one of the highest deforestation rates.

Figure 3. Summary of Weather Data for Zambia

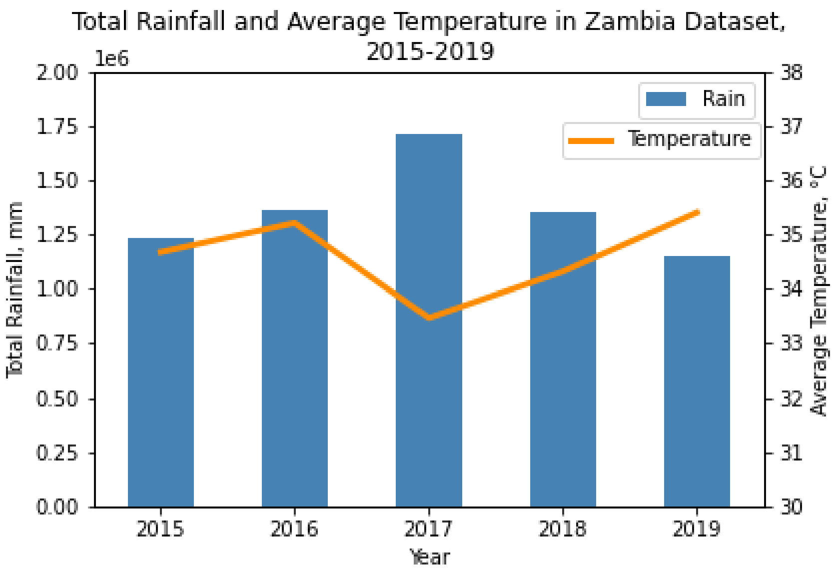
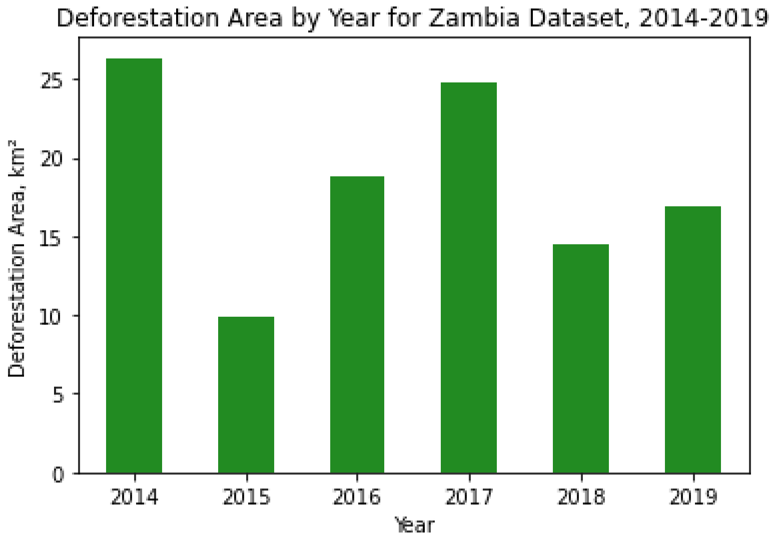


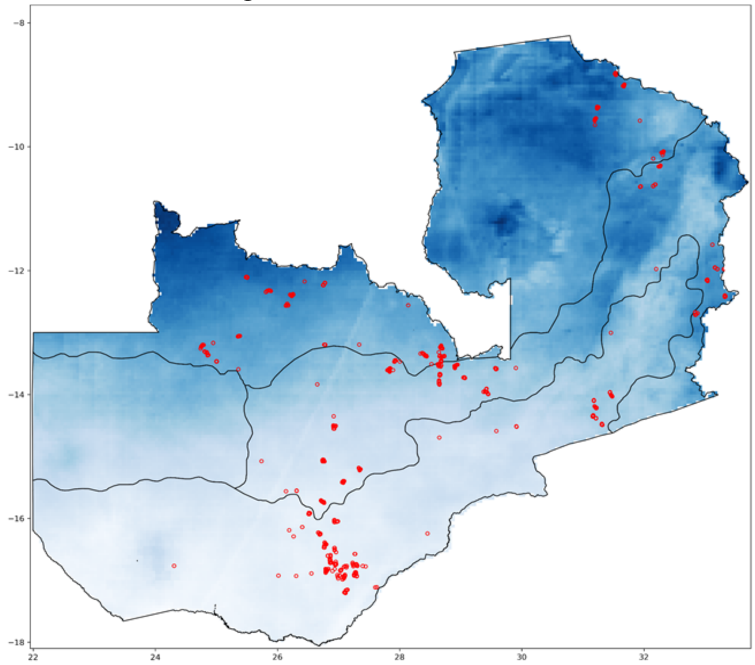
Figure 4. Deforestation Data for Zambia



Zambia is classified into three main agro-ecological zones according to climatic factors, rainfall patterns and common agricultural practices. The three ecological zones extend from the west to the east of the country with Zone I. In the middle, we have Zone II which consist of two parts: a and b. Finally, we have Zone III further to the north with the highest rainfall amounts.

These classifications are matched with Fig. 5 that shows rainfall amounts in 2019. Deeper color suggests we had a lot of rain in those areas. We have the highest rainfall amount in zone 3 and less rainfalls in the southern part of the country. In Fig #, red dots are showing household locations (geocodes) that we use to extract the deforestation, temperature, and rainfall from by taking a buffer. They spread into these 3 agro-ecological zones evenly.

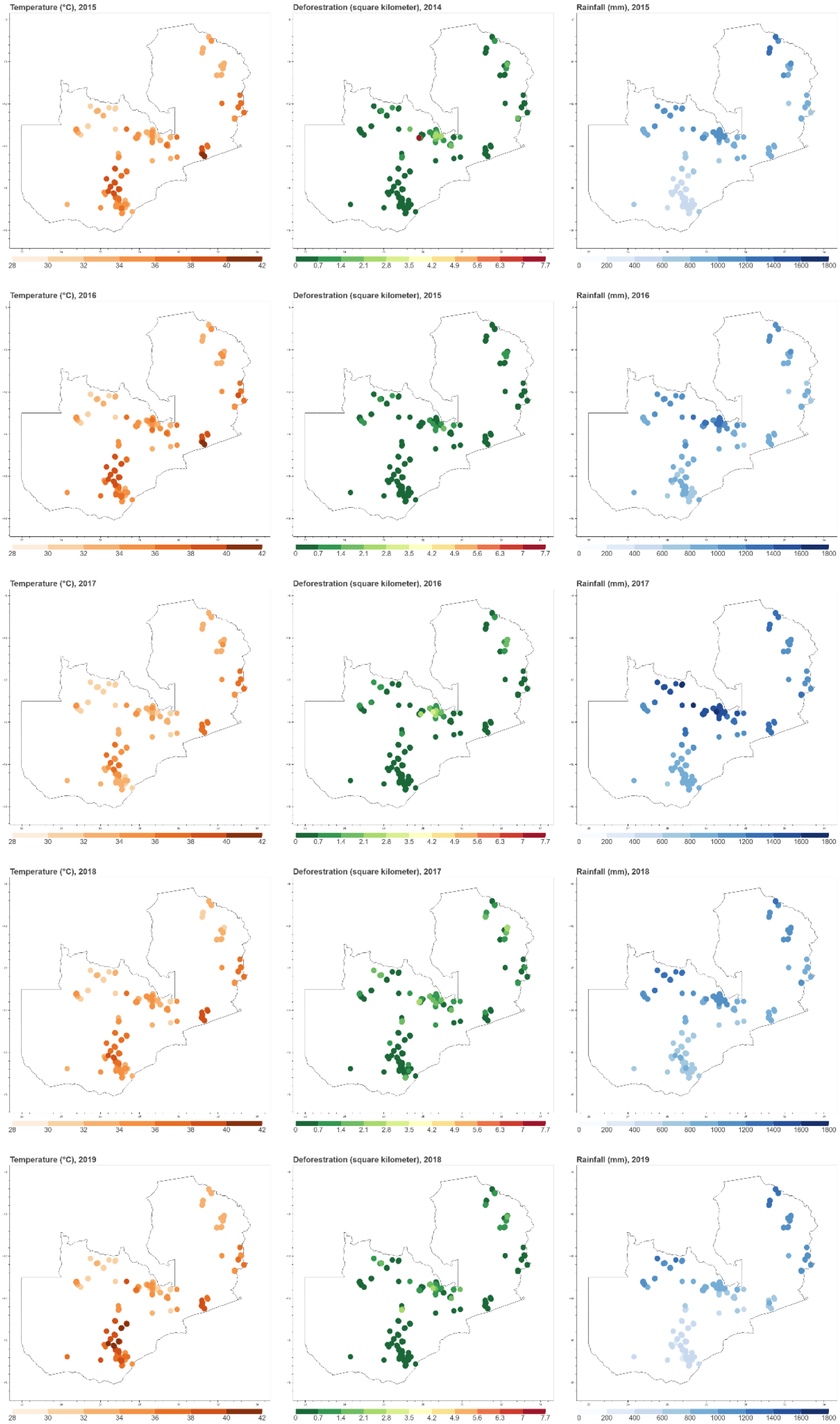
Figure 5. Rainfall amount



Note: deeper blue color indicates higher amount of rainfall.

Then, Fig 6 shows the annual changes in the 3 variables. As we saw in the graphs (Fig 3 and Fig 4), temperature reached the highest point in 2019, and the lowest in 2017. We can see this pattern having deeper colors in 2019, especially in the southern part of the country. For deforestation and rainfall, we see the opposite patterns to temperature, having the deepest colors in 2017 and lighter colors in 2019. For temperature, we can see a lot of changes especially in the southern part of the country, while for deforestation, we see a lot of changes in the upper part of the country. When we look at the amount of rainfalls, changes are happening throughout the country, compared to the other two factors.

Figure 6 Household level changes in temperature, deforestation, and rainfall



VI. Econometric model

To estimate the effects of deforestation on temperature change (climate change), we employ a linear fixed effects (FE) model as specified in equation (1).

$$y_{it} = \mu_t + \beta \text{Defor}_{idt-1} + \mathbf{X}_{idt} + \psi_i D_d \times T_t + \alpha_i + \varepsilon_{idt} \quad (1)$$

The dependent variable Yit is the natural log of temperature for the ith household at time t (t=1, 2, 3,4 and 1= 2015/16, 2=2016/17, 3=2017/184=2018/19 agricultural seasons). We transform temperature into logs to mitigate the effect of outliers and to allow us to interpret the effects in terms of percentage change. Further, we lag the deforestation variable by a year because the changes in temperature (climate change) is mainly dependent on the previous year's deforestation rates.We change all the covariates into natural logs as well for the same reason and we interpret the results as elasticities. β is the variable of interest which indicates the rate of deforestation around the households. **Xidt** is a set of predictor variables that vary over time (cultivated land area) , Dd x **Tt** controls for the changes for the variations across time and districts. αi combined effect on y of all unobserved variables that do not change over time, εidt is the error term.

VII. Main results

We analyze the effects of deforestation rates (5km buffer) on climate change (temperature) using linear fixed effects, the deforestation rate with the 10 km and 15 km buffer as robustness checks. Column 2 of Table 1 presents the estimates with a 5 km buffer which are also the main results. We control for the district, year fixed effects and also district by year fixed effects while controlling for cultivated land area. We find a positive correlation between deforestation and changes in temperature. Although we understand that a single year of deforestation may not lead to such high temperature estimates, due to lack of data from the survey, we could not lag the deforestation for more than one year. In column 3, we use the 10 km and control for the district, year fixed effects and also district by year fixed effects while controlling for cultivated land area and see that estimates are smaller than those with the 5 km buffer and the correlation is not as strong. Lastly, in 3 we use the 15 km buffer and control for the district, year fixed effects and also district by year fixed effects while controlling for cultivated land area. The estimates with the 15 km buffer are smaller than the smaller buffers and the correlation is not as strong.

We can observe that the estimates get smaller as the buffers increase. This could be because the accuracy reduces given that the maximum land holding is with 5 km and there many households in the camps and villages, thus increasing the buffers merges the households are they will fall with the same area of deforestation and as such that reduces the accuracy as the data is extracted and also may reduce the accuracy of the estimates.

Table 1. Effects of deforestation on temperature

VARIABLES	(1) Temperature	(2) Temperature	(3) Temperature
Lag defo 5km	0.265***		
	(0.0972)		
Lag defo 10km		0.0552**	
		(0.0279)	
Lag defo 15km			0.0200
			(0.0152)
Rainfall	-0.000341	-0.000338	-0.000318
	(0.000260)	(0.000260)	(0.000260)
Cultiavted Land area	0.00320	0.00323	0.00313
	(0.01299)	(0.00299)	(0.0129)
Weather controls	Y	Y	Y
District FE	Y	Y	Y
Year FE	Y	Y	Y
District*Year FE	Y	Y	Y
Observations	2,233	2,233	2,233

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

VIII. Conclusion

Increasing rates of deforestation are a major concern in Sub-Saharan Africa in recent years (Bain, L.E., Awah, P. K., Geraldine, N., Kindong, N. P., Siga, Y., Bernard, N., &

Tanjeko, A. T., 2013). An important cause of deforestation is charcoal production. Charcoal production has been widely seen as an income safety net to cushion households against negative income shocks during crop failure. In this study, we estimate the relationship between deforestation and temperature and compare the effect of varying the deforestation rate buffers.

Our results indicate that as the deforestation rates increase, the temperature increases and that may result in climate change. Our results shed new light on the effects of deforestation on temperature (climate change) and the mechanisms that lead to that. From a policy-making perspective, the results show that if the objective of the policy makers is to reduce climate change (temperature increases), then the policy makers must focus on interventions that decrease deforestation and promote afforestation as opposed to focus only on policies that target emissions.

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