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Analysis

The effect of climate change and adaptation policy on agricultural production in Eastern Africa

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ABSTRACT

We estimate the production function for agricultural output in Eastern Africa incorporating climate variables disaggregated into growing and non-growing seasons. We find a substantial negative effect of within growing season variance of precipitation. We simulate predicted climate change for the region and find a resulting output reduction of between 1.2% and 4.5%. Our simulation also demonstrates substantial potential for economic benefits from mitigating the effects of within growing season precipitation variability through conventional technologies such as flexible planting and rainwater harvesting on the same scale as the potential loss from predicted climate change.

1. Introduction

The East African economy is highly dependent on agriculture, which is dominated by traditional rain-fed small scale production (FAOSTAT, 2011). This dependence is expected to continue for decades to come (World Bank, 2007; Ravallion et al., 2007). In particular, Eastern Africa is characterized by substantial weather variability *within* the main growing seasons.[1] At the same time, climate change studies (Hulme et al., 2001; IPCC, 2001, 2007a,b) predict substantial increase in mean temperature and precipitation and a substantial increase in weather variability *within* the growing seasons. If these scenarios begin to unfold, it could have a substantial effect on agricultural production and livelihoods in the entire region (IPCC, 2001; Jagtap and Chan, 2000; Eriksen et al., 2008). Agronomic research in the region suggests that increased precipitation can have a positive effect on output, while the effect of increasing temperature depends on the type of agro-ecological zone and crop (Fischer and Van Velthuizen, 1996; Downing, 1992; Thornton et al., 2006). This research also finds that within growing season precipitation variability reduces agricultural output (Schulze et al., 1993; Semenov and Porter, 1995; Agnew and Chappell, 1999; Wheeler et al., 2000; Barron et al., 2003). The importance of within growing season precipitation variability for agricultural output is especially interesting from a policy perspective because its effects are more easily mitigated by small-scale technologies, which are already used by local farmers, than the effects of falling mean precipitation.

In the present article, we estimate the production function for aggregated agricultural output in the Eastern African region while taking account of the effects of key climate variables on production changes. Specifically, we estimate the effect of changes in mean growing season temperature and precipitation over time *as well as* the effect of changes in within growing season variability of these variables. We then simulate the effects of predicted climate change and investigate the potential benefits of different policy strategies for adapting to climate change by reducing the effects of within season precipitation variability.

A number of prior studies (Ben Mohamed et al., 2002; Van Duivenbooden et al., 2002; Molua, 2008; Barrios et al., 2008; Lobell

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[1] The importance of within growing season precipitation variability in Eastern Africa has been the focus of many studies (Mutai and Ward, 2000; Schreck and Semazzi, 2004; Pohl and Camberlin, 2006; Chan et al., 2008; Conway and Schipper, 2011; Bahaga et al., 2014).

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and Burke, 2008, 2010; Lobell et al., 2008; Fermont et al., 2009; Schlenker and Lobell, 2010; Rowhani et al., 2011; Lobell et al., 2011; Blanc, 2012; Ward et al., 2014) which estimate regional and country level production functions mostly for specific crops in the region have included either annual or growing season temperature and precipitation. Some studies also include climate indicators other than temperature and precipitation such as degree days (e.g., Schlenker and Lobell, 2010; Lobell et al., 2011), evapotranspiration, standardized precipitation index, droughts and floods (Blanc, 2012), precipitation variance (Barrios et al., 2008; Rowhani et al., 2011; Ward et al., 2014) and temperature variance (Rowhani et al., 2011). The last three studies that like ours also estimate effects of temperature and precipitation *variance*. Ward et al. (2014) find that within *growing season* precipitation variability has a positive effect on aggregate cereal yield in Sub-Sahara Africa, while Rowhani et al. (2011) find that *within growing* season precipitation variability has a negative effect on sorghum, maize and rice yields in Tanzania. Like our study, Barrios et al. (2008) estimate the effect of climatic variables on *aggregate* agricultural output, although they focus on Sub-Saharan Africa as a whole. They find that rising annual mean temperature affects agricultural output negatively, while rising annual mean precipitation affects agricultural output positively. They investigate the effect of within *year* variation in precipitation, and find it to be insignificant. Outside Africa, we are aware of only two studies which estimate agricultural production functions that include within growing season climate variability. McCarl et al. (2008) find that temperature variability has a negative effect on key crops in the US, while Cabas et al. (2010) find that both temperature and precipitation variability have a negative effect on key crops in Canada.

We estimate a region-wide production function for aggregate agricultural output similar to Barrios et al. (2008). We depart from Barrios et al. (2008) by focusing on East Africa and disaggregating annual climate variables so as to differentiate between the two growing seasons' characteristic of the region and the non-growing seasons. This disaggregation allows us to estimate the effects of climate changes in the particular parts of the year where climate is critical for crop growth. It turns out that growing season climate variables are highly significant, while out of season variables are not. Consistent with the agronomic literature, we find positive effects of increased precipitation, mixed effects of increased temperature depending on the growing season, and significant negative effects of *within growing season* precipitation variability. Our results are also consistent with most of the previous studies that use micro and macro data which find a positive effect of precipitation and negative effect of temperature. Our study is the first to investigate the effect of within growing season climate variability on aggregate agricultural output in this region.

In addition to generating results that are consistent with the agronomic literature, this allows us to take account of within growing season effects when we simulate climate change, as well as when simulating the effects of adaptation policies. This is important for climate simulation because substantial increase in within growing season precipitation variability is predicted for Eastern Africa. This is also important for policy investigation because within growing season precipitation variability can be addressed by small-scale initiatives such as rainwater harvesting[2] and greater flexibility in the timing of the planting of crops. Our policy simulations show a substantial potential for such policies that mitigate within growing season variance in precipitation.

The remainder of the article is organized as follows. Section 2 discusses East African climate and agricultural production, while in Section 3 we present the model specification. Section 4 presents the data description, while in Section 5 we present and discuss estimation results. Section 6 presents policy simulations and Section 7 concludes.

[2] Rainwater harvesting is defined as a method for collecting, storing, and conserving local surface runoff for agriculture (Boers and Ben-Asher, 1982).

2. East African Climate and Agricultural Production — Background

Agriculture contributes about 40% of Gross Domestic Product (GDP) and provides the main income for 80% of East Africans (Runge et al., 2004). Agricultural practices in the region are traditional, dominated by small-scale farms under 2 ha and characterized by low inputs of physical capital, fertilizers and pesticides (Eriksen et al., 2008). Rain-fed agriculture accounts for more than 95% of the cultivated area (FAOSTAT, 2011) making agriculture in the region highly dependent on climatic conditions (Slingo et al., 2009). One implication is that farmers follow a specific seasonal farming pattern which is dictated by the precipitation pattern where spring is the main growing season, and fall is the minor growing season. Farmers plant similar crops in both seasons. It is during these seasons that farmers plant their crops and when periods with a shortage of rainfall can affect agricultural production. Most small-scale farmers in the region practice mixed crop-livestock production with crop residues supporting the feeding of livestock in addition to meadows and pastures. Livestock accounts for about 30% (FAOSTAT, 2014) of the total value of agricultural production in the region and plays a key role both as a source of animal products and as a key input to production in the region. This characteristic of agriculture production in the region makes it more vulnerable to climate change and variability (IPCC, 2007a,b). The higher frequency of droughts and floods in East Africa over the last 4 decades has resulted in crop failures and loss of livestock. This is further exacerbated by the limited adaptive capacity in the region due to traditional and inefficient adaptation by farmers (Jagtap and Chan, 2000), poor economic policies (IPCC, 2001), limited administrative capacity to implement and enforce policy changes (Collier et al., 2008), and lack of access to insurance and credit and limited connection to functioning input and output markets (Burke and Lobell, 2009).

Fig. 1 shows the general trend in precipitation and temperature in the region during the main growing season. In general, the temperature has increased over the last 50 years, while precipitation has generally declined. The lowest precipitation in the early 1980s is consistent with the devastating drought that occurred in 1984 in the region.

Fig. 2 shows the relationship between agricultural production growth and the percentage deviation from mean precipitation during the main growing season over the entire period. There seems to be a positive relationship between agricultural output and mean precipitation as one would expect when most of the cultivated area is rain-fed.

However, the dominance of rain-fed agriculture in the region also implies that the distribution of rainfall over the season can be critical for crop production. As pointed out by Agnew and Chappell (1999), not only is volume crucial, but also the timing, duration, and intensity of rainfall. Fig. 3 shows the relationship between agricultural production growth and percentage deviation in precipitation variance from its mean over the entire period.

Fig. 3 suggests a negative relationship between agricultural output growth and precipitation variability deviations. Thus the raw data suggest that both mean precipitation and its distribution within the growing season may be important for output. Estimating the effects that these climate variables on production within a consistent production function structure is the focus of the following sections.

3. Model Specification

The standard production function which links inputs to agricultural output can be written as follows.

$$Q = F(L, K, I) \quad (1)$$

where Q denotes agricultural output, L is labor input, and K denotes capital such as land, machinery, and livestock. I captures other inputs