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Smallholder productivity and weather shocks: Adoption and impact of widely promoted agricultural practices in Tanzania

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ABSTRACT

We investigate the impact of maize-legume intercropping, soil and water conservation practices (SWC), organic fertilizers, inorganic fertilizers and high yielding maize varieties on maize productivity under weather shocks in Tanzania using panel data. First, we estimate the determinants of adoption by applying a multivariate panel data model capturing their complementarities and/or substitutabilities. Second, after testing for their potential endogeneity, we study the impact of these practices (and combinations of them) on maize productivity controlling for weather shocks. Finally, we disaggregate results by presence/absence of seasonal rainfall and temperature shocks to explore the heterogeneous impact of adoption under weather shocks. We find strong complementarities between agricultural practices both in terms of adoption and yield impacts. Long-run variability in rainfall decreases the adoption of organic fertilizers and increases that of improved seeds. Farmers in areas where the cropping season's rainfall has been highly variable and temperature has been unexpectedly high have significantly lower maize yields. SWC emerges as one of the most important practices in increasing yields with significant benefits by itself, in combination with other practices, under average weather conditions as well as under rainfall and temperature shocks. Overall, increasing the adoption of SWC appears a promising policy option to buffer food security from increasingly frequent weather shocks in Tanzania.

1. Introduction

Sub-Saharan Africa (SSA) remains the world's most food-insecure region characterized by high levels of child mortality and poverty, low levels of human and physical capital, and poor infrastructure (FAO, 2009). The economies of countries in SSA heavily depend on a smallholder-based agricultural sector, which in turn makes them particularly vulnerable to climate change (Ziervogel et al., 2008; Barrios et al., 2008; TZG, 2009). An estimated 90 percent of the population depends on rain-fed crop production and pastoralism to meet its basic food needs (Patt and Winkler, 2007). In the absence of a policy agenda to increase economic growth and decrease poverty while maintaining the natural resource base, the negative effects of climate change on crop production will be especially pronounced in SSA. Forecasts for SSA show that *ceteris paribus*, rice, wheat, and maize yields are likely to decline in the next thirty years by 15 percent, 34 percent, and 10 percent, respectively (Nelson et al., 2009).

In Tanzania, smallholder farmers account for about 84 percent of cultivated land, of which 45 percent is devoted to maize supporting the livelihoods of 82 percent of smallholders, i.e. 4.5 million households (USAID, 2010). Projections from General Circulation Models show that food security in Tanzania is likely to deteriorate as a consequence of climate change in the next 30 years (Arndt et al., 2012). Tanzania-specific models predict an average decrease in maize yields of 33 percent, with a wide variation (10–84 percent) across the country (NAPA, 2007). Productivity drops at this scale will affect the most vulnerable households that directly depend on climate patterns for their livelihoods and have weak risk management capacities. Tanzania's National Adaptation Plan of Action (NAPA) ranked agriculture and food security as the most vulnerable sector affected by climate change and prioritized activities to improve the understanding of the impacts of climate change on agriculture and food security (NAPA, 2007).

In this paper, we provide a comprehensive analysis of the factors that influence the adoption of a set of agricultural practices that have the potential to improve farmers' adaptive capacities, including maize-legume intercropping, soil and water conservation measures (SWC), the use of organic fertilizers, inorganic fertilizers and high yielding maize varieties, as well as their

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impacts on productivity in rural Tanzania. We use the first two waves of the Tanzania National Panel Survey, a nationally representative household survey with a strong focus on agriculture merged with geo-referenced historical rainfall and temperature data to control for the effects of the levels and historical variations in climate variables on adoption and productivity. Given the overwhelming importance of maize for food security and the economy as a whole, we focus on maize farmers only.[1]

Overall, this paper contributes to the literature by combining the technology adoption and agricultural adaptation literatures with rigorous empirical analysis. The specific contributions of the paper are threefold. First, although there is a well-developed literature investigating the determinants of technology adoption, research that explicitly accounts for climate risk in this literature is still nascent (Deressa and Hassan, 2009; Di Falco et al., 2011; Kassie et al., 2013; Arslan et al., 2014; Asfaw et al., 2014). We model farmers' adoption of five different practices simultaneously using a multivariate correlated random-effects probit model, which captures the complementarities and/or substitutabilities among different agricultural practices while controlling for climatic risk factors/weather shocks and household-specific time-invariant unobserved heterogeneity. Second, after testing for the potential endogeneity of adoption using a fixed-effects instrumental variables approach, we study the impact of these practices (and combinations of them) on maize productivity controlling for weather shocks and households' fixed-effects. Third, we investigate to which extent the estimated impacts of adoption differ in the presence/absence of seasonal rainfall and temperature shocks.

We find evidence for the existence of complementarities between different practices, that can help improve targeting of extension interventions. There is a negative relationship between the historical variability in growing season rainfall and the adoption of organic fertilizers, while this relationship is strongly positive and significant for improved seeds. This finding suggests that farmers are decreasing the use of fertilizers the more variable the rainfall becomes, and that they perceive improved seeds as an adaptation strategy to variable rainfall. We also find that access to government extension services and price information significantly increase the likelihood of adoption of modern inputs as well as SWC, highlighting the key role of extension services in influencing the adoption decisions of farmers.

As for the determinants of maize productivity conditional on adoption, SWC and inorganic fertilizers are the only practices with a positive and statistically significant impact on maize yields when analyzed by themselves. When the combinations of practices are accounted for, the yield effect of SWC emerges as the most robust given its significance in most of the combinations. All our specifications point to a strong negative relationship between maize productivity and two prominent shock indicators during the growing season: higher than average within-season rainfall variation and too high maximum temperatures. This indicates a lack of adaptive capacity to these shocks that are expected to increase in frequency under climate change. Therefore, we also analyze the ways in which the effects of the practices analyzed here change in the presence/absence of these shocks. SWC in combination with various practices is found to provide yield benefits that are resilient to these shocks, suggesting synergies between short-term productivity and resilience benefits. Our policy implications draw on these results to improve the design and targeting of policies for food security under climate change.

The rest of this paper is organized as follows. We provide a short overview of the relevant literature in Section 2, present our conceptual framework and empirical specification in Section 3, and introduce our data with descriptive statistics in Section 4. We discuss our results in Section 5 and conclude in Section 6 with a brief summary of results and policy implications.

2. Literature review

The well-established economic literature on the adoption of agricultural technologies and productivity provide the main back-drop for the analyses in this paper. Based on the theoretical model of constrained decision-making, this literature highlights the importance of risk and uncertainty, credit constraints, tenure security, wealth, access to information, gender and safety-first behaviour (Feder et al., 1985; Feder and Umali, 1993; Just and Zilberman, 1983; Rosenzweig and Wolpin, 1993; Besley, 1995; Doss, 2003; De Groote and Coulibaly, 1998; Kassie and Holden, 2007; Smale et al., 1994 among others) in shaping adoption decisions. Given our context of adoption and productivity under increasing climatic variability, it is important to underline how the changes brought by climate change are affecting the standard economic model. Even though the averages of climatic variables take a long time to manifest themselves, the extremes of the distribution change much faster (Fankhauser et al., 1999). The increasing frequency and intensity of extreme weather events primarily affects the risk profiles of alternative technologies (livelihood strategies), thereby changing incentives. Although agriculture has always been subject to weather risks, these new challenges increase the importance of controlling for the effects of relevant weather related risks on adoption decisions as well as productivity.

The more recent empirical literature tries to address this need assisted by the improvements in the availability of weather data. Most of this literature uses annual average rainfall and temperature data (lagged values, current year values or averages over a couple of years) from weather stations to capture their impacts on adoption behaviour (Deressa and Hassan, 2009; Chomba, 2004; Bezabih et al., 2013; Gebrehiwot and Veen, 2013; Falco and Bulte, 2013; Pangapanga et al., 2012). Annual averages from sparse weather station data over short time periods, however, fail to capture the spatial as well as temporal heterogeneity in these variables. This problem is addressed by some studies using interpolation techniques to introduce spatial heterogeneity to average rainfall and temperature data (Di Falco et al., 2011; Basinger et al., 2012). Average values of these variables, regardless of their resolution, fail to capture the impacts of changing expectations due to changes in weather patterns on adoption decisions. Longer time periods to control for variation in these variables is therefore desirable. Bezu et al. (2014) use 5 year averages and standard deviations to control for longer term expectations. Arslan et al. (2014) and Asfaw et al. (2014) improve on earlier studies by using longer term (29 years) data on temperature and rainfall at high resolution from satellite based sources to capture both the short- and the long-term changes in relevant variables (both in levels and variations) and their impacts on adoption and productivity in Zambia and Malawi, respectively.

When it comes to the impacts of agricultural technologies on productivity (or other welfare outcomes) there are two strands of literature relevant for our study: agronomic and socio-economic. Agronomic studies (specifically focused on the practices analyzed in this paper) find that maize-legume intercropping system has the potential to alleviate binding soil quality constraints and improve productivity compared to mono-cropping (Schmidt et al., 2003; Rusinamhodzi et al., 2012). The use of organic fertilizer is found to be one of the most important sustainable agricultural practices, since it improves soil permeability and water holding capacity as well as soil chemical properties (such as N, P, K) and other fundamental mineral nutrients. Moreover, it may contribute

[1] This implies that our results are valid for about 80 percent of all agricultural households in the sample, i.e. maize farmers.