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Does water harvesting induce fertilizer use among smallholders? Evidence from Ethiopia

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ABSTRACT

Rainfall shortage is a major production risk for smallholder farmers. Due to rainfall shortage, smallholders limit the use of modern inputs such as fertilizer and improved seeds. This study investigates if water harvesting technologies (WHTs) induce fertilizer use and whether there is joint adoption of fertilizer and water harvesting technologies. Using panel data collected from Ethiopian farmers in two regions in 2005 and 2010, a random effects probit model and a bivariate probit model are estimated to investigate these two issues. Both models include variables that are hypothesized to affect fertilizer and WHT use. The findings indicate that: (1) water harvesting increases the probability of using fertilizer; (2) past WHT use positively affects the probability of current fertilizer use but past fertilizer use does not affect current WHT use; (3) total landholding, farm capital, and education significantly increase the probability of fertilizer use whereas the price of fertilizer and distance to market decrease the probability of fertilizer use; (4) there are significant regional and yearly differences in fertilizer use; and (5) growing perennial crops, and distance from natural water sources increase the probability of using water harvesting in 2010 whereas distance from markets, age and altitude decreases it. These results imply that measures encouraging water harvesting can also lift low fertilizer use among Ethiopian smallholders.
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1. Introduction

Rainfall shortage is a major production risk for smallholder farmers. Due to rainfall shortages smallholders limit the use of modern inputs such as improved seeds and fertilizer (Alem et al., 2010). Especially in developing countries, limited use of modern inputs has prevented farmers from reaching high yields (Ruttan, 2002). Therefore, limited and irregular rainfall leads to low production directly and indirectly (via low fertilizer use), and consequently to food insecurity and occasional famines in developing countries such as Ethiopia. The World Bank (2011) stresses that already in Ethiopia in 2011 five to seven million people suffered from chronic food insecurity due to recurring rainfall shortage and low output.

Ethiopia implemented several water and soil conservation programs to ensure food security since the severe droughts of the mid-1970s. Communities carried out soil and water conservation activities throughout the country. Additionally, public institutions invested substantial resources in R&D to stimulate innovations that increase productivity (e.g. improved seed varieties). Although these programs had positive contributions (Gebremedhin et al., 2009; Gemeda et al., 2001; Shiferaw and Holden, 1999), their success in increasing productivity is often constrained by water shortages. Due to low investment in water supply mechanisms such as irrigation, farmers do not apply productivity increasing innovations sufficiently.

Recently, in an attempt to reduce risks for smallholders, there is a policy shift to encourage farmers to invest in risk reducing technologies on their land. Whereas Ethiopian farmers in the past had little incentive to invest on their land due to lack of property rights, the land certification that started in some of the regions in 2003 and that safeguards tenure security (Deininger et al., 2008) has changed this. Among these risk-reducing investments are small-scale water-saving technologies that are often denoted as water harvesting technologies (WHTs).

Water harvesting technologies include ponds, shallow-wells and stream/river diversions. These technologies help to accumulate rainfall water or water from floods that can be used if rainfall shortages occur in the future. Ponds are the dominant WHT used in Ethiopia, accounting for 65% of the constructed WHTs. The surface of ponds is often sealed with plastic, cement or clay so that they can hold water for a relatively long time. Average capacity is about 65 m^3 and the catchment area varies from 0.4 to 2.5 ha. Run-off from natural catchments or from roads, natural water courses, foot paths and cattle-tracks is used to fill ponds. Some ponds are covered to protect evaporation. The second type of WHT (20%)

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are shallow-wells. Farmers dig them in areas of accumulated flood or in areas with high groundwater levels. The remaining 15% of WHTs are stream/small river diversions. Some farmers divert the run-offs to their plots to increase soil moisture. In our study we do not distinguish between these three types of WHT.

In Ethiopia, WHTs are introduced and encouraged on a large scale since early 2000s. Since this period a large number of Ethiopian farmers adopted WHT, although they were used before in some regions of Ethiopia. Farmers that invested in these technologies are expected to use fertilizer due to the reduced risk of water shortage. This is because the functioning of fertilizer nutrients in crop production depends on the availability of sufficient water, in line with Von Liebig's agronomic principle of law of the minimum (de Wit, 1992; Paris, 1992). If sufficient water is available, it dissolves the fertilizer nutrients so that roots can properly absorb the nutrients. In contrast, if there is a shortage of water, the chemical fertilizer would dehydrate the roots and damage the crop. This indicates that to use purchased fertilizer, a farmer has to have confidence in the quantity of rainfall/water. If the water from rainfall happens to be insufficient, the farmer may use an alternative source of water, e.g. water collected in WHT. So, WHT could have a positive impact on fertilizer use. However, even though the availability of water is a precondition for effective use of fertilizer, its demand is not only conditioned by the availability of water but also by other factors that affect supply and demand of fertilizer. Dercon and Hill (2009) reported that fertilizer use by small farmers in 2007/2008 was only on 39% of cultivated area. Zerfu and Larson (2011) investigated the functioning of fertilizer markets in Ethiopia and focused on factors that determine fertilizer demand without looking into the interaction between water availability and fertilizer use.

A preliminary analysis of the data used in this study indeed shows that farmers who use WHT use fertilizer more often than those who do not use WHT. However, such a casual glance is not sufficient to conclude that differences in fertilizer use are due to the use of WHT. It could be that farmers who have better financial means are better able to both invest in WHT and purchase fertilizer. Moreover, there can be regional factors that encourage both the use of WHT and fertilizer. For instance, in regions with strong emphasis on promoting WHT, extension agents may also emphasize the benefits of using fertilizer in conjunction with WHT. In regions that pay more attention to rain-fed farming there may be less attention for promoting fertilizer. This may lead to a situation of joint technology adoption, i.e. farmers adopting both technologies simultaneously. In this case it is not only WHT that stimulates fertilizer use via its risk-reducing effect, but use of fertilizer may in turn spur investment in WHT. In other words, one question is whether WHT has a causal effect on fertilizer use, but another question is whether this causal effect also is the other way around. To assess the presence and direction of these causal effects between WHT and fertilizer use a more rigorous analysis is required.

Empirical literature shows that modern inputs are used more in irrigated farming than rain-fed farming and as a result productivity is higher in the former. For instance, Gollin et al. (2005) underlined that the green revolution had the highest impact in irrigated cereals. Similarly, Byerlee and Siddiq (1994) reported that the increased use of fertilizer was substantially higher in irrigated areas compared to rain-fed areas. Lamb (2003) and Smith (2004) suggested that the use of irrigation increases fertilizer demand. Additionally, some studies showed that because of water shortage the use and effectiveness of fertilizers may be limited. Olwande et al. (2009) and Jayne et al. (2003) concluded that production risk and low returns cause low fertilizer application in Africa. To see how the quantity of water affects the effect of fertilizer, Li et al. (2004) conducted a field experiment in a Chinese semi-arid area and found that the highest quantity of water from water harvesting (400 mm) gives a maximum wheat yield from fertilizer compared to the yield from fertilizer on successive lower quantities of water. In related studies focusing on Ethiopia, agronomists conducted studies focusing on optimal fertilizer in various soil types (e.g. Kebede and Yamoah, 2009; Abegaz, 2008) and in various water supply conditions (Bekele and Tilahun, 2007), and the effect of supplementary irrigation on yield (Bello, 2008).

The objective of this study is to investigate the causal relation between water harvesting and fertilizer use in Ethiopia. We first focus on a potential causal effect of WHT on fertilizer use. Second, we consider the possibility of joint technology adoption of WHT and fertilizer. To analyze these issues we exploit two-period panel data collected from Ethiopian farmers in two regions in 2005 and 2010 and estimate two binary choice models. The use of panel data in our analysis has a number of advantages compared to cross-sectional data, which is often used in technology adoption studies. First, panel data allows for dealing with unobserved heterogeneity among farmers and across time. Unobserved differences in attitudes towards technology, farm management, risk and time preferences, and environmental conditions are relevant in our context and can be accounted for. The same holds for unobserved year effects. This reduces omitted variable and selection bias problems increasing the reliability of parameter estimates. Second, panel data provides both variation between farms and variation within farms (over time), leading to better parameter estimates. Third, it allows for investigating the changes in WHT and fertilizer use over time, which can be exploited to investigate whether WHT preceded fertilizer use or vice versa. This feature of panel data has proven valuable in other impact assessment studies (e.g. Berhane and Gardebroek, 2011).

The use of farm panel data to analyze the relation between WHT and fertilizer is one of the contributions of this study to the literature. Other studies that focus on the effect of WHT or irrigation on fertilizer use are often based on cross-section data (e.g. Gebregziabher and Holden, 2011) or data from research stations (Fox et al., 2005). Another contribution of this study is to analyze the direction of causality between WHT and fertilizer use. Fox et al. (2005) and Gebregziabher and Holden (2011) consider the importance of supplementary irrigation on fertilizer use, but do not investigate whether fertilizer use could also spur investment in WHT, although Fox et al. (2005) do suggest the importance of joint adoption. Compared to other studies that specifically focus on fertilizer use decisions (e.g. Alem et al., 2010; Jayne et al., 2003; Olwande et al., 2009) our study adds WHT, which reduces soil moisture stress, as an important factor in explaining fertilizer use.

The paper is organized as follows. Section 2 describes the conceptual framework and Section 3 describes the available data and the variables used in estimation. Section 4 presents the empirical models and the estimation procedures. Estimation results are presented in Section 5. Conclusion and implications are given Section 6.

2. Conceptual framework

2.1. Factors affecting fertilizer use

Fertilizer is added to soil to provide nutrients that are deficient in the soil. Plants absorb these nutrients if soil moisture and other soil characteristics are favorable, which may lead to yield improvement. Numerous studies exist that investigate yield changes due to fertilizer use under various conditions (e.g. Gandorfer et al., 2011; Fox et al., 2005; Rötter and van Keulen, 1997). However, agronomic conditions such as soil moisture and soil quality are not the only factors that determine fertilizer use. In developing countries

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