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Share of irrigated land and farm size in rainwater harvesting irrigation in Ethiopia

Mekonnen B. Wakeyo [a, *], Cornelis Gardebroek [b]

[a] Ethiopian Development Research Institute, Blue Building/Addis Ababa Stadium, P.O.Box 2479, Addis Ababa, Ethiopia
[b] Agricultural Economics and Rural Policy Group, Wageningen University, Hollandseweg 1, 6706 KN, Wageningen, The Netherlands

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A B S T R A C T

Rainfall shortages constrain small-holders' agricultural production in developing countries and with ongoing climate change these shortages may increase in volume and frequency. Rainwater harvesting irrigation is an interesting technology that decreases this risk. Therefore, one would expect an increasing use of this technology in drought-prone areas, particularly for large and wealthy farms. This study investigated the relation between farm size and share of irrigated land among smallholders from two regions in Ethiopia. It also analyzed which factors explain the share of irrigated land using panel data collected in 2005 and 2010. A random effects tobit model was estimated for the share of irrigated land as a function of variables affecting returns, market prices, source of finance, and expectation formation. The findings show that the share of irrigated land declines with farm size. Moreover, the share of irrigated land depends on distance to market, ease of selling output, age, aridity, distance from natural water sources, credit access, and regional differences. These results question the relevance of water harvesting for farm enlargement. However, they also show that by safeguarding the availability of credit and improving local infrastructure farmers may extend the share of land irrigated by harvested water.

1. Introduction

Rainfall shortages constrain production in smallholder agriculture in developing countries. Farmers face a risk of rainfall shortage especially during ripening periods. The use of collected and stored rainwater (harvested water) at the ripening stage decreases this kind of production risk. Additionally, at lower risk farmers are more inclined to use modern inputs such as fertilizer and improved seeds (Barron and Okwach, 2005; Wakeyo and Gardebroek, 2013). Chemical fertilizer and improved seeds require sufficient water to effectively increase yields. Thus, water harvesting technologies increase yields and sustain income by reducing production risk (Barron and Okwach, 2005; Rockström et al., 2002). These technologies may become even more important in the future since drought spells are expected to become more frequent and severe in various parts of the world due to climate change. A number of studies documented their role in overcoming the negative impact of climate change and drought in Africa (e.g. Kahinda et al., 2010; Rockström et al., 2002). Given their benefits, one would expect an increasing use of water harvesting technologies.

However, recent research in Ethiopia shows that some farmers disadopted water harvesting technologies after a few years of using them due to shortage of materials for construction, maintenance and operation, lack of credit, and shortfall of rainfall (Wakeyo and Gardebroek, 2015). Moreover, the aforementioned study suggests that farmers only use the harvested water on specific plots, which raises the question whether water harvesting technologies are adopted proportional to farm size. In some areas, limited rainfall could constrain the expansion of the area irrigated by collected rainwater so that when farms get larger, the area of irrigated land grows less than proportionately.

If there is indeed a declining share of irrigated land this suggests that irrigation based on harvested water becomes less relevant when farm size increases. This may imply that water harvesting has no future when the scale of agriculture increases and farms get more commercial. However, before concluding that the technologies become inappropriate with increasing farm size, it is worth investigating whether such a declining share exists and what the determinants of the share of land irrigated with harvested water are. For example, farmers may face credit constraints, which could

* Corresponding author.
E-mail addresses: mwakeyo@gmail.com, wmekonnen_bekele@yahoo.com (M.B. Wakeyo), koos.gardebroek@wur.nl (C. Gardebroek).

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limit the financial capacity to buy plastic sheets, clay and cement for pond construction. Shortage of credit may also constrain purchase of water lifting equipment such as treadle and motor pumps. Another constraint may be labor availability. Labor shortage could constrain big farmers severely because irrigation is a labor intensive activity and if large farms are short on labor they can use irrigation only on a small portion of their land.

Scientific literature suggests that farm size may negatively relate to adoption intensity because farmers may try to learn the outcome of new technologies by applying them on a portion of their farm (Feder, 1980) before fully adopting them. However, this argument only holds in the first few years of adoption. Various studies found other factors than size determining intensity of technology use (e.g. Benin et al., 2004; Feder et al., 1985). Suggested explanations for the declining intensity of water harvesting adoption are available volume of water and water losses (Barron and Okwach, 2005), crop choice (Moreno and Sunding, 2005), and socio-economic factors such as income (Feder et al., 1985), low investment (Pender and Kerr, 1998) and education and learning (Foster and Rosenzweig, 2010).

This study investigates how the share of irrigated land relates to total landholding among a sample of Ethiopian smallholders. Moreover, it analyzes which factors are relevant in explaining the share of land irrigated with harvested water. This is important to understand since for smallholders water harvesting may be a promising way of coping with droughts that may occur more frequently in the future (Biazin et al., 2012; Rockström et al., 2002) due to climate change. In this study a theoretical model is developed that shows investment in water harvesting technologies is beneficial for two reasons. First, the harvested water increases output levels and second, it reduces output variability. Besides investment costs there may also be other factors that impede farmers from investing in water harvesting technologies such as lack of credit, limited opportunities for marketing (surplus) products, and environmental and geographical conditions. In the empirical analysis a panel tobit model is used to investigate which factors explain the share of land irrigated by harvested water. This model is estimated using two-period panel data on 400 Ethiopian households.

This study contributes to the literature on water harvesting in three distinct ways. First, it shows how investment in water harvesting technologies in theory reduces production risk. Previous studies contributed a lot to understanding various aspects of water harvesting technologies (e.g. Ngigi et al., 2005; Fox et al., 2005) but neglected to look into this relationship. Second, the study analyzes determinants of the share of irrigated land in the total land area of smallholders. This share is often considered as an indicator of crop production risk and used in agricultural policy documents and impact studies (e.g. MoFED, 2010; Hanjra et al., 2009) to make a case for increased investments in irrigation. By analyzing the determinants of the share of land irrigated by harvested water we may be better able to judge the feasibility of such recommendations. Third, the study uses panel data to investigate the share of irrigated land. In many previous studies on water harvesting technologies, except Wakeyo and Gardebroek (2013, 2015) panel data is not used. Panel data helps in understanding water harvesting technologies irrigation by observing individual smallholder farm-households over a longer period of time. In econometric estimation, the use of panel data decreases the bias from unobserved time-invariant variables.

The study is organized as follows. Section 2 discusses the theoretical framework of decision making on the share of irrigated land considering both the output increasing and risk-reducing effects of harvested water. Section 3 discusses the study area, data collection procedure and the tobit model used in the empirical analysis. Section 4 presents the results. In the final section conclusions are drawn and policy implications are given.

2. Theoretical framework

2.1. Theoretical model

Though they may have other objectives, farmers in arid and semi-arid areas mainly invest in water harvesting to decrease production risk (Fox et al., 2005; Gezahegn et al., 2006; Hatibu et al., 2006; Kato et al., 2011; Ngigi et al., 2005). Investment in water harvesting technologies for supplementary irrigation is different from participation in large and medium-scale irrigation, where ownership is usually communal and where using the water from a dam beyond a certain distance is costly. In that case the distance of plots from a dam determines the share of irrigated land (Amacher et al., 2004). In water harvesting, however, farmers can locate the water collection schemes near their plots and this enables them to increase the share of their irrigated land.

Our theoretical framework for analyzing how farmers decide on the share of irrigated land using water harvesting, starts with a Just-Pope production function (Just and Pope, 1978) that explicitly considers production risk:

$$y = f(x, L, A_I, A_{NI}) + \varepsilon \cdot h(x, L, A_I, A_{NI}) \tag{1}$$

where y is output, x are variable inputs, L is labor, A_I is irrigated land, A_{NI} is non-irrigated land. The function $f(x, L, A_I, A_{NI})$ gives the mean output level and $\varepsilon \cdot h\ (x, L, A_I, A_{NI})$ reflects the variation in output, where ε is a random term that reflects the production risk (e.g. due to drought) and where $h\ (x, L, A_I, A_{NI})$ indicates how inputs and other variables relate to these production risks. Some inputs may reduce the effects of these risks, whereas others may increase it. Important assumptions are that output is increasing in A_I at a decreasing rate ($\partial f/\partial A_I > 0$, $\partial^2 f/\partial A_I^2 < 0$), and that irrigated land is risk-reducing ($\partial h/\partial A_I < 0$, $\partial^2 h/\partial A_I^2 < 0$).

The one-period benefit of an additional unit of irrigated land is given by the value marginal product (*VMP*), which is the combined value of the marginal increase in output and the marginal decrease in output risk due to an additional unit of irrigated land:

$$VMP = p \cdot \partial y/\partial A_I = p[\partial f(x, L, A_I, A_{NI})/\partial A_I + \varepsilon \cdot \partial h(x, L, A_I, A_{NI})/\partial A_I] \tag{2}$$

where p is output price. In investment decisions, farmers usually have a longer time horizon than one period (Gardebroek, 2004). The relevant time horizon T depends on the expected number of years the invested water harvesting system lasts, which to a large extent depends on the kind of construction material used, i.e. plastic sheet, cement or clay (Wakeyo and Gardebroek, 2013). The expected discounted sum of the yearly VMPs (dynamic value marginal product, DVMP) is a function of A_I, and is used to assess the long-run benefits of investment:

$$DVMP(A_I) = E\left[\sum_{t=0}^{T} p_t[\partial f_t(x, L, A_I, A_{NI})/\partial A_I + \varepsilon \cdot \partial h_t(x, L, A_I, A_{NI})/\partial A_I] \Big/ (1+r)^t\right] \tag{3}$$

where E is the expectation formation operator and r is the discount rate. These expected long-run benefits are compared with the acquisition costs of water harvesting technology (Johnson and Pasour, 1981). Acquisition costs are costs to construct a water harvesting system, which are related to the irrigated area A_I, and on the