Farm Size and the Share of Irrigated Land in total Landholding: the case of Water-Harvesting Irrigation in Ethiopia

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Abstract

Rain-fall shortage constrains production in small-holder agriculture in developing countries and with ongoing climate change these shortages may increase. Rain-water harvesting are interesting technologies that decrease this risk. Therefore, one would expect an increasing use of these technologies in drought-prone areas. However, data collected in Ethiopia shows that the share of irrigated land in total landholding declines with farm size. This study investigates why the share declines with farm size using panel data collected in 2005 and in 2010. A random-effect tobit model is 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 farm-specific factors such as credit per hectare, distance to market, ease of selling output, landholding, regional differences, aridity and distance of plots from natural water sources significantly affect the share. Thus, encouraging investment has to consider farm-size, and also geographical, environmental and regional diversity.

1. Introduction

Rain-fall shortage constrains production in small-holder 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. Chemical fertilizer and improved seeds require sufficient water to effectively increase yields. Therefore, harvested water is a safe option against weather risk that safeguards the application of those costly modern inputs. Thus, water harvesting technologies increase yield and sustain income by reducing production risk. These technologies may become even more important in the future since due to climate change drought spells are expected to become more frequent and severe in various parts of the world. Given these benefits, one would expect an increasing use of these technologies. However, survey data collected from Ethiopia in 2005 and 2010 show that the share of irrigated land by water harvesting successively declines with farm size. This suggests that when farms get larger, they increase the area of irrigated land less than proportionately.

In some areas, limited rainfall could constrain expansion of the area irrigated by collected rainwater. However, in our survey only 10% of the farmers indicated that limited rainfall is a constraint in the adoption of water harvesting technologies. In several areas, farmers using the technologies earn high returns, and despite various constraints, the number of farmers adopting is increasing (Gezahegn et al. 2006). In fact, though the share is declining, the mean irrigated land area increases from small to large farm size quartile, indicating that large farmers also pay attention to the technologies. Thus, that rainfall shortage doesn't seem to constrain big farms of area irrigated by water harvesting.

A declining share of irrigated land suggests that the technologies become less relevant when farm size increases, implying water harvesting has no future when the scale of agriculture increases. In other word, if big farmers show low intensity, this could imply that the importance of these technologies declines when farms grow in size and become commercial farms. However, before concluding that the technologies are inappropriate with increasing farm size, it is worth investigating what the causes are for the declining share. For example, farmers may face credit constraints, which could limit the financial capacity to buy plastic, clay and cement for pond construction. Shortage of credit may also constrain buying water lifting equipment such as treadle and motor pumps. Labor shortage could also constrain big farmers severely because irrigation is a labor intensive activity and if big farmers have labor shortage they can only use irrigation on a small portion of their land.

This study investigates why the share of irrigated land in water harvesting decreases with farm size among the surveyed Ethiopian farmers. This is important to understand since for subsistence farmers water harvesting may be a promising way of coping with droughts that may occur more frequently in the future due to climate change. Unlike most of the farm size studies on fertilizer and improved seeds that suggest mainly input prices affect the degree of new technology use (Feder, 1980), in risk reducing water harvesting, investment impending factors such as lack of credit, lack of market access and customers to sell outputs, and natural conditions (environmental and geographical) could play a significant role. The study uses a panel tobit model to investigate the dynamics of these new technologies.

The study is organized as follows. Section 2 discusses the theoretical framework of decision making on the share of irrigated land. Section 3 discusses the model and data used in the empirical analysis. Section 4 presents the estimation results. The final section concludes and suggests policy implications to deal with the declining share of irrigated land.

2. Theoretical Framework Explaining the Share of Land Irrigated by Harvested Water

This section discusses a theoretical framework explaining the share of land irrigated by harvested water. It starts with existing conditions related to water harvesting in Ethiopia, and finally shows how farmers decide on the share of land to be irrigated.

Though they may have other objectives, farmers mainly invest in water harvesting to decrease production risk. Investment in water harvesting 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 plot distance from a dam determines the share of irrigated land (Amachur et al. 2004; Dumagay, 1984). In water harvesting, however, farmers can locate them near their plots.

Differences in investment in water harvesting technologies, which determine the quantity of water available for irrigation, are a plausible explanation for different shares of irrigated land among farmers. Two kinds of investment are common in water harvesting in Ethiopia. The first is the investment on the physical structure of the schemes. It includes digging (pond, shallow-well or a canal), permanently sealing the floor of ponds (with plastic, cement or clay), installing filtering canals and various mechanisms to increase water flowing in (e.g. planting grasses and trees). The second is investment in water lifting equipment, including manual and motorized irrigation equipment such as water-cans, buckets, treadle pumps and motor pumps. The second kind of investment complements the first by creating the capacity to catch, preserve (Owise and Hachum, 2006) and distribute water (Takeshima, et al 2009. Both investments together determine the irrigated land size.

Investment is a trade-off between current and future benefits. In investing in water harvesting there is a trade-off between current investment costs and the reduction of future production risk. In investing, farmers face various constraints related to credit, labor, land (to locate ponds) and availability of materials such as plastic. If they expect benefits from the investment those who secure those resources invest while others do not invest. To model how farmers decide on the share of irrigated land using water harvesting, the assumption is that this supplementary irrigation reduces production risk. Pope and Just (1978) suggested a production function that explicitly considers production risk and we will use this as a starting point in our analysis of investment in water harvesting technologies:

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

where y is output, x are variable inputs, L is labor, A_I is irrigated land, A_{NI} is non-irrigated land. The function $f(.)$ gives the mean output level and $\varepsilon \cdot h(.)$ reflects the variation in output, where ε is a random term that reflects the risk in production (e.g. due to drought) and where $h(.)$ 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 $f(.)$ 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 value of the combined marginal increase in output and the marginal decrease in output risk due to an additional unit of irrigated land. In investment decisions, farmers usually have a longer time horizon than one period. The relevant time horizon T depends on the expected number of years the invested scheme lasts, which depends on the kind of construction material used i.e. plastic, cement or clay (Gezahegn et al. 2006). However, subsistence farmers could also use a time-horizon based on the duration of microcredit to finance the investment.

These expected long-run benefits are compared with the acquisition costs of WHT (water harvesting technology), (Johnson and Pasour, 1981). Acquisition costs depend on the labor and material costs to construct WHT, which are related to the irrigated area A_I, and on the possibility and amount of loans. Farmers require a financial resource to buy the investment inputs such as plastic and cement. The source of finance could be either own saving or a loan. Poor farmers lack own saving and the option is to look for credit at some cost of borrowing. Farmers who use saving do not incur borrowing cost and their acquisition cost is low than those who borrow at some cost. Recognizing that both benefits and costs are a function of A_I, the optimal size of irrigated land A_I^* can be determined. If benefits are below fixed acquisition costs (e.g. because funds cannot be obtained or only at extremely high costs), A_I^* is zero, else it is positive. Assuming acquisition cost C_o is a function of credit B_o, saved income (e.g. off-farm income S_o) and family labor L_o, then the size of irrigated land A_{It} is:

$$A_{Ii} = \begin{cases} A_{Ii}^* \quad if \quad E\left[\sum_{t=0}^{T} \dfrac{p\left(\dfrac{\partial f(.)}{\partial A_I} + \varepsilon \cdot \dfrac{\partial h(.)}{\partial A_I}\right)}{(1+r)^t}\right] - C_o(B_o, S_o, L_o) > 0 \\ 0 \qquad\qquad otherwise \end{cases} \tag{2}$$

The theoretical framework shows that the area of irrigated land depends on the expected return from investment and the acquisition cost. Optimal land allocated to irrigation in water harvesting is thus a function of variables affecting long-run returns and costs of investment. The long-run expected return in turn encompasses a series of short-run (annual) returns from production, including risk reduction. In the short-run (annual) costs of production, input costs such as labor cost, fertilizer, etc other costs related to water are implicitly available. Letcher (2003) underlined that short-run decisions in long-run capital investment on water projects should never be neglected. Accordingly, relevant variables are variables that affect the change in output due to the change in irrigated land ($\partial f(.)/\partial A_I$),output variability ($\varepsilon \cdot \partial h(.)/\partial A_I$),prices p , discounting factor *r*, expectation formation *E* and initial investment costs $C_o(B_o, S_o, L_o)$.

3. Empirical Model and Data

Empirical Model

As indicated in the introduction, an important objective of this study is to investigate why the share of irrigated land decreases with farm size. Since farmers usually decide on the acres to be irrigated, the theoretical model described in the previous section explains the level of irrigated land rather than the share. However, in the econometric analysis we will use the share of irrigated land as the dependent variable. It is important to realize that explanatory variables may have a different impact on irrigated area and share of irrigated land. A large farmer may have more irrigated acres than a small farmer, but still have a lower share. To solve this problem, we included several explanatory variables on a per hectare basis.

The dependent variable share of irrigated land is a continuous variable ranging from zero to one. Given this the double-censored nature of the dependent variable and the fact that we have two years of data available on all households, a panel tobit model is most appropriate to estimate. Depending on how to treat the farm-specific effects, a fixed or random effects panel tobit model has to be chosen. However, with short panels fixed effects tobit models are problematic to estimate. Due to the non-linear character of the In panel tobit model, fixed farm effects cannot be differenced out as in linear fixed effects models ('incidental parameter problem', see e.g. Cameron and Trivedi, 2005: 800), and estimation therefore would yield inconsistent estimates. Therefore, in this study a random distribution of the farm-specific effects is assumed and based on this assumption a random effect tobit (RE) model is estimated. The RE tobit assumes a strong condition of zero correlation between the two error components and the dependent variable. Despite, the RE tobit has two advantages: it captures both between and within variation; and compared to a pooled model a random effects model explicitly considers the unobserved heterogeneity that has impact on the dependent variable. The households in various sub-districts vary in culture, institutional support, etc and we assume that those unobserved variables are randomly distributed. The standard random effect tobit model follows from equation (2). Let S_{it} be the share of irrigated land of farmer i at time t . In terms of latent variable S_{it}^* :

$$S_{it}^* = X_{it}^{'}\beta + \alpha_i + \varepsilon_{it} \qquad i = 1, 2, \ldots, N$$

$$S_{it} = \begin{cases} 1 & if \quad X_{it}^{'}\beta + \alpha_i + \mu_{it} \geq 1 \\ S_{it}^* & if \quad 0 < X_{it}^{'}\beta + \alpha_i + \mu_{it} < 1 \\ 0 & if \quad X_{it}^{'}\beta + \alpha_i + \mu_{it} \leq 0 \end{cases} \qquad (3)$$

where $X_{it}^{'}$:vector of explanatory variables; α_i and ε_{it} : identically, independently distributed error terms with mean 0 and variances σ_α^2 and σ_u^2 respectively. In the random effect model, α_i captures the unobserved time invariant variables while ε_{it} is the stochastic disturbance or the residual of the listed explanatory variables. The RE tobit uses weighted maximum likelihood, which is based on weighted random components of the model to obtain unbiased, consistent and efficient estimates of parameters β_i . The weighted random component is based on the combined distribution of α_i and ε_{it}. Both α_i and ε_{it} contain randomly distributed stochastic components when they are combined $\xi_{it} = \alpha_i + \varepsilon_{it}$ and assumed $\xi_{iT} \sim N(0, \Lambda)$, where $\Lambda = \begin{bmatrix} \sigma_\alpha^2 & \sigma_\alpha \sigma_\varepsilon \\ \sigma_\varepsilon \sigma_\sigma & \sigma_\varepsilon^2 \end{bmatrix}$. The joint error component ξ_{it} is normally distributed with mean 0 and variance 1, with both components distributed with mean 0 and their variances adding up to 1. The constant variance assumption makes maximum likelihood estimation possible.

Based on the theoretical model and other literature, the following explanatory variables are presumed to explain share of irrigated land: credit per hectare, off-farm income per hectare, Labor per hectare, soil fertility, total landholding, management experience, education: ease of getting buyers, distance to market, membership in marketing cooperative, training, aridity index, average plot distance from water source, gender and region dummy.

Data

In 2005 the Ethiopian Development Research Institute (EDRI) conducted a national survey and interviewed 2082 randomly selected households from 30 sub-districts. In 2010, out of those 2082 households, 400 are randomly selected from 9 of the sub-districts and interviewed for a second time. This study uses 400 panel households interviewed in both years.

The dependent variable, share of irrigated land, is computed as the share of irrigated land to total land. Total land is the sum of crop land, homestead, fallow and unused lands. Users of water harvesting technologies can use water on those lands to grow crops. Excluding non-crop land in computing the share of irrigated land would exaggerate the scarcity of land and so they must be included. Defined in this way, the overall mean of the share of irrigated land of users is only 0.23 (table 1) indicating very low overall share possibly because of water scarcity and other factors. Table 1 shows that the share of irrigated land declines from quartile 1 to 4 in both years: from 36% to 11% in 2005 and from 31% to 13% in 2010. The table indicates also despite the declining share, the mean irrigated land successively increases with farm size, probably indicating the attention paid to the technologies by the big farmers. The mean irrigated land also increased from 0.32 to 0.35 hectare over the period 2005 and 2010.

Table 1: Averages for total land, irrigated land and shares for water harvesting users

Quartiles of Land- holding	*Mean Landholding (hectare)*	*Mean Irrigated-Land and Mean Share (Std. dev in parenthesis)*	
		Mean Irrigated Land	*Mean Share*
2005			
1	0.621 (0.15)	0.232 (0.23)	0.361 (0.27)
2	1.084 (0.13)	0.274 (0.21)	0.255 (0.19)
3	1.807 (0.28)	0.377 (0.35)	0.214 (0.20)
4	3.880 (1.39)	0.343 (0.53)	0.105 (0.18)
Mean 2005	1.972 (1.40)	0.320 (0.37)	0.220 (0.22)
2010			
1	0.601 (0.14)	0.179 (0.11)	0.315 (0.20)
2	1.090 (0.13)	0.319 (0.27)	0.292 (0.24)

3	1.903 (0.30)	0.382 (0.34)	0.217 (0.22)
4	4.042 (1.92)	0.589 (1.15)	0.134 (0.16)
Mean 2010	1.696 (1.51)	0.345 (0.57)	0.252 (0.22)
Overall Mean	1.863(1.45)	0.329 (0.46)	0.233 (0.22)

With respect to the explanatory variables, table 2 shows that average values for credit per hectare, off-farm income per hectare, and labor per hectare also decrease for higher quartiles. The descriptive statistics thus suggest these variables have a positive correlation to the share of irrigated land. Except for the 3rd quartile, the trend of mean irrigated land have some similarity with capacity investment as the theory suggests.

Table 2. Means of variables for different land quartiles

Variables	*Quartile Mean*			
	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Total land in hectare (a)	0.61	1.08	1.84	4.22
Share of irrigated land (b)	0.19	0.19	0.16	0.07
Total irrigated land (= a x b)	0.12	0.21	0.28	0.27
Capacity investment per ha (‘000 ETB)	0.27	0.66	0.59	0.57
Credit per ha (‘000 ETB)	0.90	0.56	0.28	0.09
Off-farm income per ha (‘000 ETB)	1.46	1.02	0.37	0.33
Labor per ha (in adult equivalent)	6.77	3.65	2.32	1.44

*****Note: ETB is the Ethiopian currency Birr. 1 ETB was 0.0741 USD in June 2010.

Table 2 shows that the mean per hectare capacity investment is low in the first and in the last quartile groups showing that small-farmers invest low per hectare possibly due to land constraints for small farmers while large farmers could face constraints on savings, credit and labor. The summary of the descriptive statistics is depicted in Table 3.

Table 3. Descriptive statistics of variables used in estimation (all farmers)

Variables	*Mean*	*Std. Dev*	*Min*	*Max*
Share of irrigated land (*dependent variable*)	0.16	0.21	0.00	1.00
Explanatory Variables				
Education dummy (1= years of schooling)	0.35	0.48	0	1
Experience independent of parents (years)	21.17	11.30	0.00	59.00
Training on water harvesting?(yes=1)	0.66	0.47	0	1
Sex (1= male)	0.93	0.24	0	1
Total land (hectare ha)	1.92	1.69	0.13	13.75
Credit per ha (‘000 ETB)	0.46	0.97	0.00	9.36
Off-farm Income per ha (‘000 ETB)	0.79	1.82	0.00	20.91
Labor per ha (in adult equivalent)	3.55	3.04	0.23	36.80
Distance to market (hour)	1.39	0.94	0.00	3.67
Do you get buyers easily? (yes = 1)	0.68	0.47	0	1
Membership in cooperative? (yes = 1)	0.24	0.43	0	1
Soil fertility index	12.69	12.55	0.25	97.25
Plot distance to natural water source (hours)	0.46	0.71	0.00	6.00
Aridity index	0.67	0.27	0.11	1.12
Region dummy (1 = Oromia)	0.70	0.46	0	1

4. Results

Equation (3) was estimated as a random effects tobit model. The parameter estimates of the random-effects tobit are summarized in table 4. At the end of the section, we discuss the estimation method used and some general specification tests.

Table 4 indicates credit per hectare received and the ease of selling output increase the share of irrigated land, in line with our expectation. Those farmers using water harvesting use the credit to buy plastic, cement and clay, and water-lifting equipment such as motor pumps. In other words, farmers receiving credit have a better chance to catch, lift and distribute water than farmers who receive little credit. The estimated coefficient shows a thousand ETB increase in credit received per hectare increases the share of irrigated land on average by 0.029, which is modest. Similarly, farmers who are confident in selling their outputs grow marketable crops by harvested water more often than farmers who worry about getting their crops sold. Farmers that can easily sell their crops have a share of irrigated land that is on average 0.048 higher. An increase in ease of selling can be due to rising demand for products, market information resulting from new transport and communication infrastructure.

The results also show that distance to a natural water source, and low aridity increase the share of irrigated land. Unlike farmers whose plots are close to lakes, rivers or marshy wet-lands, farmers who are far away face higher weather risk and tend invest on water harvesting to increase their land under irrigation. Plots far away from the natural water sources tend to have relatively less moisture than plots close to natural water sources. In other words, farmers whose plots are close to those sources may not even feel weather risk as a problem and so they tend to invest less. The coefficient of average plot distance from natural water sources shows an hour increase to reach a natural water source increases the share by 0.028.

From a water availability perspective, the effect of aridity is contrary to the effect of distance to natural water source. It is discussed that being far away from natural water sources increases the share of irrigated land, showing the need for water harvesting in dry areas is higher. Contrary to this, low aridity (of high aridity index) increases the share of irrigated land. In less arid areas, farmers have more rainfall to catch, save and use than farmers in more arid areas, so that the former can irrigate a larger share of their farmland. This is because low aridity implies more rainfall to harvest and lower evaporation to save the harvested-water than high aridity. The estimated coefficient also shows with a rise in aridity index by 1 (with less aridity), share of irrigated land increases by 0.12. The larger coefficient compared to other coefficients shows availability of rainfall in water harvesting is essential.

Table 4. Estimates explaining the share of irrigated land

Variable	*Description*	*Random Effects Tobit*
Constant		0.195***
		(0.059)
Total Landholding	hectare	-0.028**
		(0.012)
Credit per hectare	‘000 ETB	0.029**
		(0.014)
Off-farm income per hectare	‘000 ETB	-0.007
		(0.007)
Labor per hectare	Number	-0.005
		(0.005)

Cooperative	Dummy	0.0001
		(0.027)
Ease of selling	Dummy	0.048**
		(0.023)
Distance to market	hours	-0.034***
		(0.011)
Experience	Years	-0.003***
		(0.001)
Training	Dummy	-0.037**
		(0.017)
Soil Fertility index	Index	-0.001
		(0.002)
Plot distance to natural water source	hours	0.027**
		(0.011)
Aridity Index	Index	0.118***
		(0.035)
Oromia	Dummy	0.087***
		(0.024)
Education	Dummy	0.014
		(0.032)
Sex	Dummy	-0.075
		(0.052)
σ_α	Sigma α_i	0.084***
		(0.028)
σ_ε	Sigma ε_i	0.258***
		(0.013)
ρ	rho	0.096
		(0.064)
Likelihood Ratio Test of σ_u		2.790 (p-value: 0.047)
Log -likelihood		-271.988
Wald Test : $\chi^2(15)$		149.150
N= 787		lc[b]:257, uncensored:523, rc:7

Numbers in parentheses are standard errors; *** p < 0.01, ** p < 0.05 and * p < 0.1.

On the other hand, total landholding, distance to market, the experience of the farmer after becoming independent of parents, and training have a statistically significant negative effect on the share of irrigated land. The effect of total landholding and the time it takes to reach a market is in line with our expectation. The result shows with increasing landholding, the share of irrigated land falls, in line with what this study investigates but is contrary to the hypothesis that land shortage constrains size and number of WHT schemes. The coefficient shows a hectare more land decreases the share of irrigated land by 0.027.

The results also shows that when the time to reach the nearest market center increases, the share of irrigated land decreases. Lack of rural transport-roads and the high transport costs increase the time to access markets. Especially in east Ethiopia, the hilly-terrain exacerbates the problem. The available option for farmers is to transport by animals or on their own back. Of course, this transport problem is smaller when farmers are closer to the market center. Thus lack of efficient and cheap transportation discourages investment on water harvesting and causes low shares of irrigated land. The estimated coefficient indicates an additional hour of travel time to the market center decreases the share of irrigated land by 0.03. This time to market effect is similar to the effect of ease of selling output. Significance of both variables points out that market access strongly affects the share of irrigated land. The result also indicates that in Oromia (compared to SNNP) the share of irrigated land on average is 0.087 higher. A recent census indicates in Oromia, the number of farmers using motor-pumps by far exceeds those in SNNP and this may cause the difference. Other explanations may be geographical or ecological differences, or simply a difference in unobserved farm structure.

The signs of parameters for management experience after becoming independent of parents, and for taking training on water harvesting are not in line with our expectation. The result indicates that more management experience lowers the share of irrigated land. Experience, measured by the number of years is collinear with age. Older farmers may stick more to traditional production practices, which may be an explanation for the negative sign. Similarly, taking training on water harvesting decreases the share of irrigated land. An explanation for this finding is found in the descriptive statistics that shows 73% of the farmers who do not use water harvesting nevertheless participated in training for using WHT. Of course, this is a remarkable finding questioning the relevance of these training programs. Additionally, the results show that off-farm income, cooperative membership, gender and education do not significantly affect the share of irrigated land. Labor also has a insignificant effect on the share of irrigated land, contrary to our expectations. A possible reason for the insignificance of labor is that use of equipment such as motor pumps is more important in irrigating farmland than labor. Finally, the results show that the unobserved farm-specific effects have significant effect on the share because σ_α is significant at 1% level.

Tests are carried out to check the quality of estimation. Before estimating the random effect (RE) tobit model, we tested for endogeneity using a Hausman-Durbin-Wu test and found that land size is an endogenous variable. To fix endogeneity, a pooled IV-tobit model was estimated and endogeneity is rejected at 1% significance level. Later, the IV-tobit is compared with the RE-tobit by carrying out Hausman specification test. The test failed to reject the null that the difference between the coefficients in RE-tobit and pooled IV-tobit is not systematic (p-value= 0.93). Moreover, the log likelihood ratio test rejected the pooled tobit in favor of the random effect tobit at 5% significance level (p-value = 0.040). These tests show that the RE tobit is superior to both pooled tobit and IV-tobit. Finally, to control for heteroscedasticity estimation are carried out with bootstrapped standard errors. Surprisingly, coefficients in all tobit models have no big difference in magnitude and sign.

5. Conclusions and Implications

In countries where agricultural production is risky due to unpredictable rainfall, harvested water can be used for supplementary irrigation to decrease production risk. In those areas, the more land of a smallholder is irrigated the more a farmer could control production risk arising from rainfall-shortage. In recent years, Ethiopian farmers invested in water harvesting to collect rainwater and use it for supplementary irrigation. However, the data shows the share of irrigated land decreases with farm size. This declining share suggests that for large commercial farms water harvesting has no future. This study investigates why the share falls with farm size. Using two-period panel data, factors behind the declining share are analyzed. As a basis for the empirical analysis, the study developed a theoretical framework of investment decision making to optimize long-term returns by decreasing output variability. The framework is based on the idea that deciding level of investment determines the quantity of harvestable water which in turn determines the size of irrigable land. The framework gives a foundation to identify variables presumed to affect investment and share of irrigated land.

To test the effect of the variables presumed to affect the share of irrigated land in Ethiopia, a random effect tobit model is estimated using panel data collected in 2005 and in 2010. The findings show observed and unobserved farm-specific factors affect the share of irrigated land. Observed farm specific factors such as credit per hectare, ease of selling output, aridity index, and differences between Oromia and SNNP have positive and significant effect whereas landholding, distance to market, management experience and training on water harvesting have negative and significant effects. When large farmers face a credit shortage, they invest on a smaller scheme to irrigate a small proportion of their land. Similarly, if farmers with a lot of land are market constrained, they use the water only on a small portion of their land to produce what they expect to sell. The finding that the geographical and environmental variables determine the share is also reasonable. Water harvesting uses rainfall, accumulated in ponds, and shallow wells or obtained from stream diversions, indicating that some rainfall is a basic condition to invest. Highly arid areas are characterized by low rainfall, not highly variable rainfall. Therefore, farmers cannot collect enough rainfall if they invest; evaporation is also high. Those conditions decrease the attractiveness of water harvesting.

The findings also show unobserved farm-specific factors causes diversity among households. Households are diverse in culture, the local institutional support they receive (e.g. with the supply of investment inputs, and post investment advices) and information they receive about water harvesting. For instance, in some sub-districts local development agents give continuous advise, provide investment and post-investment inputs such as plastics and improved seed varieties. Those kinds of institutional supports are not uniformly available to households across sub-districts and this could cause difference in returns by decreasing variability of weather. Overall, both economic and natural constraints discourage investment and cause a decreasing share of irrigated land for larger farmers. On the other hand, per hectare labor, per hectare off-farm income, soil fertility, education, gender, membership in marketing cooperative has no significant effect on the share of irrigated land.

Giving farmers access to credit, link them to markets by investing on infrastructure and linking them to customers encourages farmers to increase the generally low share of irrigated land. Mainly, if farm size is considered in encouraging investment for instance by making credit available, then the proportion of irrigated land increases in the high farm size quartiles. This implies encouraging investment on water harvesting has to consider farm size. The issue is that when economic constraints combined with natural constraints and other unobserved farm specific constraints the problem gets complex. Therefore, it is vital to consider farm size, and environmental, geographical conditions in encouraging investment.

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