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Adoption and impacts of an irrigation technology: Evidence from household level data in Tigray, Northern Ethiopia

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The occurrence of frequent droughts due to low and erratic rainfall poses high uncertainty and agricultural production risks leading to wide spread poverty and food insecurity. Hence, for agricultural intensification, water is an entry point implying that irrigation development especially small holder irrigation and adoption of water saving technologies is very important. This paper aims at indentifying factors that affect farm households' decision on whether to adopt pumps for lifting irrigation water and at making comparisons between the income of adopters and non-adopters. A logit model and an ordinary least-squares (OLS) regression are estimated using a total sample of 301 farm households to identify the factors that influence adoption of the technology and to determine impacts. Consistent with the findings of other studies, the regression results indicated that the most important determinants of the adoption of the small-scale irrigation technology include access to ground and surface water, yearly availability of water, sex of household head, level of education, access to credit and number of adult family members. The results also showed that the adoption of irrigation technologies has significant positive effect on agricultural income relative to the non- adopters.

Key words: Small-scale, household, irrigation technology, pumps, adoption, logit.

INTRODUCTION

Ethiopia in general and Tigray region in particular faces a major challenge in poverty reduction and food security mainly due to climatic factors that severely affect its agricultural performance. According to the Ministry of Finance and Economic Development (MoFED, 2010), the major challenges encountered in implementing the past Five Year Plan (2005/06-2009/10), known as PASDEP, were mainly due to irregular rainfall patterns. On the other hand, land scarcity driven by population pressure puts agricultural intensification high on the agenda of food security and poverty reduction.

Although Ethiopia has immense surface and groundwater potential (Makombe et al., 2007; Awulachew, 2010; Awulachew et al., 2006), the country fails to use this potential to produce enough food to feed its population. While irrigation in Ethiopia has the potential to increase cereal yields by up to 40% (Diao et al., 2010), agricultural producers have used only about 5 to 6% of the country's irrigation potential mainly through large and small-scale community irrigation schemes. The

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reality is similar in Tigray region. Tigray has a potential of about 350 thousand hectares of irrigable land of which, only about 83 thousand hectares or 6% of the potential is currently under irrigation (Awulachew et al., 2007).

The government and people of Tigray have been working intensively on agricultural development as a result of which, crop production has increased continuously in the past 5 years. Although most of it is through scheme/community irrigation systems, irrigated land has increased from 4000 ha in 2003 to 83000 ha in 2010. Moreover, the general direction of the region is to increase the use of irrigation with a target goal of irrigating about a quarter of the cultivated area in the region (Tigray Agriculture and Irrigation development Bureau, 2010). Scheme-level irrigation is capital intensive and limited to reach many farmers. Consequently, there is a need to give more emphasis to small household-level irrigation technologies. Small household irrigation technologies, including small pumps, are smallholder-friendly that can be used in diverse water sources. Based on its technical and socioeconomic attributes, small pump irrigation is categorized as smallholder private irrigation technology.

In the context of this paper, motor pumps are small size if they are between 1 and 10 horse power (HP) and less expensive if they cost between US$ 200 and 1000. They are initiated and financed by small farmers themselves mainly to irrigate small plots of cash crops. Unlike the community level irrigation infrastructures, they are owned and managed individually or by informal group of farmers to pump water from diversified sources such as rivers, reservoirs and shallow aquifer. Furthermore, investment in small-scale household level irrigation plays crucial role to reduce the dependence of agricultural production on rainfall and climate risk and improve crop production (MoFED, 2006; Diao et al., 2010).

The use of small scale pump irrigation schemes has proven successful in various parts of Asia, Africa and Latin America over the last fifteen years. Similarly, based on information from the Bureaus of Agriculture and Water Resources of the Tigray region, motorized small pumps are among the emerging small private irrigation technologies in the rural areas. The spread of this technology is made through two channels: motor pumps distributed through the regional bureau of agriculture mainly on credit and farmers' direct purchase motor pumps using own resource which happens spontaneously and unregulated. Accordingly, data from the bureau of agriculture shows that between 2004 and 2010, the Bureau of Agriculture and Rural Development has distributed about 9675 and 20184 of motor pumps and treadle pumps, respectively (Tigray Agriculture and Rural Development Bureau, 2010).

The occurrence of frequent drought due to low and erratic rainfall poses high uncertainty and agricultural production risks leading to widespread poverty and food insecurity. This is a serious problem in the drought prone areas of Tigray region. Population pressure has pushed land holdings to its low level. On the other hand, cultivable agricultural land has almost reached its limit implying that agricultural intensification is the best available option to increase agricultural production and food security.

For agricultural intensification (such as improved input use), water is an entry point implying that irrigation development, especially smallholder private irrigation and adoption of smallholder private irrigation technologies is very important. On the other hand, lack of simple and affordable irrigation technology that fits the production conditions of smallholder is a serious limiting factor to achieve food security. While there is evidence that there is high demand from smallholder farmers' for different types of water lifting technologies (such as motorized and human powered technologies), the level of adoption of the technologies is very low. Therefore, the general objective of this paper is to investigate factors that affect farm households' decision to adopt motor pump and its impact on household income. More specifically, it is intended to identify factors that affect decision to adopt irrigation technologies and examine if adopters attain significantly higher income levels.

METHODOLOGY

Description of the study area

The total area of Kilite Awulaelo Wereda[1] is about 105,758 ha. Out of the total area, about 21,620 ha are currently being cultivated and 84,138 ha are forests and sloppy areas. From the total cultivable areas 5,235 ha (5%) are currently irrigated. Up to now only 105 water pumps, 480 treadle pumps and 26 drip irrigation are being used in the wereda – all of which were distributed by the wereda adminstration. From this figures, we can see that most farmers of the wereda are still applying traditional methods of irrigation while applying irrigation technologies has strategic importance in improving the productivity of irrigation efforts in the wereda (Wereda Kilte Awlaelo Rural and Agriculture Office, 2010).

Sampling methods and data collection

The data used in this study comes from a household survey carried out in Abraha-Atsebeha and Adikesindad tabias (communities) of Kelete-Awlaelo wereda (district) in Tigray region. Primary data was collected from 301 randomly selected farm households of which 200 households were from Adikesindad and the rest from Abraha-Atsebeha. The research used a multi stage stratified random sampling method. In the first stage; we used information from the regional bureau of agriculture and Rural Development to identify wereda (district) with a high concentration of smallholder irrigation technologies, such as bucket, treadle pump and motorized pump. In the second stage, we used information from wereda agricultural offices to select Tabias (communities) that have high adoption rates of these technologies where we found that Adikesindad and Abraha-Atsebeha have high adoption rate of motor and treadle pumps, respectively. In the third stage, we used the list of farm households in selected communities and disaggregated them into adopters and non-adopters. Out of the total households of the two tabia (2373), every 8th from the list of the households (n+8) was

[1]Wereda (which means district) is the third smallest administrative unit next to kebele (meaning peasant association) and tabia (community).

Table 1. Total population and sample household heads by Tabia (community).

Tabia	Total number of household heads	Number and percentage of households in the Tabia		Sample size		
		Adopters	Non-adopters	Adopters	Non-adopters	Total
Adikisindad	1427	206 (14%)	1221 (86%)	54 (4%)	146 (10%)	200 (13%)
Abraha- Atsbeha	946	510 (54%)	436 (46%)	48 (5%)	53 (6%)	101 (12%)
Total	**2373**	**716**	**1657**	**102**	**199**	**301 (12.5%)**

considered for the study. Finally, a proportional random sampling technique was used to select sample households. Out of the total household 716 are adopters whereas 1757 are non-adopters. The 8th of 716 are more or less 102 and that of 1757 were 199 households. Of the total 301 sample households, 102 were using motor and/or treadle pumps (Table 1).

A comprehensive structured questionnaire was used to capture both qualitative and quantitative information. Secondary data from bureau of agriculture, wereda office of agriculture and tabia administration offices were also used.

Methods of analysis

In this paper, both descriptive and econometric data analysis methods are used. The production system in the study areas represents a multi-crop agricultural production where land holdings is fixed, the allocation of land into crop type and the adoption of irrigation technology is possibly endogenous (Negri et al., 1990). The adoption decision of irrigation technology is discrete where a farmer can decide to adopt or not to adopt in which case the farmer faces a dichotomous decision problem to adopt or not to adopt smallholder micro irrigation technologies. In this context, smallholder irrigation technology adopters are those who were using motor pump (treadle pump) to irrigate part of their land during the survey, while the rest are non-adopters.

Empirical model

The binomial logit model is used to estimate the probability of water lifting technology adoption that is, $\Pr(y_i = 1|x)$ where the model is transformed into the odds ratio specified as follows (Long, 1997):

$$\frac{P(y_i = 1|x)}{P(y_i = 0|x)} = \frac{\Pr(y_i = 1|x)}{1 - \Pr(y_i = 1|x)} \quad (1)$$

The odds indicate to what extent farmers have adopted smallholder irrigation technology $(y = 1)$ relative to those who didn't adopt $(y = 0)$. The log of the odds specified in Equation (2) suggests that it is linear in the logit.

$$\ln\left[\frac{P(y_i = 1|x)}{1 - P(y_i = 1|x)}\right] = x\beta_i \quad (2)$$

Which is equivalent to the logit model derived as:

$$P(y_i = 1|x) = \frac{\exp(x\beta_i)}{1 + \exp(x\beta_i)} \quad (3)$$

where P denotes the probability that the i^{th} farmer has adopted one or more type of the smallholder irrigation technologies, x_i captures household and farm level characteristics that affect household's adoption of smallholder irrigation technology, while β_i s are parameters to be estimated. A binomial logit model is useful for investigating the influences of household and farm level attributes on household's technology adoption relating the probability of smallholder irrigation technology adoption to the underlying characteristics. The dependent variable (y) is the logarithm of the odds in favor of motor/treadle pump adoption, and the parameters are interpreted as derivatives of this logarithm with respect to the independent variables. The estimated coefficients can be used to predict the adoption probability of motor/treadle pump. In the logit model, like in any nonlinear regression model, the parameters are not necessarily the marginal effects (Greene, 2000; Kennedy, 2001), but represent changes in the natural log of odds ratio for a unit change in the explanatory variables.

The logit model specified above estimates the probability of adoption of smallholder irrigation technology.

On the other hand, to estimate the effect of irrigation technology adoption on agricultural income, we used a simple Ordinary Least Squares (OLS) regression model specified as follows:

$$Y_i = \beta_0 + \beta_1 W_i + \beta_2 P_i + \varepsilon_i$$

$$\mathrm{y_i} = \beta_0 + \mathrm{x_{1i}}\,\beta_1 + \mathrm{x_{2i}}\beta_2 \ldots \mathrm{x_{ki}}\beta_k + \mathrm{p_i}\beta_{k+1} + \varepsilon_i$$

Where; $\mathrm{y_i}$ = agricultural income; $\mathrm{x_{ki}}$ = is a vector of household's asset endowments, and household characteristics such as household size, education level, adult hour, oxen, fertilizer usage, access to loan, contact to local development agents (workers), age of household head, TLU (Tropical Livestock Unit); $\mathrm{p_i}$ = is irrigation technology adoption status, a dummy variable which is 1 for adopters and 0 for non-adopters; ε_i is the error term, which is assumed to be normally distributed (zero mean and unit variance).

To predict the probability of water lifting technology adoption, family size, gender, age, river source availability, access to ground water source, education, contact to development agents (DA), distance to market, access to loan and TLU were used as explanatory variables. Variables type, unit of measures and expected signs are shown on Table 2.

RESULTS AND DISCUSSION

Analysis of the survey data showed that about 68.6% of the irrigation technology adopters were producing at least two crops per year. Furthermore, variables such as livestock and oxen ownership show that adopters of the

Table 2. Variables included in the regression equation and their expected signs.

Variable type	Type of variable	Unit of measurement	Expected direction of effect on adoption
Adult labour	Continuous	Number	+
Household sex	Binary	1 if Female, for male	-
Household age	Continuous	Years	+
River source	Binary	1 if Available, 0 for otherwise	+
River yearly availability	Binary	1 if Yes, 0 for otherwise	+
Ground source	Binary	1 if Yes, 0 for otherwise	+
Yearly ground water availability	Binary	1 if Yes, 0 for otherwise	+
Irrigation season	Binary	1 if Yes, 0 for otherwise	+
Education	Binary	1 if Literate, 0 for otherwise	+
Contact to DAs in wet season	Binary	1 if Yes, 0 for otherwise	+
Access to loan	Binary	1 if , 0 for otherwise	+
Distance to market	Continuous	Kilometres	+
Motor pump awareness	Binary	1 if Aware, 0 otherwise	+
Farm size	Continuous	*Timad*= 1/4 of hectar	+
Tropical Livestock Unit (TLU)	Continuous	Number	+

+, Positive effect; -, negative effect.

Table 3. Descriptive statistics of the major variables.

Variable description	Non-Adopters (N=199)	Adopters (N=102)	Significance Test (T-test and Chi^2)
	Mean	Mean	
Number of adult family members	4.317 (1.037)	4.873(1.912)	0.001***
Household head age	46.201 (13.957)	43.971(11.692)	0.167
Household head sex (1=male)	0.688 (0.464)	0.922(0.270)	0.000***
River source accessibility (1=available)	0.101(0.301)	0.363(0.483)	0.000***
River availability yearly (1=yes)	0.065(0.248)	0.118(0.324)	0.119
Ground source accessibility (1=yes)	0.050(0.219)	0.510 (0.502)	0.000***
Ground water availability yearly (1=yes)	0.040 (0.197)	0.245(0.432)	0.000***
Irrigation season (1=throughout the year)	0.131(0.338)	0.686 (0.466)	0.000***
Motor pump awareness (1=aware)	0.357(0.480)	0.814 (0.391)	0.000***
Farm size (Timed)	4.364(2.542)	4.437 (2.555)	0.8127
Household's livestock holding in TLU	2.078 (1.669)	2.636 (1.729)	0.007***
Male adult labour (Number)	2.106 (0.806)	2.441 (1.215)	0.004***
Total harvest (birr)	3597.623(5106.762)	6715.558(5505.570)	0.001***
Adult female labour (No)	2.211(0.616)	2.431(1.239)	0.040***
Fertilizer value (birr)	398.472 (388.142)	734.480(825.257)	0.000***
Education (1=literate)	0.276 (0.448)	0.569 (0.498)	0.000***
Distance to market (Km)	6.699 (4.570)	6.130 (4.955)	0.304
Access to loan (1=yes)	0.543 (0.499)	0.637 (0.483)	0.117
Contact to DAs in wet season	0.653 (0.477)	0.676 (0.470)	0.162

***p < 0.01; **p < 0.05; *p < 0.1.

new irrigation technology are wealthier than the non-adopters (Table 3). Estimates from the logit and Ordinary Least Square (OLS) models are presented in Tables 4 and 5, respectively.

The regression results show that access to water sources (ground and surface water) have positive relationship with adoption of irrigation technology implying that farm households which have better access to water sources are more likely to adopt the technology. As an irrigation technology does not stand alone, the result is not unexpected. The implication is that motor pump as well as other technologies are suitable in groundwater and surface water potential areas and that enables farm households to produce during the dry season. Evidence

Table 4. Determinants of adopting irrigation technology - regression results from binary logit model.

Variable	Coef.	SE
Adult labour	0.350**	0.170
Household sex	-2.140***	0.730
Household age	-0.031	0.020
River source	2.033***	0.516
River yearly availability	-1.097	0.729
Ground source	3.662***	0.695
Ground yearly availability	-1.164	1.032
Irrigation season	2.586***	0.560
Education	0.788*	0.466
Contact to DAs in wet season	0.319	0.471
Access to loan	0.746*	0.438
Distance to market	-0.006	0.043
Motor pump awareness	0.783	0.638
Farm size	0.017	0.077
Tropical Livestock Unit (TLU)	0.132	0.128

***p < 0.01; **p < 0.05; *p < 0.1.

Table 5. The impact of motor pump adoption on agricultural income: OLD result.

Variable	Coef.	SE
Irrigation status	1525.438**	672.79
Adult labour	681.951***	203.66
Household sex	-827.522	711.84
Household age	25.041	22.92
Oxen quantity	1354.876***	501.13
Fertilizer value	1.957***	0.49
Contact to Das	-910.944	605.49
Education	2656.810***	614.76
Access to loan	192.944	574.49
Tropical Livestock Unit (TLU)	.-660.717***	245.38

***p < 0.01; **p < 0.05; *p < 0.1.

from Debrekerbe watershed, Tigray (Tadesse et al., 2008) supports the argument. Hence, as watershed development and other type of water harvesting activities are likely to improve groundwater recharge, investment in watershed development and environmental rehabilitation activities has paramount importance.

Literate household heads are also found to be more likely to adopt motor pumps as compared to illiterate household heads implying the positive role of education on technology adoption. Tjornhom (1995) and Feder and Slade (1984) argue that educated people develop positive attitude towards new innovations and are relatively ready to take risk of new farming practices. As educated people are better informed, they can easily respond to unforeseen events.

Furthermore, access to credit can reduce capital constraints. Results indicated that access to credit positively affects the adoption of irrigation technology. In this case, it is likely that liquidity constrained households are rationed out in the adoption process.

Male headed households are found to have higher likelihood of adopting the technology than female headed households. Given the finding above where liquidity is a major constraint for adoption, a possible explanation for this result is that female headed households are often poorer and hence are less likely to adopt the technologies.

Smallholder irrigation technologies like small pumps are labour intensive and smallholder-friendly because farmers can use family labour and diverse water sources. In line with this, our result confirms that households who have more adult family labour are more likely to adopt motor pump. In ordinary least-squares (OLS) -based impact analysis, the dependent variable is households' total agricultural income. Similar to its effect on adoption of motor pump, level of education of household head captured by years of schooling has positive effect on household's agricultural production (Table 5). This is not surprising, because relatively educated farm households are more likely to easily understand the benefits of extension packages and adopt other production enhancing inputs. This has been demonstrated in the probability of adoption of motor pump where literate farm household heads were found to be more likely to adopt smallholder irrigation technologies.

We hypothesized that adoption of irrigation technologies positively contributes to agricultural production. Both the descriptive data and regression results show that agricultural production of irrigation technology adopters was significantly higher as compared to non-adopters providing evidence to validate the hypothesis. This result is consistent with our expectation because, farm households who adopt an irrigation technology can produce more than one crop per year - usually high value crops for the market, that enable them to generate additional income. Small scale irrigation is generally considered as labour intensive compared to scheme level irrigation. In imperfect labour market conditions, households' family labour is an important factor for adoption of labour intensive smallholder technologies. Accordingly, the results show that number of adult family members of the farm households positively and significantly affects agricultural income. Furthermore, households' oxen and other livestock (in TLU) ownership has significant effect on agricultural income. As expected, the value of fertilizer that farm households have used has positive and significant influence on agricultural income.

CONCLUSIONS AND POLICY IMPLICATIONS

This paper examines factors influencing farmers' decision on whether or not to adopt smallholder irrigation technologies in the Kilete-Awlaelo district of Tigray region, in Ethiopia. Regression results showed that the availability of family labour positively affects the adoption of smallholder irrigation technologies. This is because the availability of higher number of family members working on the farm reduces the farm's external labour requirements. Moreover, in a situation where the opportunity cost of family labour is low, farm households with higher number of adult labour are likely to adopt labour intensive technologies. This is in line with the policy direction that gives due consideration for the use of agricultural technologies that can intensively use farm household labour and land.

Male headed households are found to be more likely to adopt irrigation technologies as compared to female headed counterparts. This indicates that women have not benefited much from innovations in micro-irrigation technologies. To change this gender imbalance, programs that target both gender groups will be necessary to ensure equitable adoption of practice between male and female headed households. Level of education increases the likelihood of adopting small scale technology. This indicated the fact that small scale irrigation technologies need special technical and managerial skills for their proper utilization. Hence, special training programs (on both operation and maintenance of the technologies) need to be instituted to manage irrigation technologies. Furthermore, access to credit positively influences the adoption of pumps. It is important to stress that due to capital requirement for acquisition of irrigation technologies, targeted credit programs will ameliorate the financial constraints of farmers. At the moment, the training for credit handling to small scale household farmers is poor. Access to ground and surface water is found to positively and significantly influence the adoption of smallholder irrigation technologies. This implies that the use of such micro irrigation technologies is suitable and appropriate in surface and/or shallow ground water potential areas and an extension approach of 'one fits all' is not appropriate. Hence, even though, the use of smallholder irrigation technology needs to be promoted, it is suggested that areas where these technologies are suitable need to be identified. Furthermore, the effect of wider application of smallholder irrigation technologies on the environment needed to be considered.

In general, there are important and significant differences between farm households who did and did not adopt smallholder irrigation technologies. In terms of output, in 2010 harvest season, the average per season value of production of adopters was significantly higher (about two fold) compared to the value of production of non-adopters. Furthermore, smallholder irrigation technology adopters are more likely to employ more labour as compared to non-adopters, which might be an indicator of the multi-dimensional role of smallholder irrigation in generating employment opportunities and then highlighting the broader community benefits from adopting smallholder irrigation technologies.

The policy implications of the above findings are that improved access to financial services, educating and raising farmers awareness through extension and provision of other complementary services would enhance the adoption of these technologies. Particularly, affirmative action, in the form of targeted interventions, is needed to help female headed households benefit from the new technologies.

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