Agricultural Water Management 250 (2021) 106855

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Assessment of smallholder farmers' demand for and adoption constraints to small-scale irrigation technologies: Evidence from Ethiopia

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ARTICLE INFO

Handling editor: Dr. B.E. Clothier

Keywords:
Adoption
Small-scale irrigation
Demand
Ethiopia
Smallholder farmers
Water lifting technologies
Willingness to pay

ABSTRACT

Increasing agricultural productivity through irrigation technologies is recognized as an effective way to improve smallholders' livelihoods and food security in developing countries. However, most smallholder farmers do not have access to irrigation technologies. Using a double-bounded contingent valuation survey data from smallholders in Ethiopia and probit and bivariate probit models, this paper analyzes smallholder farmers' demand for agricultural water lifting technologies (WLTs) and the factors affecting the demand for these technologies. Assessment of farmers' preferences among three water lifting technologies available in local markets (motorized pump, rope and washer and pulley) show that farmers prefer motorized pumps to pulley or rope and washer technologies. Use of motorized pumps is more efficient and save labour than pulley or rope and washer technologies. However, results show that smallholders are constrained by inadequate access to financing options to adopt more efficient and labour-saving water lifting technology and hence operate below the production possibility frontier. Enhanced access to finance could help ease this constraint and allow smallholders to acquire more efficient irrigation technologies, enhance adoption and improve productivity. With a growing population pressure and land fragmentation in rural Ethiopia, the livelihoods of smallholders depend mainly on the meagre land endowment they possess. Increasing the productivity of land using yield enhancing technologies, particularly multiple cropping per year via small-scale irrigation is key to improve their livelihoods. Targeted interventions are thus warranted to mitigate the key adoption constraints such as improving access to credit and technical know-how of smallholders.

1. Introduction

Studies in Sub-Saharan Africa (SSA) and other developing countries show a positive impact of irrigation in agricultural productivity and poverty reduction (Ayele, 2011; Etissa et al., 2014; Desilva et al., 2014; Woodhouse et al., 2017; Xie et al. 2018; Wiggins and Lankford, 2019). Irrigation increases agricultural production through protecting crops against risks of uneven, unreliable, and insufficient rainfall or by enabling production of high-value crops in a dry-season and multiple cropping (Burney and Naylor, 2012; Balana et al., 2020). Irrigation creates additional employment and helps smooth seasonal shortfalls in food supply and encourage the production of crops that contribute towards diverse and nutritious diet. It could also benefit the urban poor by keeping food prices low despite growing demand for food (Girma and Awulachew, 2007).

Ethiopia, which is referred to as the water tower of Africa, has an estimated ground water potential of 2.6–6.5 billion m^3, 12 river basins with an estimated mean annual flow volume of 122 billion m^3 and 11 freshwater lakes (Awulachew et al., 2007). The country also comprises of an estimated cultivable land area between 30 and 70 Mha (Awulachew et al., 2010). Despite this potential, the country's agriculture is highly dependent on rain-fed agricultural system where rainfall is erratic and often insufficient. Only 15 Mha of land is under cultivation, of which only about 640,000 ha are irrigated. According to Gebregziabher (2012), the country has used 5% of its water resources to irrigate only 5% of its irrigation potential which implies underutilization of agricultural water resources. One of the potential solutions in addressing agricultural water management problem in Ethiopia could be the

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https://doi.org/10.1016/j.agwat.2021.106855
Received 4 December 2020; Received in revised form 3 March 2021; Accepted 4 March 2021
Available online 15 March 2021
0378-3774/

promotion of affordable small-scale water lifting technologies (WLTs) for irrigation such as motorized water pumps, pulley, and rope and washer pumps. Such technologies could increase smallholder farmers' access to agricultural water during dry seasons that allow farmers to practice multiple cropping in a year. By providing supplemental irrigation, access to agricultural water also cushions failure of the main wet season crops from dry-spells in rain-fed agriculture system (Fox and Rockstrom, 2000, 2003).

However, most smallholder farmers in Sub-Saharan African countries lack access to irrigation technologies (Burney and Naylor, 2012; Acheampong et al., 2018). Several factors such as high cost of the technologies, lack of access to financing options, lack of technical know-how, limited access to productive resources (land and water sources) or lack of market access may constrain adoption of irrigation technologies. Some studies claim that high prices of the technologies and operating costs are the key factors for the low demand for WLTs (Nunes and Boatwright, 2004). It may also be the case that the availability or supply of the technologies are limited (Ngigi, 2003). Lack of knowledge and technical knowhow could also be confounding factors in limiting the adoption of the WLTs. Despite the claims on the potential factors that could impede smallholder's demand for WLTs, there is lack of empirical evidence for the low demand for the productivity enhancing WLTs among smallholders in Ethiopia.

Understanding smallholder's preference and demand for WLTs and the factors influencing their demand for these technologies are key for designing sustainable and effective agricultural water management interventions and policies targeting smallholders. However, there exist knowledge gaps on the farmers' preference for specific types of WLTs, and their demand for these technologies. Only few studies examined the factors affecting smallholders' preference to certain water lifting technologies. These studies focused on estimating the economic value of irrigation water and provision and improvement of potable water supply for urban people in Ethiopia (Gebregziabher, 2012, 2014), but did not attempt to estimate the willingness to pay of smallholder farmers for the small-scale irrigation technologies and the factors for low adoption of these technologies. The purpose of this study is thus to fill the knowledge gap on smallholders' effective demand for WLTs, identify the key factors that influence their demand and adoption of these technologies in Ethiopia and other developing countries with similar conditions. This could guide targeted interventions on agricultural water management technologies to benefit smallholder farmers. A contingent valuation approach was applied to elicit the preference and demand for the set of selected agricultural water lifting technologies. Primary data were collected from 208 smallholders farm households sampled from four selected '*weredas*' (districts) in rural Ethiopia. A probit modelling approach was used to estimate the willingness to pay for the technologies. Key factors influencing smallholder's demand, adoption constraints and policy implications for scaling up of small-scale irrigation technologies are discussed.

The remaining part of the paper is organized as follows. Section 2 presents a concise review on the application of contingent valuation approach on market goods. Data, analytical approach, and empirical model specifications are presented in Section 3. Section 4 presents the findings and followed by discussions in Section 5. The last section concludes the paper with key policy implications.

2. Application of contingent valuation to market goods

Contingent valuation (CV) is a survey-based approach used to elicit individual's preference for the non-market values of environmental and other non-market goods or values of marketed goods based on the attributes of the good (Hoevenagel, 1994; Stewart and Khan, 2006; Mattia et al., 2010; Arcadio et al., 2012). Even if there is a market for the good, it may not reflect the true value or willingness to pay (WTP) of individuals (Mattia et al., 2010). Two assumptions that underly the CV method are: (1) people have well-ordered, but hidden, preferences for goods, and (2) people are capable of transforming these preferences into monetary values (Hoevenagel, 1994; Balana et al., 2012). For value elicitation, the CV method presents respondents with a description of the attributes of the good under consideration or scenario of proposed changes, and asks the respondents to express (in monetary terms) their maximum willingness to pay for the good or the minimum compensation they would be willing to accept for a certain negative change (Balana et al. 2012).

Estimation of WTP for marketed goods, using a CV method is relevant in testing its validity and assessing how the real market operates (Perman et al., 2003). In particular, in rural economies of developing countries where market imperfections appears to be a norm, the validation test gives an insight in deviation between prices of market good such as irrigation equipment or technologies elicited through CV survey and the existing market price of the technologies so that one can examine the attributes or factors that account for the deviation. More broadly, the WTP measure for market goods ensures the knowledge about consumers' valuations and choice behavior which helps marketers and companies in setting optimal pricing decisions and predictions of individual consumer choice. The study by Arcadio et al. (2012) presents the importance of WTP in valuation of both marketed and non-marketed goods. WTP estimates can be used to assess the price elasticity of demand and for modeling demand functions. It also helps apply market segment based on demand functions. Similar studies indicate that the importance of WTP study for marketed goods in measuring product brands, setting price for new products, predicting future demand and price for the existing and novel goods (Jesdapipat, 2009; Renee, 2012).

Despite these advantages, there is limited application of WTP estimation approach for the marketed goods. Notable exceptions are Andersson et al. (2008) for safety car; Philip (2012) for mobile application; Arcadio et al. (2012) for organic apples; and Kabyanga et al. (2018) for biogas digester. Regarding water lifting technologies for irrigation use in SSA, few studies applied variants of WTP estimation. Fentahun et al. (2020) used CV method to elicit irrigators' willingness to pay for soil moisture tools in South-Eastern Africa. Using discrete choice experiment method, Houessionon et al. (2017) estimated farmers' preferences and their demand for agricultural water management technologies using primary data collected from 300 smallholder farmers sampled from two municipalities in Burkina Faso. Zongo et al. (2015) analyze farmers' practices and willingness to adopt supplementary irrigation on rain fed crops in the long dry spell areas of Burkina Faso. Nakanyike (2014), estimates farmers' demand for virus free sweet potato vines in Uganda from randomly selected 200 households using a contingent valuation method. The same study also estimates the market potential for the sweet potato vines and shows vine production was an economically viable enterprise and vine producers should target commercial sweet potato farmers. Ulimwengu and Sanyal (2011), analyze farmers' demand for agricultural advisory services in Uganda using a contingent valuation method.

Falola et al. (2013) examine uptake of agricultural insurance by cocoa farmers in Nigeria and their willingness to pay.The study also identifies several factors such as education and extension services that influence the up-take and willingness to pay. Using a propensity matching technique, Zeweld et al. (2015) investigated the adoption constraints and impacts of small-scale irrigation in northern Ethiopia. Gebergziabher et al. (2014) analyze the economic factors influencing adoption of motor pumps in Ethiopia. Their findings show a positive correlation between the factors influencing adoption of motorized pumps and other water lifting technologies. Socio-economic and demographic factors and spatial variability in biophysical characteristics such as rainfall, topography, soil, and water conservation influence farmers' decision to adopt water lifting technologies.

The preceding literature indicate the relevance and empirical application of stated preference methods, particularly, contingent valuation method, to assess preferences and estimate the demand for irrigation and other agricultural technologies in developing countries.

3. Materials and methods

3.1. Conceptual model

The conceptual model guiding our empirical analysis of the willingness to pay data is based on the random utility theory (RUT) (Train, 2003). The key idea in this theory is that an individual's or household's resource allocation decision (e.g., purchase of goods) is driven by the underlying utility maximization behavior. The RUT is based on the 'rationality' assumption of economic agents in that a decision-maker i, in making a choice from j alternatives, selects the alternative that maximizes his/her utility and the utility assigned to each alternative depends on the attributes of the alternative (A_j) and the characteristics of the decision-maker (X_i). According to this theory the utility assigned to alternative j by individual i is not known by certainty by external analyst, i.e., some parts the utility are unobservable (ε) from the perspective of the researcher. Thus, in the context of contingent valuation, the analyst can only make probability statements about the respondent's 'yes' or 'no' answer to the suggested scenario. Following Haab and McConnell (2002), the 'yes' and 'no' responses can be specified using an indirect utility function for each respondent assuming that a decision-maker gains utility from the use of the water lifting technology as compared to the status quo.

Let $U_{ij} = U_i(I_i X_i A_j \varepsilon_{ij})$ is an indirect utility function for the i^{th}respondent from use of the j^{th} technology; $j = 1$ if the individual uses the technology for irrigation or $j = 0$ otherwise (i.e. the status quo); I_i is the i^{th}respondent's income; X_i is a vector of household characteristics, and A_j attributes of a given water lifting technology chosen by the individual and ε_{ij} is a random component.

Based on this model, respondent i answers 'yes' (i.e., technology $j = 1$) for a required payment of ρ_i^* (bid value), if the utility of adopting the chosen water lifting technology (U_{i1}) net of the required payment, exceeds utility of the status quo (U_{i0}) (Eq. 1).

$$U_{i1}((I_i - \rho_i^*), \quad X_i A_j, \quad \varepsilon_{i1}) > U_{i0}(I_i, \quad X_i \varepsilon_{i0}) \tag{1}$$

However, a researcher does not know the random part of preference and can only make probability statement about a 'yes' or 'no' response. The probability that the respondent says 'yes' is the probability the individual gets better off in the proposed change, so that $U_{i1} > U_{i0}$. For individual i this probability is given by $P(y_i = 1)$ as in Eq. (2).

$$P(y_i = 1) = P[U_{i1}((I_i - \rho_i^*), \quad X_i A_j, \varepsilon_{i1} \quad) > U_{i0}(I_i, \quad X_i \varepsilon_{i0})] \tag{2}$$

Where $y_i = 1$ if the respondent says 'yes' to a given bid value and $y_i = 0$ otherwise. Denoting the utility difference between adopting and not adopting the j^{th} technology by a latent variable y_i^*, an individual chooses the j^{th} technology if the utility difference (y_i^*) exceeds the bid value (ρ_i^*) and we observe $y_i = 1$ (adoption) and $y_i = 0$ otherwise (Eq. 3).

$$\left\{ \begin{array}{l} \quad y_i^* = z_i'\beta + \varepsilon_i \\ y_i = 1, \quad if\ y_i^* > \quad \rho_i^* \\ y_i = 0, \quad if\ y_i^* \leq \quad \rho_i^* \end{array} \right\} \tag{3}$$

Where the z_i' vector contains both technology attributes and the characteristics of decision-makers. From Eq. (3) and assuming a standard normal distribution of the error term, the probability that an individual farmer is willing to pay for a given irrigation technology can be estimated using a probit model (Eq. 4).

$$\begin{aligned} P(y_i = 1) &= P\left(y_i^* > \quad \rho_i^*\right) = P(z_i'\beta + \varepsilon_i \quad > \rho_i^*) = P\left(-\varepsilon_i < z_i'\beta - \rho_i^*\right) \\ &= \mathrm{F}(z_i'\beta) \end{aligned} \tag{4}$$

where $y_i^* = z_i'\beta + \varepsilon_i$ and $\mathrm{F}(z_i'\beta)$ is the cumulative distribution function of ε_i.

3.2. Description of the study areas

This study is based on data gathered from four districts ('*weredas*') in Ethiopia – Adami-Tulu district in Oromia Regional state, Dangla and Bahir-Dar Zuria districts in Amhara Regional state and Lemo district in Southern Regional state (Fig. 1). From 2013 to 2018, the Feed the Future Innovation Laboratory for Small-scale Irrigation (ILSSI) project promoted use of small-scale irrigation (SSI) technologies in these districts in Ethiopia. ILSSI is a USAID funded project implemented in Ghana, Ethiopia, Mali, and Tanzania (http://ilssi.tamu.edu/) and aims at providing technical knowledge base and local capacity for sustainable smallholder irrigation development. The project has conducted extensive field studies on socioeconomics of water lifting technologies, assessment of water availability for irrigation and the scalability of various small-scale technologies. However, the project does not provide the technologies to farmers for free, rather facilitates the partnership between farmers or farmers' associations and microfinance institutions in the respective study sites.

In terms of agro-ecology, all the four study areas fall under the mid-altitude ('*woina-dega*[1]) and thus share similar biophysical characteristics (average elevation, temperature and rainfall). Adami-Tulu is in the Ethiopian Rift Valley characterized by drought prone agro-ecology, tropical rainy ('*woina-dega*') agro-climatic zone with elevation between 1560 and 2300 m.a.s.l. (meter above sea level) and an annual average rainfall of around 750 mm (Ministry of Water Resources, 2008). The general climate in Dangla is moist sub-tropical ('*woina-dega*') characterized by moderate temperature and enough '*kiremt*'[2] rainfall (Assefa, 2015). The average annual rainfall in the area is about 1600 mm. Bahir-Dar Zuria is mainly characterized by a plain area with an average elevation of 1848 m.a.s.l., its annual rainfall ranges between 1200 and 1800 mm and characterized by a '*woina-dega*' agro-ecology. Most part of Lemo falls under moist '*woina-dega*' agroecological zone (Dubale et al., 2015). The rainfall in Lemo varies between 950 and 1200 mm annually and most of the area is between 2100 and 2500 m.a.s.l.

The farming system in all the four study districts is characterized by a mixed crop-livestock production with rain-fed production dominates though some districts, e.g., Bahir-Dar Zuria and Adami-Tulu, practice limited irrigated farming. Maize, finger millet, teff, rice, and chickpeas are the major annual crops grown in Bahir-Dar Zuria and Dangla. In Lemo district, farmers grow some trees crops such as coffee and 'enset' (*Ensete ventricosum*, Musaceae) as well as annual crops mainly wheat, maize and fava beans. The main crops grown in Adami-Tulu include maize, haricot beans and teff. The ILSSI project intervention on small-scale water lifting technologies aimed at improving smallholders' access to these technologies for growing high value vegetables in dry season and improve livelihoods and nutrition.

The four study areas generally exhibit peri-urban population settlements with good connections to roads and market centers. Adami-Tulu is a district town with over 10,000 population and located at about 168 km south of Addis Ababa. With a population of over 26,000, Dangla is a town situated along the Addis Ababa-Bahir Dar road at 77 km south west of Bahir Dar (the capita of Amhara Region). Bahir-Dar Zuria is a peri-urban district around the city of Bahir-Dar. Lemo is a district surrounds the town of Hosaena in Southern Ethiopia., a major settlement of over 76,000 population. Overall, the study areas have good access to markets to sell their agricultural produce.

[1] '*woina-dega*' is an agro-ecological zone classification in Ethiopia covering altitudes between 1500 and 2300 m a.s.l.

[2] '*kiremt*' is the Amharic word and represents the main rainy season (July-September) in Ethiopia.

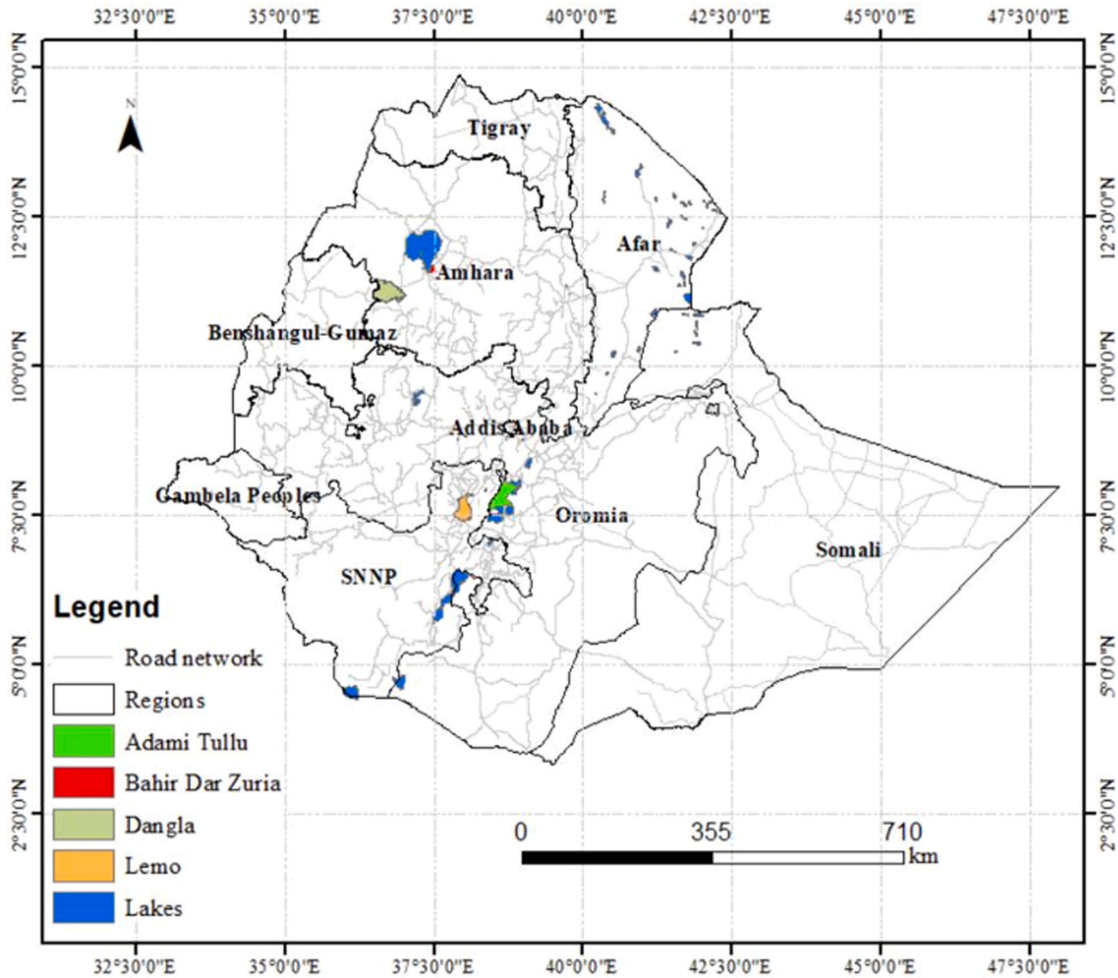

Fig. 1. Location Map of the study sites in Ethiopia.

3.3. Data and survey design

Data were collected from a survey of smallholder farmers sampled from the four ILSSI intervention sites in Ethiopia as decribed above. A contingent valuation survey with close-ended elicitation format and open ended follow up questions were employed. The questionnaire includes demographic, economic, market access and valuation questions. The questionnaire was pre-tested and revised based on feedbacks before final administration of the survey. Survey was administered in a face-to-face interview through trained enumerators conversant of local languages and field experience of the study areas. Relevant secondary data were obtained from the districts' agriculture offices, Central Statistics Agency, and the International Water Management Institute.

A multi-stage sampling technique was employed. The four districts were already selected by the ILSSI project for piloting small-scale irrigation intervention. Based on the information from the District Agriculture Offices, five *kebeles*[3] which were identified as intensive users of small-scale irrigation technologies were selected. Finally, a random sampling technique was used to select 208 sample farm households. The sample size was determined using the minimum sample size formulae of Fowler (2013) and then adjusted to the target population following Cochran (1977). The sample was divided into two groups. A group of respondents who participated in the ILSSI project interventions (treated group) and another group which did not participate (control group). ILSSI intervention i.e., 'treatment' assignment was made to a randomly selected smallholders in the study locations.

Prior to the CV survey, an open-ended reconnaissance survey was conducted with selected farmers where they were asked to state the prices they would be willing to pay for three different WLTs - fuel-powered motorized pumps, rope and washer, and pulley. This helps reduce the effect of start-up price bias, which is often encountered in 'double-bounded' dichotomous choice survey. Farmers participated in the reconnaissance survey were excluded from the final survey. Market prices of the three WLTs were obtained from local markets. Based on the reconnaissance survey and information on market prices, five starting prices were determined for each technology (Table 1) and sampled households were randomly assigned into five equal groups. Each sampled farmer was then provided with a random initial price for the selected technology. The farmers who accepted the first price were given a second value, which is higher than the first price. On the other hand, if the interviewee responded 'no' to the initial price, in a follow-up question he/she is provided with a lower value than the initial price. This process results in four possible outcomes: (1) both answers 'yes'; (2) both answers 'no'; (3) a 'yes' followed by a 'no'; and (4) a 'no' followed by a 'yes'. The responses elicited through the survey are summarized in Table 1.

The 'no, no' responses, i.e., the unwillingness to pay to both the initial and follow-up prices, could be an indication of either a genuine lack of demand for the technology or a protest response even though a farmer may have positive demand for the technology. Though there is no established criteria to differentiate such responses between genuine and

[3] *Kebele* is the lowest administrative unit in Ethiopia.

Table 1
Summary of bid responses to the double-bounded questions.

Water lifting Technology	Market prices (ranges, in ETB[1])	WTP bid prices (ranges, in ETB)	Responses to Initial price (%)		Responses to follow-up price (%)	
					Yes	No
Motorized pump	8000–15,000	7000–19,000	Yes	57.35%	56.4%(YY)	43.6%(YN)
			No	42.65%	58.62%(NY)	41.38%(NN)
Rope and Washer	2600–3700	1500–6000	Yes	72.41%	34.88% (YY)	65.12%(YN)
			No	27.59%	62.5% (NY)	37.5% (NN)
Pulley	1500–2500	1000–3500	Yes	80.39%	73.17% (YY)	26.8% (YN)
			No	19.61%	100% (NY)	0% (NN)

[1] ETB (Ethiopian Birr) is the official Ethiopian currency. The official exchange rate during the survey(2017): 1$UD= ETB27.1486

protest, Boyle (2003) suggested certain follow up questions to identify such responses. Inclusion of protest responses (i.e., zero WPT values) in the estimation of mean and aggregate WTP leads to biased estimates. Thus, following (Alebel et al., 2009; Mezgebo et al., 2013) we excluded protest responses from the aggregate willingness to pay estimation.

3.4. Empirical model

Cameron and Quiggin (1994) assume separate distributional parameters for the underlying latent willingness to pay in their empirical double-bounded binary models, i.e., one for the initial bid value and another for the follow-up value. Based on this assumption, the two latent willingness to pay values for the respondent, $WTP_{i1} = y_1^*$ and $WTP_{i2} = y_2^*$, can be described by the bivariate probit model as in Eq. (5) (Greene, 2003):

$$\left\{ \begin{array}{l} y_1^* = x_1^{'}\beta_1 + \varepsilon_1 \\ y_2^* = x_2^{'}\beta_2 + \varepsilon_2 \end{array} \right\} \tag{5}$$

The error terms in Eq. (5) are assumed to be jointly normally distributed with zero means and variances δ_1^2 and δ_1^2; correlation coefficient ρ; β_1 and β_2 are coefficients for the first and second equations; and x_1 and x_2 *are* explanatory variables. The choice of explanatory variables in the empirical model (Table 2) is based on the theory of demand (Mas-colell et al., 1995), random utility theory (Train, 2003), and literature (Arcadio et al., 2012; Balana et al., 2012; Gebergziabher et al., 2014; Nonvide, 2017). Following Hanemann (1991), the probabilities of the four possible outcomes in the double-bounded dichotomous value elicitation format can be expressed by a set of equations (Eq. 6):

$$\left\{ \begin{array}{c} P(yes, \quad yes) \equiv P(\rho_u \le y_i^*) = G(\rho_u;\theta) \\ P(yes, \quad no) \equiv P(\rho_i^* \le y_i^* < \rho_u) = G(\rho_u;\theta) \quad -G \quad (\rho_i^*;\theta) \\ P(no, \quad yes) \equiv P(\rho_l \le y_i^* < \rho_i^*) = G(\rho_i^*;\theta) - \quad G(\rho_l;\theta) \\ P(no, \quad no) \equiv P(\rho_l > y_i^*) = 1 \quad -G(\rho_l;\theta) \end{array} \right\} \tag{6}$$

Where, ρ_u is the upper value followed by a (yes, no) response situation; ρ_l is a lower value followed by a (no, yes) response, and $G(\rho_i^*;\theta)$, $G(\rho_u;\theta)$, and $G(\rho_l;\theta)$ denote the cumulative probability distributions for the initial, upper, and lower follow-up values respectively. From Eq. (6), the log-likelihood function for the i^{th} respondent can be specified as in Eq. (7):

$$lnL(\theta) = d_i^{yy}[lnG(\rho_u;\theta)] + d_i^{yn}[ln(G(\rho_u;\theta) - G(\rho_i^*;\theta))] + d_i^{ny}[\ln(G(\rho_i^*;\theta) - G(\rho_l;\theta))] + d_i^{nn}[\ln(1 \quad -G(\rho_l;\theta))] \tag{7}$$

Where: $d_i^{yy} = 1$ for a (yes, yes), $d_i^{yn} = 1$ for a (yes, no), $d_i^{ny} = 1$ for a (no, yes), and $d_i^{nn} = 1$ for a (no, no) responses; and zero otherwise for each combination. Bivariate probit model estimation deliver two parameter estimates from the two rounds of bidding process. However, the first-round parameters are generally used in the computation of mean WTP. This is because the second equation parameters are likely to contain more noise in terms of anchoring bias where the respondent is assumed to take the clue from the first bid while forming his response for the second question. Table 2 presents the description of the variables used in the empirical model.

Table 2
Description of variables used in the study.

Variable name	Description and measurement
Age-head, (years)	Age of the household head (in completed years)
Sex-head, (male=1)	Sex of the household head
Household-size, (#)	Number of household members (headcount)
Education-head, (years)	Years of formal schooling (in completed years)
Income-household, (ETB[1])	Total household annual income (in Ethiopia Birr)
Livestock-size, (#)	Number of livestock owned by the household (in tropical livestock unit (TLU))
Bid-initial price, (ETB)	Initial bid value provided to the respondent (in Ethiopia Birr)
Bid price follow-up, (ETB)	Follow-up bid value provided to the respondent (In Ethiopian Birr)
Off-farm activity, (yes=1)	Whether adult members of the household participate in any off-farm earning activity
Land-size, (ha)	The size of land owned by the household (in hectare)
Credit-access, (yes=1)	Whether the household has access to credit
Market-access, (yes=1)	Whether household has good access to market
Information-access, (yes=1)	Whether household has access to information on irrigation technology

[1] ETB (Ethiopian Birr) is the official Ethiopian currency. The official exchange rate during the survey(2017): 1$UD= ETB27.1486

4. Results

4.1. Descriptive analysis

Table 3 summarizes the descriptive statistics of the variables included in the model. About 82% of surveyed households are male headed; 40% do have prior experience or knowledge about the water lifting technologies and 44% responded that they engage in off-farm activities. About 76.5% of the sample households expressed their willingness to pay for the WLTs. However, there is statistically significant difference in WTP among male-headed and female-headed households. Household size varies from a minimum of 1 to a maximum of 18 persons. Respondents' age ranges from 18 to 76 years with an average age of 43.6. It is expected that the younger farmers are willing to pay more for the WLTs assuming that older farmers have more farming experience and tend to stick to their traditional farming systems. The education

Table 3
Summary statistics of the explanatory variables[a].

Variables	Pooled sample				Respondents (WTP)	Respondents (Not WTP)	Mean diff
	Mean	Std. dev.	Min	Max	Mean	Mean	t- test
Sex-head, (male=1)	0.82	0.38	0	1	0.85	0.69	0.730*
Household-size, (#)	6.40	2.49	1	18	6.64	5.63	1.008**
Age-head, (years)	43.59	11.06	18	76	42.61	46.75	4.150**
Education-head, (years)	3.82	3.61	0	12	4.02	3.20	0.815
Income-household, (ETB[1])	21,798	20,268	1578	126,480	23,981	14,713	9267.41***
Off-farm activity, (yes=1)	0.48	0.49	0	1	0.39	0.59	−0.202**
Land-size, (ha)	1.42	1.03	0.20	6	1.46	1.32	0.141
Livestock-size, (#)	4.58	3.00	0	18.51	4.98	3.29	1.690***
Credit-access, (yes=1)	0.52	0.50	0	1	0.56	0.37	0.205**
Market-access, (yes=1)	0.35	0.73	0	1	0.47	0.37	0.236**
Information-access, (yes=1)	0.40	0.49	0	1	0.43	0.33	0.101

Notes:
diff= mean (Not WTP) –mean (WTP). H0: diff= 0; HA: diff ≠ 0.
Significance:
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.
[a] The mean values for all the dummy variables in Table 3 should be interpreted in percentages.
[1] ETB (Ethiopian Birr) is the official Ethiopian currency. The official exchange rate during the survey(2017): 1$UD= ETB27.1486.

level of respondents ranges from illiterate to secondary school graduate, with an average of 3.83 years school schooling. About 69.2% of respondents attended formal education while the rest are illiterate.

Average annual income (farm and off-farm income) for those 'willing' and 'unwilling' respondents show a statistically significant difference at 1% level. The average farmland holding is about 1.42 ha (with min. 0.2 ha and max. 6 ha). Farmers on average have 0.81 ha of irrigable land. The difference in average land holding among 'willing' and 'unwilling' households is statistically insignificant. In terms of livestock ownership 'willing' households on average own more livestock than the 'unwilling' households which is also statistically significant.

About 52% of the respondents reported that they have access to credit. Access to credit (for the purpose of this study) refers to either the ability of farmers to borrow money from the financial institutions or the possibility of farmers to own the technologies in credit term. Farm households can acquire technologies either in cash payment or in credit.

Table 4
Mean comparison between intervention households and control group.

Variables	Intervention households (n = 102) (mean)	Control households (n = 106) (mean)	Mean diff. (*t*-test)
Sex-head, (male=1)	0.88	0.76	0.11**
Household-size, (#)	6.27	6.54	−0.26
Age-head, (years)	45.40	41.70	3.60**
Education-head, (years)	3.60	4.10	0.34
Income-household, (ETB[1])	20,194.00	23,464.00	3270.00
Off-farm activity, (yes=1)	0.48	0.39	0.09
Land-size, (ha)	1.40	1.44	0.04
Livestock-size, (#)	4.23	4.90	−0.62
Credit-access, (yes=1)	0.53	0.51	0.02
Market-access, (yes=1)	1.29	1.39	0.01
Information-access, (yes=1)	0.30	0.51	−0.21**

** significant at 5% levle
[1] ETB (Ethiopian Birr) is the official Ethiopian currency. The official exchange rate during the survey(2017): 1$UD= ETB27.1486

Buying on credit increases farmers ability to pay for the technologies. In the study areas, all the surveyed households prefer either annual or semi-annual credit term as a payment option for the technologies to immediate cash payment. Table 4 reports mean comparisons of household characteristics to test presence of selection bias and no significant difference was found among the intervention and control group.

4.2. Econometric results

4.2.1. Probit model results

Table 5 reports results of the probit model estimation. A Wald test was used to test the joint significance of the explanatory variables. The overall significance of the model was good. Eight of the variables in the model show the a priori expected sign and more than half of them were found to be significant in affecting WTP decision (Table 5). These include household size, age of the household head, farmland size, initial bid values, household income, off-farm activity, access to credit and livestock ownership. Family size, household income, livestock ownership, initial bid values and access to credit affect WTP positively but off-farm activity, farmland size and age of the head affect WTP decision negatively.

Table 6 presents the marginal effects i.e., the partial derivatives of explanatory variables with respect to discrete 'yes' or 'no' responses to the initial bid price (ρ_i*) computed following. Age has a negative and statistically significant effect on the farmers' decision to pay for the WLTs. The marginal effect shows that, other things being equal, a one-year increase in the age of the head decreases the probability of accepting the initial bid price by 1.3%, indicating that younger farmers are willing to pay more for the technologies compared to older farmers. The result is consistent with the findings of Mezgebo et al. (2013) and Alebel et al. (2009).

Holding other things constant, a unit increase in the family size of the farm household increases the probability of accepting the first proposed bid by about 4.2%. This may be due to the economic contribution of additional family members in the household assuming that additional labor force could increase the efficiency of technology utilization. The study by Alhassan et al. (2013) also found similar results. Households income has a positive and statistically significant (at 1% level of significance) effect on accepting the initial bid price which is consistent with economic theory (assuming water lifting technologies are 'normal goods'). The result is also consistent with previous works by Mezgebo et al. (2013) and Bane (2005). Results show that the initial bid values have negative effect on a 'yes' response to the WTP question and

Table 5
Results from probit model estimation[1] (robust standard error in parenthesis).

Variables	(1) WTP (pooled sample)	(2) WTP (Intervention households	(3) WTP (Control households)
Age-head, (years)	−0.0357***	-0.0579***	−0.00631
	(0.0107)	(0.0198)	(0.0159)
Household-size, (#)	0.114***	0.129*	0.0703
	(0.0412)	(0.0769)	(0.0627)
Sex-head, (male=1)	−0.469	−0.228	0.281
	(0.322)	(0.677)	(0.573)
Education-head, (years)	−0.205	−0.198	−0.477
	(0.277)	(0.649)	(0.385)
Income-household, (ETB)	0.526***	0.145	1.002***
	(0.149)	(0.232)	(0.247)
Bid-initial, (ETB)	−0.0298**	−0.115***	0.00694
	(0.0131)	(0.0275)	(0.0175)
Off-farm activity, (yes=1)	−0.537**	−0.960**	−0.321
	(0.233)	(0.456)	(0.345)
Land-size, (ha)	−0.257**	0.338	−0.406**
	(0.112)	(0.304)	(0.186)
Market-access, (yes=1)	0.0959	−0.286	0.345
	(0.149)	(0.255)	(0.267)
Livestock-size, (#)	0.0888**	0.0678	−0.0497
	(0.0423)	(0.0915)	(0.0639)
Information-access, (yes=1)	0.00463	0.223	−0.664*
	(0.216)	(0.437)	(0.367)
Credit-access, (yes=1)	0.525**	0.429	1.175***
	(0.208)	(0.325)	(0.345)
Constant	−3.293***	2.254	−9.896***
	(1.168)	(1.741)	(2.232)
Observations	208	102	106
R^2	0.24	0.36	0.37

Note:
[1]The dependent variable is discrete response (yes=1 or no=0) to initial bid price (ρi*); Standard errors are in parentheses.
Significance:
*** $p < 0.01$.
* $p < 0.1$.
** $p < 0.05$.

Table 6
Marginal effect of covariates in the probit model (pooled sample with robust standard error).

Variables	dy/dx [(a)]	Std. Err.	p > |Z|
Age-head, (years)	−0.0131	0.0039	0.001***
Household-size, (#)	0.0417	0.0151	0.006***
Sex-head, (male=1)	−0.1591	0.0995	0.110
Education-head, (years)[1]	−0.0738	0.0978	0.450
Income-household, (Birr)	0.1932	0.0546	0.000***
Bid-initial, (Birr)	−0.00001	0.000	0.022**
Off-farm activity, (yes=1)[1]	−0.1977	0.0850	0.020**
Land-size, (ha)	−0.0942	0.0411	0.022**
Market-access, (yes=1)	0.0352	0.0546	0.520
Livestock-size, (#)	0.0326	0.0156	0.037**
Information-access, (yes=1)[1]	0.0017	0.0791	0.983
Credit-access, (yes=1)[1]	0.1918	0.0751	0.011**

Model diagnostics: Log pseudo likelihood= −107.39; chi-square= 54.43; Pseudo $R^2 = 0.43$; Prob > chi^2
Significance:
$p < 0.1$
(a)Marginal effect: dy/dx is for discrete change of dummy variable from 0 to 1.
***$p < 0.01$.
**$p < 0.05$.

significant at 5% level. This explains the fact that higher initial bid values lead to lower number of ‘yes’ responses to the initial bid values. This is intuitive and in line with the law of demand that postulates, ceteris paribus, a negative relationship between price and quantity demanded.

Farmers’ participation in off farm activity is found to have an adverse effect on the probability of a household willingness to pay. Farm households involved in off-farm activities are less likely to show their willingness to pay for the WLTs. This apparently counterintuitive result may be explained by either that off-farm income is too small to finance investment in WLTs or the households who engage in off-farm activities are landless poor or irrigated farming is no longer their preferred activity due to high return alternate off-farm businesses. Given that 39% of the respondents reported that they engage in daily labour works as a means for additional income in the survey area, off-farm activities appear to be carried out by relatively poor and landless households.

Size of farmland has a negative effect (significant at 5% level) on the probability of accepting the initial bid prices of the WLTs (Table 6). A possible reason could be that households with large land holdings have more options to diversify their rain fed crops. It may also be the case that, households with large land holdings tend to engage largescale irrigation systems such as gravity-based irrigation as shown by Gebregziabher et al. (2013). Similar findings have demonstrated the relative efficiency of agricultural inputs by farmers with smaller land holdings compared to larger ones (Ricker-Gilbert et al., 2009; Balana et al., 2011a, 2011b; Woodhouse et al., 2017).

The probability of the household willingness to pay for the technologies increase by 19.2% with credit access, suggesting that access to credit increases farmers’ willingness to pay. Limited access to credit has been found the major constraints to adoption of agricultural technology such as pumps (Nakawuka et al., 2017). De Fraiture and Giordano (2014) show that 80% smallholders used own saving to acquire irrigation equipment. This may imply a low access to credit by smallholders. However, it should be noted that credit constraints need not to be entirely associated with supply side factors, demand side factors such as risk-averse behavior and lack of access to information could also affect smallholders’ access to credit (Balana and Oyeyemi, 2020).

Table 7a
Bivariate estimates for motorized pump.

	(1) WTP (pooled sample)	(2) WTP (intervention group)	(3) WTP (controls)
Dependent variable (yes_1 =1 (if ‘yes’ to the initial bid price, 0 otherwise)			
Initial bid price	-0.000178***	-0.000190***	-0.000158***
	(0.00004)	(0.00006)	(0.00005)
Constant	3.235***	3.802***	2.639***
	(0.636)	(1.024)	(0.929)
Dependent variable (yes_2=1 (if ‘yes’ to the second bid price, 0 otherwise			
Second bid price	-0.000219***	-0.000191***	-0.000259***
	(0.00005)	(0.00007)	(0.00007)
Constant	3.257***	2.853***	3.929***
	(0.713)	(0.951)	(1.084)
Athrho	3.061	2.329	14.33
	(84.48)	(134.2)	(874.3)
Rho (ρ)	0.996		
	(0.738)		
	Wald(χ2)= 29.76, Prob > $chi^2(2)$= 0.0000, Log likelihood -51.3547		
	Likelihood-ratio test of rho=0: chi^2 (1) = 22.5589		

Standard errors in parentheses.
*$p < 0.10$.
**$p < 0.05$.
***$p < 0.010$.

Table 7b
Bivariate estimates for rope and washer pump technology.

	(1) WTP (pooled sample)	(2) WTP (intervention group)	(3) WTP (controls)
Dependent variable (yes_1=1 (if 'yes' to the initial bid price, 0 otherwise)			
Initial bid price	-0.000664***	-0.00125**	-0.000350*
	(0.0002)	(0.0005)	(0.0002)
Constant	3.566***	6.930***	1.698
	(0.800)	(2.595)	(1.037)
Dependent variable (yes_2=1 (if 'yes' to the second bid price, 0 otherwise)			
Second bid price	-0.000302**	-0.000733**	-0.000221
	(0.0002)	(0.0004)	(0.0002)
Constant	0.561	1.780	0.499
	(0.621)	(1.174)	(1.031)
Athrho	2.528	0.874	3.093
	(116.3)	(14.80)	(106.9)
Rho (ρ)	0.987345		
	2.92435		
Wald(χ2) = 16.47; Prob > chi^2(2)=0.0003; Log likelihood=-51.76785.			
Likelihood-ratio test of rho=0: chi^2 (1) = 7.77023; Prob > chi^2 (2) = 0.0053			

Standard errors in parentheses.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.010$.

Table 7c
Bivariate estimates for pulley technology.

	(1) WTP (pooled sample)	(2) WTP (intervention group)	(3) WTP (controls)
Dependent variable (yes_1 =1 (if 'yes' to the initial bid price, 0 otherwise)			
Initial bid price	-0.00146**	-0.00294	-0.000872
	(0.0007)	(0.002)	(0.0008)
Constant	3.061***	5.417*	2.017*
	(0.999)	(2.917)	(1.174)
Dependent variable (yes_2=1 (if 'yes' to the second bid price, 0 otherwise)			
Second bid price	-0.00242***	-0.00430***	-0.00187**
	(0.0006	(0.0012)	(0.0008)
Constant	3.117***	4.793***	2.899**
	(0.734)	(1.306)	(1.184)
Athrho	2.069	1.061	16.55
	(8.907)	(8.736)	(841.7)
Rho (ρ)	0.9686		
	(0.5506)		
Wald(χ2) = 17.43; Prob > chi^2(2)=0.0002; Log likelihood=-37.07054			
Likelihood-ratio test of rho=0; chi^2 (1) =7.4751; Prob > chi^2 (1) = 0.0063			

Standard errors in parentheses.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.010$.

4.2.2. Bivariate probit model results

We estimated three bivariate probit models for each of the water lifting technologies (motorized pump, rope and washer, and pulley) and the estimation results are reported in Tables 7a–c. In each of the tables, column 1 presents the coefficients to pooled sample WTP estimate for the technologies in response to the change of the initial and follow-up bid prices. Columns 2 and 3 respectively present the corresponding estimates for intervention and control household groups. In column 1 of the three tables, the results show that the initial and second bid prices have the expected signs and statistically significant mostly at 5% level of significance. Assuming higher initial and second bid prices lead to lower probability of accepting the bid prices, the initial and the follow up bids have a negative and significant effect in determining farmers stated WTP.

The effects of the initial bid price for pulley technology in both intervention and control groups (columns 2 and 3, Table 7c) and the that of the second bid price for rope and washer technology in the control group (column 3, Table 7b) on farmer's willingness to pay are statistically insignificant, though negative. For rope and washer pump technology, we observe differentiated effects of the initial and follow bid prices on WTP of the intervention and control groups (Table 7b). However, we did not observe differential effects of the bid values on farmers WTP for the motorized pumps in both the intervention and control groups; the effects are negative and statistically significant for both groups (columns 1 and 2, Table 7a). This may imply that there is no selection bias and both the intervention and control groups had similar experience and prior knowledge and information on these agricultural water lifting technologies.

The coefficients of the bid prices were used to compute the mean WTP (Table 8). The mean WTP of the pooled sample, the intervention and the control groups are computed for each of the three water lifting technologies. Results show that the intervention group are more willing to pay for motorized pump and rope and washer technologies. But the control group are willing to pay a higher price for the pulley technology. This is perhaps because farmers who benefited from the intervention scheme gained more experience and knowledge and have better access to technologies via credit sales and hence would be willing to pay for the more efficient and costly technologies (e.g., motorized pumps) compared to those who were not included in the program. Farmers who do not have access to credit scheme would tend to pay more for the pulley technology which is relatively cheaper but less efficient.

Besides double-bounded questions, farmers were also asked an open-ended question on the maximum amount they are willing to pay for the three technologies. The mean WTPs from the open-ended elicitation approach are generally lower than the one obtained from double-bounded method. Possible explanation for this could be that when asked an open-ended question; farmers may believe that the technology is to be provided at the discount rate through the government so that they tend to state lower values for the technologies. Similar behavioral anticipations were reported by Mezgebo et al. (2013).

While aggregating mean WTP to derive total WTP estimates, Mitchell and Carson (1989) indicate that, before computing total WTP, one has to be careful on population choice bias, sampling frame, sample non-response bias, and sample selection biases to have valid aggregation of benefits. Use of random sampling method in sample selection, in-person interview, and exclusion of protest zero bidders minimize the occurrence of such biases and hence valid estimation of aggregate willingness to pay.

Taking the above cautions into account, we derived the aggregate willingness to pay values for the three technologies by extrapolating the preference of the sampled farmers and the mean WTP (column 5 and the last column in Table 8). Consistent with that of the mean WTP values for the three technologies, the aggregate WTP values obtained from the open-ended questions are lower than that obtained from the double-bounded method.

5. Discussions and policy implications

Smallholder farmers in developing countries are constrained by lack of access to agricultural technologies such as improved seeds, fertilizer, and irrigation which led to low productivity and persistent food insecurity (Minten and Barret, 2008; Collier and Dercon, 2014). Several factors such as market imperfections, high cost of the technologies and lack of access to credit may contribute to low adoption of agricultural technologies (Balana and Oyeyemi, 2020). Particularly, with growing population pressure on natural resources and changing climate, intensification and boosting productivity through adoption of improved technologies such as small-scale irrigation is vital for poverty reduction, food and nutrition security and income to smallholder farmers (Rosegrant et al., 2009; Balana et al., 2020). Agriculture development-related literature emphasize the promotion of small-scale irrigation technologies as a key strategy towards improving low yielding smallholder

Table 8
Summary of estimated mean WTP and population totals (in ETB[a]).

Water lifting technologies	WTP estimates from the double-bounded approach				WTP estimates from the Open-ended approach (pooled sample)	
	Intervention group Mean WTP[I]	Control group Mean WTP[C]	Pooled sample Mean WTP[P]	Pooled sample Total WTP	Mean WTP	Total WTP
Motorized Pump	18,500	16, 703	18,174	22,008,174	13,750	16,651,250
Rope and Washer	5444	4851	5370	5928,480	3550	3919,200
Pulley	1, 843	2, 313	2097	1876,815	1195.5	1069,973

Notes:
WTP[I], WTP[C], and WTP[P] are mean willingness to pay for the technologies computed for intervention group, control group and pooled sample.
[a]ETB (Ethiopian Birr) is the official Ethiopian currency. The official exchange rate during the survey(2017): 1US$= ETB27.1486

farming systems and food security in Sub-Sahara Africa (Barron et al., 2008; Burney and Naylor; 2012). Increasing smallholders' agricultural productivity through irrigation technologies is recognized as one of the most effective ways to fight poverty and reduce farmers' vulnerability to climate change (Burney and Naylor, 2012). In two recent case studies in Northern Ghana, Balana et al. (2019) and Balana et al. (2020) show that access to irrigation technologies enable smallholder farmers produce high-value crops and help promote crop diversification and multiple-cropping in a year which significantly increase returns to land and labour and reduce risk. Small-scale irrigation technology could enhance a dry-season (off peak production) activity, thus provide additional employment opportunities and income for smallholder farmers to meet their cash demands (Balana et al., 2020).

However, despite increased emphasis on irrigation technology and its potential for agricultural development, its adoption has been lagging among smallholders in SSA; for instance, only about 5% of the irrigation potential is utilized in Ethiopia (Gebregziabher, 2012) and less than 2% of the total cultivatable area is irrigated in Ghana (Namara et al., 2011). One could logically ask as to why the adoption rates of irrigation technologies are so low by smallholders despite the immense economic benefits of irrigated farming. One of the key findings in the present study indicates lack of access to credit as a key impediment to adoption of irrigation WLTs. The results show that farmers participated in the ILSSI project intervention where financing for the purchase of WLTs was facilitated via the project have adopted the technologies as well as were willing to pay more for the technologies as compared to the control groups. Previous studies reported similar findings where lack of access to low-cost irrigation technologies as one of the main barriers to the adoption of small-sacle irrigation technologies (Getacher et al., 2013; Gebergziabher et al., 2014; Nonvide, 2017; Merrey and Lefore, 2018). Studies in Ghana, Ethiopia, and Zambia showed that more than 80% of small-scale irrigators did not access to credit to purchase irrigation equipment and hence relied on their own savings (De Fraiture and Giordano, 2014). Similarly, Gebergziabher et al. (2014) showed that smallholder farmers do not have access to formal credit and usually use their own financing mechanisms to purchase irrigation water pumps.

As part of the ILSSI project, several early consultation meetings with ILSSI stakeholders showed that a fundamental barrier to adoption SSI technologies at household level was related to farmers low capacity to finance the initial investment costs for the SSI technology (ILSSI, 2016). A baseline household survey conducted under the ILSSI project in 2015 in one of the study locations in Amhara region showed that even those farmers whose loan application was accepted have received only about 50% of the amount needed to invest in WLTs (i.e., an average loan amount received was ETB 4370 against the ETB 8560 amount required to purchase typical 5.0 Horse Power (HP) diesel-powered motor pump) and the loan was acquired at an annual interest rate of 17.5%. Depending on the make or model and HP, the market prices of motorized pumps can go up ETB 15,000 during the study time. Thus, it can be argued that supply-side credit constraints appear to be a major factor affecting adoption of small-scale irrigation technologies.

However, besides supply-side credit constraints discussed above; credit constraints to smallholders may manifest itself in demand-side too (Balana and Oyeyemi, 2020; Boucher et al.,2009). For example, smallholders may voluntarily withdraw from the credit market due to 'fear of risk of losing collateral' even if they have the collateral wealth needed to qualify for a loan (Boucher et al.,2009). Similarly, high transactions costs, for instance, bureaucratic administrative processes, information asymmetry, financial illiteracy of borrowers, lengthy loan application and processing, and transport costs due to far distance may generate negative incentives to loan application even if bankers would approve their application. For instance, in Ethiopia, the ILSSI project worked with local microfinance institutions and facilitated provision of water lifting technologies on credit to increase uptake of the WLTs. However, loan diversion for non-agricultural purposes, lack of loan management skills and low repayment of loans hampered this initiative (ILSSI, 2016). Thus, improving financial literacy of smallholders and risk mitigation interventions could provide a remedy for demand-side credit constraints and potentially improve smallholders credit access and irrigation technology adoption.

Another key finding in this study is the relationship between endowments i.e., land holdings and access to credit. One could intuitively assume that as a fixed asset, land can serve as a collateral and hence would enhance credit access and higher willingness to pay for irrigation technologies. Our model results however show that land size and willingness to pay are negatively related and statistically significant. In other words, the less the size of landholdings the higher the WTP for irrigation technology. This is an interesting finding in the sense that by investing in irrigation technologies, smallholders with small land holdings can increase productivity and farm income. This is consistent with previous findings elsewhere in Africa. In a case study on smallholders' willingness to adopt catchment management measures in Kapingazi river catchment in central Kenya (Balana et al., 2011a, 2011b) found a negative relationship between 'land size owned' and the likelihood of program adoption. In a study on farmers preference to soil management measures in southern Ethiopia, Tarfasa et al. (2018) showed that small landholding was not a major constraint for the adoption of soil management measures. A study (Balana et al., 2020) in floodplain zones of northern Ghana indicates that most of the crops grown under supplementary irrigation are produced by smallholder women farmers on small plots of land (< 0.1 ha). Thus, small land holdings do not seem to deter adoption of agricultural technologies provided that appropriate mechanisms such as access to finance, cost-effective technologies and risk mitigation options are in place. Farmers with small holdings are more likely to adopt productivity enhancing agricultural technologies. These empirical findings confirm Boserup's theory which postulates that an increasing agricultural intensification and higher productivity as population pressure on land increases (Boserup, 1965; Demont et al., 2007).

6. Conclusion and recommendations

The agricultural sector in Ethiopia is dominated by a rain-fed system and characterized predominantly by low productivity smallholders' subsistence farming. Increasing smallholders' access to agricultural water and small-scale irrigation technologies is a promising strategy to enhance productivity and improve rural livelihoods. Particularly, with a growing population pressure on natural resources and changing climate, intensification and boosting productivity through small scale irrigation technology can play a key role in poverty reduction, food and nutrition security and livelihoods. However, currently, smallholder farmers are constrained from accessing irrigation technologies. Several factors such as market imperfections, risk-averse behaviour, knowledge gaps, and lack of access to financing options contribute to low adoption rates of these technologies. Understanding the factors affecting farmers' preference for different small-scale irrigation technologies and their potential willingness to pay for the technologies will provide decision support evidence for increasing access and up-scaling of such technologies among smallholders.

This study is designed to understand farmers' adoption constraints and estimate their willingness to pay for the three commonly available irrigation water lifting technologies (fuel-powered motor pumps, rope and washer, and pulley technology) using empirical data from Ethiopia. Primary data were collected using a double-bounded contingent valuation elicitation method. We estimated the likelihood of adoption of these technologies (i.e., proxied by their willingness to pay) and the factors affecting farmers' WTP for the technologies using probit and bivariate probit models. Results indicate that high bid prices, land size and age of the household head are likely to reduce households' WTP for the WLTs. On the other hand, access to credit, household income, number of livestock and household size have positive effects on the probability of households adopting, and their willingness to pay for, technologies.

The prices, efficiency, operational costs, and labour requirement vary among the three WLTs considered in the study. Overall, farmers are willing to pay/adopt more efficient and less labor-intensive WLTs such as fuel-powered motorized pumps even at higher investment cost. Based on the findings, we propose four policy recommendations.

1. Resource-poor smallholders are constrained by lack of financing options to adopt or use more capital-intensive but efficient WLTs such as fuel-powered motorized pumps. Thus, they choose to invest in a less efficient, low-cost, and labor-intensive WLTs such as pully and hence operate below the production possibility frontier. Improving smallholders' access to alternative options (e.g., via in cash credit, on credit-sales or irrigation equipment leasing arrangements) could help ease this constraint and allow farmers to acquire more efficient and less laborious WLTs and enhance wide-scale adoption.
2. Smallholders face supply-side constraints to credit. This was demonstrated by the differences observed in the willingness to pay (or adopt) for WLTs by the ILSSI beneficiary farmers against the control group. Policy on improving smallholders' access to finance should be considered as an important intervention to enhance adoption of small-scale irrigation technologies.
3. Smallholders also face demand-side constraints to credit. Lack of prudent financial management, financial literacy, loan diversion, gaps in technical know-how, and low repayment should be addressed by targeted interventions on strengthening smallholder's capacity and entrepreneurship skill so that they can be self-motivated to engage in irrigated farming as a profitable undertaking.
4. Our finding show that farmers with small landholdings are willing to pay more for small-scale irrigation technologies as compared to farmers with large landholdings. The livelihoods of the former group of farmers mainly depend on the meagre endowment they possess. Increasing the productivity of land using yield enhancing technologies, particularly multiple cropping per year via small-scale irrigation is key to improve their livelihoods. Thus, farmers with relatively small landholdings require targeted policy interventions to improving their access to cost-effective irrigation technologies, other complementary inputs and their technical capacity.

This study focused on the demand side of the WLTs with limited number of technologies and smaller sample size. Building on the findings of this study, we suggest future studies covering more locations, larger sample size and broader set of small-scale irrigation technologies. Future studies need also to focus on uncovering the supply side factors such as the supply-chain, availability of affordable technologies to smallholders, information asymmetry and transaction costs. Besides the economics and livelihoods effects, there is also lack of evidence on the environmental effects of scaling up of small-scale irrigation in a changing climatic scenario. An integrated assessment is warranted to understand a complete picture of the socio-economic and environmental effects of small-scale irrigation technologies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships or any other conflict of interest that could have appeared to influence the work reported in this paper.

Acknowledgement

This publication was partly made possible through support provided by the Feed the Future Innovation Lab for Small Scale Irrigation through the U.S. Agency for International Development (USAID), under the terms of Contract No. AID-OAA-A-13-00055. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the USAID or the authors' affiliated organizations. We would like to express our thanks to three anonymous reviewers for their constructive comments that significantly improved the paper.

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