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ADOPTION OF SMALL-SCALE IRRIGATION AND ITS LIVELIHOOD IMPACTS IN NORTHERN ETHIOPIA†

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ABSTRACT

The potential of smallholder-irrigated agriculture to enhance food security and improve livelihoods has led the government of Ethiopia to invest significantly in irrigation establishment. This article aims to investigate the impact of small-scale irrigation on households' livelihood. To deal with the problems of purposive targeting and self-selection which are likely to occur for this type of intervention, we use a sophisticated econometric technique called 'propensity score matching' to study this impact. Our findings confirm the presence of a statistically significant difference in income, overall expenditure, asset accumulation and expenditures on agricultural inputs between the treated and control households. In contrast, no statistically significant differences in livestock resources, food consumption, and expenditure on education and health were found. Furthermore, the proportion of poor is respectively 20 and 30% for the treated and control households. So, overall it can be concluded that participation in the small-scale irrigation has robust and positive effect on most of the livelihood indices and that an expansion of irrigation schemes is a good strategy in the water-stressed and drought-prone areas of Ethiopia. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS: small-scale irrigation; livelihood; propensity score matching; northern Ethiopia

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RÉSUMÉ

Le potentiel de l'agriculture irriguée à améliorer la sécurité alimentaire et améliorer les moyens de subsistance des petits exploitants a conduit le gouvernement éthiopien à investir de manière significative dans l'établissement d'irrigation. Cet article vise à étudier l'impact de l'irrigation à petite échelle sur les moyens de subsistance des ménages. Pour faire face aux problèmes de ciblage téléologique et d'auto-sélection qui sont susceptibles de se produire pour ce type d'interventions, nous utilisons une technique économétrique sophistiqué appelée score de propension pour étudier cet impact. Nos résultats confirment la présence d'une différence statistiquement significative dans le revenu, les dépenses globales, l'accumulation d'actifs et des dépenses sur les intrants agricoles entre les ménages traités et de contrôle. Nous n'avons par contre pas trouvé de différence sur ressources en cheptel, la consommation alimentaire et les dépenses d'éducation et de santé. En outre, la proportion de pauvres est respectivement 20 et 30% pour les ménages traités et de contrôle. Donc, dans l'ensemble, on peut conclure que la participation à l'irrigation à petite échelle a un effet robuste et positif sur la plupart des indices de subsistance et que l'expansion des systèmes d'irrigation est une bonne stratégie pour gérer les stress hydrique et la sécheresse régions d'Ethiopie. Copyright © 2015 John Wiley & Sons, Ltd.

MOTS CLÉS: irrigation à petite échelle; moyens de subsistance; appariement des scores de propension; nord de l'Ethiopie

INTRODUCTION

During the 1940s and 1950s, many Asian countries (e.g. China, India, Singapore, Vietnam, Taiwan and South Korea) frequently faced problems of food insecurity. However, in the 1960s and 1970s these countries have expanded

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their irrigated areas in combination with the introduction of high-yielding varieties and chemical fertilizer inputs. Consequently, agricultural production has increased remarkably, and the productivity of inputs has improved. This intervention has allowed them to produce enough food for their population, to generate sufficient employment, and to achieve rapid economic growth (Huang *et al.*, 2006; Bhattarai *et al.*, 2007). Other countries like, for example, Israel, Iran, South Africa, Gambia and Ghana followed this example in the 1980s and expanded their irrigated areas and stimulated the use of improved inputs. This increased the cropping frequency to two/three times a year, and also increased the farm yield. Furthermore, farmers could switch from low- to high-value production, in this way realizing more income and assets (Haddad *et al.*, 2011; Fanadzo, 2012; Kuwornu and Owusu, 2012).

These successful experiences have stimulated the government of Ethiopia to formulate agriculture-based national policies aiming to reduce existing food insecurity, malnutrition and poverty problems in the country as a whole. With the introduction of the agricultural development led industrialization in 1991 (though intensively propagated since 2000), focus was given to the expansion of irrigation schemes, and the introduction of improved agricultural practices and technologies. Since then, the government has allocated about 17% of its annual national budget to the agricultural sector. Farmers' training centres equipped with facilities and extension workers have been established at village level to improve the awareness of the local communities. In addition, non-governmental organizations have actively participated in the construction of irrigation schemes and technical–financial support for farm households. As a result of this effort, the share of irrigated output in the total agricultural output increased from 4% in the 1990s to 31% in the 2010s. The percentage of food-insecure people in the country has also fallen from more than 50% in the 1980s and 1990s to about 30% around 2010 (Tesfay, 2008; Tesfaye *et al.*, 2008; Ministry of Finance and Economic Development, 2010; Aseyehegu *et al.*, 2011; Bacha *et al.*, 2011; Gebregziabher *et al.*, 2012).

Several researchers, for example Negatu and Parikh (1999), Tesfay (2008), Tesfaye *et al.* (2008), Hagos *et al.* (2009), Aseyehegu *et al.* (2011), Bacha *et al.* (2011) and Gebregziabher *et al.* (2012), have already studied these supply-side initiatives of introducing irrigation and improved technologies. The studies report that irrigation has significantly improved farm production and productivity of inputs when compared with a rainfed system (Tesfay, 2008; Tesfaye *et al.*, 2008; Hagos *et al.*, 2009; Aseyehegu *et al.*, 2011; Bacha *et al.*, 2011; Gebregziabher *et al.*, 2012). Additionally, farmers have shifted to high-value and market-oriented production (Tesfay, 2008; Gebregziabher *et al.*, 2012). Furthermore, it was found that the income, nutrition and expenditure of those farmers who were involved in irrigation have increased significantly (Tesfay, 2008; Aseyehegu *et al.*, 2011; Bacha *et al.*, 2011; Gebregziabher *et al.*, 2012). Nevertheless, adoption rates of irrigation and improved inputs remained low (Negatu and Parikh, 1999; Tesfay 2008; Tesfaye *et al.*, 2008; Aseyehegu *et al.*, 2011; Bacha *et al.*, 2011). These studies also reported that the main factors that impede farmers from actively participating in irrigation schemes include limited access to information, improved technologies and productive resources (e.g. land, cash or oxen), and weak institutional arrangements.

In this article, we want to gain a deeper insight into the relationship between farmers' livelihood and small-scale irrigation participation. Because livelihood is too broad and complex to capture in a single indicator, we consider seven factors which are related to livelihood to evaluate the impact. Furthermore, we use a sophisticated econometric technique, propensity score matching (PSM), to overcome the typical problems (purposive targeting and self-selection) in the impact assessment of such interventions. This kind of approach is necessary because unlike assumed by, for example, Aseyehegu *et al.* (2011), and Bacha *et al.* (2011), participation in small-scale irrigation schemes is not randomly distributed over the population. Our study uses data from 400 households in northern Ethiopia. From these households, 160 participate in small-scale irrigation (= treatment group) and 240 do not (= control group).

The organization of the paper is as follows. The introduction gives the purpose and the objective of the study. This is followed by a description of the methodological literature and model specification of the study. The research design including the sampling technique and data collection method are briefly assessed in the subsequent section. Next, the results and discussion of the study are presented. Finally, brief concluding remarks, suggestions and limitations of the study are provided.

CONCEPTUAL FRAMEWORK AND ESTIMATION TECHNIQUE

Theoretical model

Adoption of technological innovation in less developed countries takes place under different imperfect conditions, for example market imperfection, limited access to productive resources and lack of some institutions. Gebregziabher *et al.* (2012) argued that depending on the existing situation, adoption decisions can be explained by benefit maximization or cost minimization. In this study, assuming that farm households are risk-neutral, their decision whether to participate or not in small-scale irrigation depends on the value of the expected utility of wealth (livelihood) from adoption and non-adoption, which is expressed by indicators such as total income, livestock, total assets, total expenditure, expenditure on education and health care, expenditure on improved agricultural inputs and food consumption. Accordingly, the general model of the study for the expected utility of wealth is given by

$$U_i(HL) = Y_i\beta + \eta D_j + \varepsilon_i \quad i = 1, 2, \ldots n \tag{1}$$

where $U(HL)$ is the expected utility of wealth (HL) for household i; Y_i is the vector of observed explanatory variables; D_j is a participation decision in small-scale irrigation (D_j = 1 if farmers adopted small-scale irrigation and D_j = 0 otherwise); η is the effect of small-scale irrigation on the expected utility of wealth or livelihood (e.g. income, assets, food consumption, animal resources and expenditure); and ε_i is an error term with mean zero and variance δ_ε^2 that captures the measurement errors and unobserved factors affecting the adoption decision and its outcomes. The utility $U(HL)$ derived from adoption is not observable but only the choice of adoption or non-adoption can be observed so this can be represented by a latent variable $U^*(HL)$. Accordingly, farm households would participate in small-scale irrigation only when the expected benefit from adoption $\left(U_{i1}^*(HL)\right)$ exceeds the expected benefit from non-adoption $\left(U_{i0}^*(HL)\right)$.

Following, both in observational and experimental studies,[1] the major interest is to determine the estimated average treatment effect for the treated population (ATT_i), which is the difference between the treated and control farm households and this is indicating whether $U_{i1}^*(HL) > U_{i0}^*(HL)$ due to technological innovation where HL_{i1} and HL_{i0} are the differences in expected utility of wealth using the predefined factors if the farmers are respectively treated and not treated. Now, the question is how to estimate the average treatment effect of the livelihood indices because the objective is to investigate the impact of small-scale irrigation on household livelihoods. In the literature, there are several evaluation strategies that help to estimate ATT_i and we have to choose an appropriate evaluation technique depending upon the nature of the study (experiment vs observation), and the available information.

$$\begin{aligned} ATT_i &= E\left\{HL_{i1} - HL_{i0}/D_j = 1, P(Y_i)\right\} \\ &= E\left(HL_{i1}/D_j = 1\right) - E\left(HL_{i0}/D_j = 1\right) \end{aligned} \tag{2}$$

Impact evaluation strategies

Evaluating the impacts of improved technologies is not straightforward because they are designed and implemented in a complex and ever-changing environment (Stern *et al*., 2012). Another problem is the bias resulting from self-selection in the adoption of the technological innovation (Khandker *et al*., 2010). Furthermore, there is a hidden bias that results from unobserved heterogeneity in the adoption decision, which can, in turn, influence the outcome of adopting a technological innovation (Smith and Todd, 2005). Nevertheless, there are several approaches by which impacts can be evaluated. These include randomized selection methods, propensity score matching, regression discontinuity design, difference-in-difference and instrumental variable estimation methods (Abadie *et al*., 2004; Khandker *et al*., 2010).

Randomized selection methods can be used to assess impact of a programme when participants were randomly selected for it (United Nations Development Programme, 2009). The difference-in-difference can be used when baseline and time series information on both participants and non-participants is available (Stern *et al*., 2012). The regression discontinuity design is a quasi-experimental pre-test–post-test design that elicits the causal effect of interventions which are assigned using a threshold. So, in that case, the difference in mean outcome of treated and control groups restricted to the vicinity of the threshold point (that is, local to the discontinuity) gives the impact of the intervention. The instrumental variable estimation regards the treatment variable as endogenous and the idea is to find an observable exogenous variable or variables (instruments) that influence the participation variable but do not influence the outcome of the programme if participating. Propensity score matching (PSM) finally is used when it is possible to create a comparison group from a sample of non-participants closest to the treated group using observable variables. Both groups are matched on the basis of propensity scores–predicted probabilities of participation given some observed variables (Abadie *et al*., 2004).

From the above-described impact assessment approaches, this study chooses propensity score matching for several reasons. Firstly, no baseline data on participants and non-participants were available. Secondly, the participants in small-scale irrigation were either purposefully placed or self-selected to participate. Furthermore, the available field data were based on a cross-sectional survey. Finally, it was possible to identify some features, in this case sociocultural practices, agro-climatic parameters and physical characteristics, to match the participants and non-participants.

The propensity score-matching method

As stated above, the policy interest is to find the average treatment effect of an intervention. The problem is that it is not possible to estimate $E(HL_{i0}/D_j = 1)$, only $E(HL_{i1}/D_j = 1)$. As an alternative, we can use $ATT_i = E(HL_{i1}/D_j = 1) - E(HL_{i0}/D_j = 0)$ but this is also potentially a biased estimator. For such a problem, PSM provides an appropriate solution (Rosenbaum and Rubin, 1985). It accounts for sample selection bias due to observable differences between treatment and comparison groups. It controls for self-selection by creating a statistical comparison group by matching every individual observation of the treatment group with individual observations from the control group with similar observable characteristics. Estimating such a treatment effect requires conditional independence and common support assumptions. The parameters of the observed variables capture the differences between the treated and control (counterfactual) groups. Both have common characteristics for matching based on the basis of the propensity scores (United Nations Development Programme, 2009; Khandker *et al.*, 2010). So the balancing property of propensity score is given as follows:

$$HL_{i1}, HL_{i0} \perp | Y_i \Rightarrow E(HL_{i1}|P_i = 1, X_i) = E(HL_{i0}|P_i = 0, Y_i) \quad (3)$$

The propensity score-matching technique is based on two equations: selection and outcome equations (Khandker *et al.*, 2010). The selection equation (4) is used to predict the probabilities of treatment for each observation and construct the set of matched observations. We use a binary logit model to estimate the value of the propensity score (selection equation) (Abadie *et al.*, 2004) because the adoption decision of the study has dichotomous values (1 for farmers who participated in irrigated farming during the survey period and 0 otherwise). All biases because of observable components can be removed by conditioning on the propensity score. Violation of the assumption is a major source of bias due to comparing incomparable individuals. For example, individuals that fall outside the region of common support have to be discarded and the treatment effect cannot be estimated.

$$\begin{aligned} P(D_i = 1|X_i) = \Phi(f(X_i)) &= \sum_{i=1}^{n} \alpha_i X_i + \varepsilon_i \\ &= \frac{e^{f(X_i)}}{1 + e^{f(X_i)}} \Rightarrow \hat{P}(X_i/D = 1) \end{aligned} \quad (4)$$

In Equation (4) Φ denotes the normal cumulative distribution of the livelihood indices function and $f(X_i)$ represents a specification of the household practising irrigation farming. Each participant and non-participant has an estimated propensity score, which is a continuous variable and has value between 0 and 1. When the propensity score model is statistically significant, the average treatment effect on the livelihood indicators for the matched households (Equation (5)) can be calculated using several criteria: the nearest neighbour, radius, kernel or stratification matching criteria (Appendix A). These matching algorithms may generate different results because they use different assumptions and principles. Consequently, it is preferable to use and compare all the matching criteria to evaluate intervention programmes (Caliendo and Kopenig, 2008; United Nations Development Programme, 2009; Khandker *et al.*, 2010).

$$\begin{aligned} ATT_i &= E(HL_1 - HL_0/D = 1, P(Y_i)) \\ &= E\{E(HL_1/D = 1, p(Y_i)) - E(HL/D = 0, P(Y))/D = 1\} \end{aligned} \quad (5)$$

Assessing the matching quality and sensitivity analysis

The purpose of the propensity score matching is to balance the observed distribution of covariates across the treated and control households. Balancing test techniques are used to check whether the differences in the covariates between the treated and control groups are eliminated. One example is the standardized mean difference before and after matching (Equation (6)), which is used to check the presence or absence of observed biases (Rosenbaum and Rubin, 1985; Rosenbaum, 2005; Nannicini, 2007), where X_T and X_c are the sample means for the treated and control households while $V_T(X)$ and $V_C(X)$ are the corresponding sample variances. The process is called the Rosenbaum–Rubin bias reduction (RB). It is the unweighted average of all covariates (the total bias) reduced due to the matching process. In order to accept the findings of PSM, it is suggested that the standardized mean difference needs to be at most 20% and the pseudo R^2 needs to be fairly low after the matching process (Rosenbaum, 2005; Caliendo and Kopenig, 2008). When the covariates are well balanced and the matching procedure is of high quality, the propensity score matching eradicates all biases from the observed variables.

$$RB = 100\left(1 - \frac{\beta_{after}}{B_{before}}\right), where \quad (6)$$

$$B(X) = 100\left(\frac{X_T - X_C}{\sqrt{\left(\frac{V_T(X) + V_C(X)}{2}\right)}}\right)$$

Nevertheless, absence of systematic difference in the distribution of the covariates between the treated and control groups (no observed bias) does not mean that there is no bias between the control and treated groups. For example, in Equation (7) which shows the odd ratio for the treatment, the probability of the treatment depends on observed components (X_i) and unobserved components (U_i). Two individuals i and j with the same observed covariates may differ in unobserved factors. Equation (7) illustrates that PSM only captures biases from observed factors. Hidden bias may arise if there are unobserved variables that simultaneously affect participation in small-scale irrigation and the outcome variables. γ shows the effect of U_i on the adoption decision of small-scale irrigation; and Γ is the effect of unobserved variables on the outcome variable, the sensitivity analysis ($e^{\gamma} = \Gamma$), which shows how the magnitude of the treatment effect changes with an increase of hidden biases (Rosenbaum, 2005) and captures the degree of departure of the estimates from an analysis with random assignment or free of hidden bias (Caliendo and Kopenig, 2008; Nannicini, 2007). In a randomized experiment, the odd ratio is unity ($\Gamma = 1$) which indicates absence of hidden bias due to an unobserved confounder. The coefficient of the unobservable heterogeneity (γ) in the logit model is zero and the matching process fully eliminates the bias from observed covariates.

$$\frac{P_i(1-P_j)}{P_j(1-P_i)} = \frac{\exp(\beta X_i + \gamma U_i)}{\exp(\beta X_j + \gamma U_j)} = \exp\{\gamma(U_i - U_j)\} \quad (7)$$

$$\Rightarrow \frac{1}{\Gamma} = \frac{P_i(1-P_j)}{P_j(1-P_i)} = \Gamma$$

In our observational study, we suspect the presence of unobserved heterogeneity and we believe that participation in small-scale irrigation would not solely be determined by X_i. The adoption decision and livelihood indices are affected by observable and unobservable multidimensional and interrelated factors. This implies that two individuals (treated and control) with the same observed covariates would differ in their chance of receiving treatment due to factors this model does not consider and Γ may differ from unity. In this case, we have to assess the strength of unmeasured influences (hidden heterogeneity) on the outcome variables (e.g. income, assets, livestock and expenditure) at different levels of Rosenbaum bounds (Γ). Some studies explained that higher values of odd ratios show progressively large logit coefficient (γ) and reflect large potential selection bias from unobserved covariates. For each value of Γ, we derived bounds on the significance levels of the treatment effect under the assumption of endogenous self-selection into treatment status and confidence intervals (Rosenbaum, 2005; Becker and Caliendo, 2007; Nannicini, 2007).

RESEARCH DESIGN

This study was conducted in the Tigray region, northern Ethiopia, which is located between 12^0 and 15^0 N latitude, and 36^0 30' and 41^0 30' E longitude. The region has 6 administrative zones with 36 districts, about 200 villages and 4 agro-climatic zones ranging from semi-arid, warm-temperate, temperate and cold. The region is about 41 410 km^2 and has a population of approximately 5 million with diversified language and culture. Crop production and animal husbandry are the main sources of livelihood for more than 70% of the population in the region (Ministry of Finance and Economic Development, 2010).

Concerning the sampling framework, from each administrative zone, the study randomly selected one district and, from each district, two villages were randomly selected. Systematic and proportional-to-size sampling techniques were also used to select the 400 sample households. The study considered five small-scale irrigation schemes using water from diverse sources including river diversion, a spring, private ponds, communal dams and ground wells. The study focused on surface irrigation because drip/trickle irrigation has only very recently been introduced and other irrigation types are not practised in the region.

A survey and focus group discussions (FGDs) were employed to collect the relevant data from the sample households. A structured questionnaire was used to collect data on demographic characteristics, welfare variables (e.g. income, animal resources, expenditure and assets), farmland variables, social capital factors, access to rural financial credit, access to information,[2] distance to rural services[3] and membership of rural formal associations/organizations.[4] The questionnaire was canvassed with 10 randomly selected households to check the adequacy of the questions. Moreover, FGDs were arranged at district level with representatives from different offices, communities and associations in order to obtain a general picture of the small-scale irrigation schemes in the study areas.

RESULTS AND DISCUSSION

Descriptive statistics

Some characteristics of the sample population, with a comparison between the treatment group and the control group, are presented in Table I. It shows that 40% of the sample households (n = 160) were participating in small-scale irrigated farming (treated group), while 60% (n = 240) were not (control group). About 67% of the sample households were male-headed. The average age within the sample respondents was about 45 years. About 55% of the respondents were literate. The average family size was about 6 while the regional mean family size was 5 (Ministry of Finance and Economic Development, 2010). Agriculture was the primary source of occupation (livelihood) for about 56% of the households. According to Ministry of Finance and Economic Development (2010), for the entire Tirgray region, this was about 75%, indicating that a higher share of people in our sample were engaged in non-agricultural activities. The average animal ownership was about 3 TLU[5] and the average landownership was 2.5 *tsimad*.[6] The average distance to a centre where social and physical rural infrastructure services are found was about 1.5 h travelling time.

The chi-square independence test shows a statistically significant difference for educational status between the treated and control farm households, with the treated households being more literate than the control households. Additionally, this test indicates statistically insignificant differences in headship of the household, and primary occupation between the treated and control households. Moreover, the chi-square test shows that there is a statistically significant difference in the application of chemical

Table I. Demographic and socio-economic characteristics of sample households (mean/%)

Household variables	Treated group	Control group	Total	*P*-value
Male-headed households	70	63	67	0.078
Agriculture as primary occupation	59	52	56	0.093
Literate household heads	59	49	55	0.021**
Use of improved seed varieties	77	45	58	0.000***
Chemical fertilizer and pesticide use	70	30	46	0.003***
Samples who had irrigated land[a]	38	32	35	–
Household head age (in years)	44	46	45	0.186
Household size	7.0	6.0	6.0	0.048**
Adult equivalence of family size	5.0	5.0	5.0	0.565
Livestock resources (TLU)	5.2	4.4	4.7	0.075
Landholding size (*tsimad*)	2.3	2.7	2.5	0.124
Distance to rural services (min)	89.4	94.2	91.4	0.535

Notes: *** and ** show the level of significance at 1 and 5%, respectively.
[a]The proportion of the sample respondents that had irrigated farmland during the survey period. Of the total treated respondents, about 38% had irrigated farmland while the remaining had none. Similarly, about 32% of the control respondents had irrigated farmland though they were not participating in irrigation. This implies that the treated farm households rented—and/or sharecropped in— irrigated land from the control households, and the land exchange arrangement is effectively working.

agricultural inputs and improved seed varieties between the treated and control households at 1% of level. Furthermore, the two-sample independence *t*-test indicates that there is a statistically significant difference in household size, whereas a statistically insignificant difference in age of the household head, livestock ownership, landholding, adult-equivalent[7] household size, and rural services between the treated and control farm households in the study area at 5% level of significance.

Apparently, the treated households have a relatively larger family size than the control households. The insignificant factors such as age, gender of headship, landholding, occupation, rural services and livestock seem to be less correlated with the participation decision. Accordingly, the adoption of small-scale irrigation seems less likely to be biased by these variables. However, the adoption of small-scale irrigation may be affected by the covariates of education and household size because they have a statistically significant difference between the treated and control groups. This was slightly contrary to previous studies (Dillon, 2011; Chazovachii, 2012; Fanadzo, 2012). They found a statistically significant difference between the treated and control groups in farmland size, livestock and education but insignificant difference in household size, age and gender.

Irrigation farming practices

Dependence on rainfed agriculture allied with the erratic nature of rainfall, and low use of improved technologies are among the factors that contribute to the low productivity of agriculture in the Tigray region. For this reason, the government has given emphasis to the expansion of small-scale irrigation schemes (Bacha *et al*., 2011; Gebregziabher *et al*., 2012). This can relieve farmers from reliance on unpredictable rainfall, shift them from subsistence to market-oriented production and improve farm yield and productivity, and enhance food security. Table II presents the irrigation practices in the study areas. As mentioned above, the dominant irrigation type is surface (or flood) irrigation. The farmers involved in surface irrigation use water from different sources such as rivers, springs, ponds, dams and wells. About 31 and 12% of the treated farmers respectively used river and private pond-based small-scale irrigation.

In Ethiopia, river diversions, spring development and communal dams have mainly been constructed by governmental and non-governmental organizations because they often provide irrigation services for larger communities. In contrast, most of the costs for the construction of wells and private ponds are borne by the farm households. That is why, as can be seen in Table II, only a small number of treated farm households rely on these sources. Dependency on a lot of family labour for construction is another contributing factor to the low adoption of these schemes. A similar finding was reported in South Africa. With the intervention of government, the number of farmers who engaged in irrigation increased greatly and irrigated areas expanded significantly. However, the situation stagnated (even declined), associated with the withdrawal of government from bearing the cost of construction (Kamara *et al*., 2002). Negative returns of small-scale irrigation were found in Senegal due to high construction costs and a limited output market. This was also given as the main reason for the low adoption of small-scale irrigation in Senegal (Comas *et al*., 2012). Makombe and Sampath (1999) also found similar findings in Zimbabwe. They found negative net present returns of smallholder-irrigated farms unless government partially or

Table II. Technology used, farmers participating and improved inputs used by irrigation system

Irrigation systems	Farmers used (%)	Irrigated land (*tsimad*)	Technology used	Produce	Inputs used
River diversion	31	1.0	Treadle pump, furrow, diesel motor, canal	Food grain, spice, animal forage, vegetables, fruits	Chemical fertilizer, manure, pesticide, improved seeds, compost, local seeds
Spring	22	0.40	Furrow, plastic jars, bucket	Vegetables, spice, fruits	Improved seeds, local seeds, manure, composts
Ground wells	16	0.65	Treadle pump, diesel motor, triddle gravity	Food grain, fruits, animal forage, spice, vegetables	Chemical fertilizer, pesticide, improved seeds, manure
Private ponds	12	0.25	Plastic jars, bucket	Vegetables, spice, fruits	Improved seeds, manure, local seeds
Communal dams	19	0.80	Treadle pump, diesel motor, furrow	Food grain, fruits, animal forage, spice, vegetables	Chemical fertilizer, manure, pesticide, improved seeds, compost, local seeds

fully covered the initial cost of these irrigation schemes. This implies that the low adoption of private ponds and wells in the study area might be linked with the cost–benefit analysis. However, such an investigation is beyond our objective. Low return (sometimes negative) due to a limited output market and high construction costs was the main reason for the low adoption of small-scale irrigation in Mauritania (Comas *et al*., 2012). Fiebiger *et al*. (2010) also reported similar findings in Namibia. However, studying the problems and limitations of small-scale irrigation in the study area goes beyond the objective of this study. As a result, we advise that further in-depth investigation be conducted on the ecological and social impacts of small-scale irrigation for decision-making benefits.

The size of the cultivated land is another important element in irrigation practice. Tigray is a rugged and mountainous area with high plateaux. On a country level, less than 67% is suitable for cultivation, and this figure for the Tigray region is about 45% (Ministry of Finance and Economic Development, 2010). Because of this reason coupled with the population density, the average cultivated land per household head in the Tigray region is less than 1 ha. For example, a study in Tigray and Amhara regions found that about 23% of farm households own less than 0.5 ha of cultivated land, while the figure for those who own less than 1 ha was about 89% (Tesfay, 2008; Ministry of Finance and Economic Development, 2010). Likewise, the sample respondents in the study area have less than 1 ha cultivated farmland. As presented in Table II, the average irrigated farmland was very small, especially when smallholder farmers rely on springs and private ponds.

There is a presumption that irrigation enables farmers to diversify crops and produce marketable crops. As indicated in Table II, farmers often produced fruits, spices and vegetables on irrigated farmland. Sometimes they also use supplementary irrigation for food crops, especially maize, faba bean and chickpea. Furthermore, the participants in the FGD explained that farmers always produce wheat, barley, teff, maize, millet, legumes and/or other subsistence crops in the rainfed farmland. The finding was consistent with previous studies in Ethiopia, Nigeria and South Africa. They found that irrigation was predominantly used for vegetables, fruits and spices though it was sometimes used for cereals and leguminous crops (Tesfay, 2008; Oruonye, 2011; Fanadzo, 2012). In the study area, the irrigated crops are mainly horticultural ones such as cabbage, potato, pepper, tomato, carrot, beetroot, Swiss chard, onion and sweet potato. Therefore, irrigation enabled the farm households to produce market-oriented crops.

The study explored whether small-scale irrigation enhanced the adoption of improved technologies. Table II shows that farm households often use irrigation equipment such as treadle pumps, motorized pumps and canalization to bring water from the source to the irrigated land. They also use tools such as buckets, large plastic jars (wheelbarrows), furrows and gravity barrels (triddle) especially in spring- and pond-based irrigation system. This might be associated with the low water capacity and the small area of irrigated farmland. The same table also indicates that the irrigation farmers used improved seed varieties, chemical fertilizer, pesticide and herbicide, though some also used local seeds, animal manure and compost. From Table I, it could be seen that about 58 and 46% of the respondents respectively applied improved seed varieties and chemical inputs. The respective figures for the treated farmers were about 77 and 70% while for the control farmers they were approximately 45 and 30%. Previous studies in Nigeria and South Africa also reported similar findings. The use of chemical fertilizer, pesticide and improved seeds was much higher in irrigated areas than in non-irrigated ones (Oruonye, 2011; Fanadzo, 2012). Due to an intensive expansion of irrigated agriculture, the use of chemical fertilizer inputs in India tripled between 1974 and 1998, and even quadrupled between 1998 and 2005

(Bhattarai *et al*., 2007). Thus, small-scale irrigation promotes the use of improved agricultural technologies.

Livelihood status of respondents

The study used three methods to highlight the general livelihood status in the study area: FGD, literature review and a survey. In the FGD, the participants were given 50 stone counters to classify the local population into poor and non-poor categories based on local livelihood classification criteria. This is presented in Table III. On average, about 18% of the local farmers who were involved in irrigation were classified as poor while the corresponding figure for households who did not engage in irrigation was about 29%. Thus, the number of non-poor households seems to be higher for farm households with irrigation than that of counterpart households.

Alternatively, using the estimated annual income from the survey, we could also classify the sample households into poor[8] and non-poor, and we found that about 80% of the treated and 70% of control groups were found to be non-poor. Finally, we looked at existing data from the region and also from the country (e.g. Ministry of Finance and Economic Development, 2010; Bacha *et al*., 2011; Gebregziabher *et al*., 2012). In these studies, about 32% of households without irrigation and 21% of households with irrigation were approximately found to be poor. We therefore conclude that irrespective of the assessment methods, farm households without irrigation, on average, seem to be worse off than the households participating in small-scale irrigation.

The discussants explained that irrigation enabled farmers to increase income, cover some medical expenses, accumulate more durable assets, purchase non-food items, send children to school and purchase farm inputs. Similar evidence was observed in other countries. In Zimbabwe farmers with irrigation invested 80% more on permanent assets (for example telephones, scotch carts, wheelbarrows, livestock, cloths, a corrugated iron sheet house, schools and clinics) than farmers without irrigation (Chazovachii, 2012). In China, irrigation income has enabled rural farm households to send children to school, buy groceries for the family, visit relatives in distant areas, and afford mobile phones (Huang *et al*., 2006). Makombe and Sampath (1999), Kamara *et al*. (2002), Mati (2008) and Haddad *et al*. (2011) reported similar findings.

The participants in our FGDs further mentioned lack of markets and shortage of improved agricultural inputs as the main problems, and death, malaria and salinity as the main limitations for small-scale irrigation in the study areas. Some previous studies also reported similar issues. Studies in the Rift Valley Lake Basin of Ethiopia showed that soil salinity/acidity, waterlogging, and communicable and non-communicable diseases were the main limitations as well as depletion of water, and continuous maintenance needs and inefficient water management were the challenges of small scale-irrigation. Such factors meant the production gain from irrigated agriculture was below the expected value (Ulsido *et al*., 2013; Ulsido and Alemu, 2014). Consistent problems were also observed in Namibia (Fiebiger *et al*., 2010). Low return (sometimes negative) due to a limited output market and high construction costs was the main reason for the low adoption of small-scale irrigation in Mauritania (Comas *et al*., 2012). However, since such issues were not part of our objective, we therefore advised for further researches.

Impact of small-scale irrigation on livelihood

The impacts of small-scale irrigation on total income, expenditure and assets of the respondents were assessed using PSM. As can be observed from Tables IV and V, and Appendix B, the overall propensity score testing was significant. The assumptions were fulfilled and the balancing property of the propensity score was considered to be satisfactory. In the pre-matching stage, the treated and control groups were significantly different for the majority of the covariates. After the matching process, only the difference in access to financial credit was statistically significant. The residual bias following matching was below 10% for all covariate variables except the access to credit. This implies that there was no significant difference in mean value for most independent variables after the matching process, and we rejected the alternative hypothesis of the matching process which states that there is a statistically significant difference in the standardized mean of the covariates even after the matching process (Appendix B).

Table III. Livelihood status of the sample farm households by local criteria (%)

	Livelihood status by previous studies		Group discussion by this study		Household survey by this study	
Livelihood group	Treated group	Control group	Treated group	Control group	Treated group	Control group
Non-poor	79	68	82	71	80	70
Poor	21	32	18	29	20	30

Table IV. Estimation of the coefficients of the propensity score in logit regression algorithm

Variables	Coefficients	Variables	Coefficients
Male household head	0.35(0.263)	Landholding size (tenure)	−0.90(0.716)
Married proportion	0.23(0.125)	Distance to district markets	−0.41(0.271)
Age of household head	−0.01(0.010)	Access to information	0.30(0.001)***
Household size	0.02(0.011)**	Distance to rural services	−0.81(0.569)
Literate household heads	0.18(0.045)**	Distance to all-weather roads	0.023(0.015)
Membership in diverse rural associations	0.16(0.041)**	Distance to farmer training centres or extension services	−0.03(0.007)***
Access to financial credits	−0.10(0.257)		
Obs. = 400 LR Chi2 (13) = 129.78 Prob>Chi2 = 0.000 Log likelihood = −35.21			

Notes: The value in the brackets is the standard error of the parameters.

Table V. Average treatment effect difference for the treated group (per adult equivalent)

Livelihood indices	Nearest-neighbour estimators	Radius estimators[a]	Kernel estimators	Stratification estimators	Rosenbaum bounds Γ = 0.05
Treated observations	160	140	160	160	
Control observations	86	161	240	231	
Livestock density	0.64 (1.80)	0.34 (1.19)	0.47 (1.78)	0.47 (1.52)	1.40
Income earnings	584 (2.87)***	532 (2.96)***	644 (3.56)***	507 (3.31)***	1.60
Expenditure	606 (2.61)***	532 (2.15)**	663 (2.90)***	506 (2.85)***	1.50
Food consumption	293 (1.30)	272 (1.62)	288 (1.87)	268 (2.78)***	1.60
Expenditure on education and health	151 (1.09)	90 (1.31)	163 (1.63)	*96 (1.96)***	*1.50*
Expenditure on improved inputs	218 (2.40)***	295 (1.98)**	269 (2.11)**	279 (2.34)***	1.60
Asset holding	475 (2.41)***	398 (2.02)**	399 (2.03)**	376 (2.17)**	1.70

Notes: The values in parentheses are *t*-statistic and bootstrapped *t*-statistics is 100 replications.
Bandwidth for kernel matching estimator is 0.001. Income, assets and expenditure are measured by Ethiopian currency, birr.
[a]The study used a radius of 0.001 ($r = 0.001$) to search for matches of the treated respondents. Imposing a small radius can produce closer matches and highly representative results for the treated population. However, this is done at the expense of sample size (Khandker et al., 2010).

Table IV demonstrates the estimates of the propensity scores. The propensity score logit model was statistically significant. Household size, access to information, distance to farmers' training centres, education level of the household head, and membership of rural associations were the main factors that significantly explain the probability of the farmers adopting small-scale irrigation. Irrigated agriculture is laborious and time demanding. Accordingly, the probability of farmers participating in irrigation increased with family size because a larger family size implies a larger labour supply. Rural associations, education, information channels and training centres for farmers can significantly enhance the knowledge or the awareness of communities about improved technologies and practices. As a result, literate households, households who were members of associations, and households who had easy access to agricultural information were found to have a higher probability of participating in small-scale irrigation than others. In contrast, distance to farmers' training centres negatively influenced the probability of farmers participating in irrigation because the greater the distance, the less the access to agricultural extension services and the less the awareness about the importance of irrigation.

Table V presents the average treatment effects of the PSM. Four matching criteria were used. The results show two points: (i) a large number of the respondents were matched, creating a high degree of covariates balance and increasing confidence in the estimated treatment effects; (ii) the adoption of small-scale irrigation in the study areas had a positive and statistically significant effect on total income, expenditure, asset holding, and expenditures on improved agricultural inputs (e.g. chemical fertilizers and improved seeds) at the 5% level. For example, using radius matching, 161 control households were matched to 140 treated households. The average adult equivalent income and asset ownership for the treated group was respectively about birr 532 and 400 higher than that of the control group. Such a finding was similar to previous studies. Dillon

(2011), for example, found that the annual per capita expenditure for irrigation farmers in northern Mali in 2010 was higher (18%) than that of farmers without irrigation, and Kuwornu and Owusu (2012) reported that the annual total expenditure of irrigators in Ghana in 2010 was 11% higher than that of non-irrigators. For Ethiopia, Bacha *et al*. (2011) found that the expenditure and income per adult equivalent for irrigator households were about 30% higher than the non-irrigator households.

The study found a statistically significant difference in expenditure on improved agricultural inputs between the treated and control groups. This implies that households participating in small-scale irrigation had allocated more income (for example birr 300 higher income using the radius method) to purchase improved inputs such as pesticides, chemical fertilizers, improved seeds and other inputs. There might be several reasons for this. Firstly, farm households have often used irrigated areas for producing fruits and vegetables. These crops are very sensitive to pests and diseases, and also require a greater use of improved inputs compared to rainfed crops. Secondly, the treated farmers have received a higher income from their sales. As a result, they can afford the higher price of fertilizers, improved seeds and chemical inputs. A similar result was found in Ghana, i.e. investment in small-scale irrigation had a significant and positive effect on the adoption of other agricultural improvements such as chemical fertilizers and improved seed varieties (Kuwornu and Owusu, 2012).

However, the PSM shows that there was no statistically significant difference in livestock resources, food consumption, and expenditure on schooling and health care between the treated and non-treated households at the 5% level. In Ethiopia, there have been intensive campaigns for area enclosures, zero grazing and conservation agriculture. Introduction of these practices might enable the relatively better-off households to destock their animals. The frequent droughts and shortage of animal feed in the areas might also contribute to reducing the quantity of animals and the focus on intensive animal husbandry. The insignificant difference in food consumption might have three explanations. First, irrigated production was mainly designated for the market, so that may not bring such a big difference in food consumption. Second, food consumption is generally relatively income-inelastic and so both groups may spend an equivalent amount of income on food items. Third, the treated households might not consider or underestimate their own irrigation products they consumed.

We expected that the adoption of improved technologies that increase income can enable households to invest more in education, health care and other social services. An empirical study in Kenya showed that households who were involved in small-scale irrigation allocated about 31% more income to schooling and health-care services than their counterpart households (Mati, 2008). Nonetheless, this study found contradictory findings. The statistically insignificant effect of small-scale irrigation on education and health expenditure between the two groups might have two explanations. First, there are limited rural infrastructure services in the areas (e.g. private schools and private hospitals) so that the local people have to access the same social and physical services regardless of their income and wealth status. Secondly, small-scale irrigation might have a long-term and dynamic effect on schooling and health care but the short-term effects might not be easily visible and might be difficult to capture using cross-sectional information.

The study checked the validity and consistency of the PSM estimates, i.e. the presence of hidden biases from unobserved covariates, using the Rosenbaum bounds sensitivity approach with the Wilcoxon signed rank test, because the PSM only removes the bias from observed variables. The Wilcoxon signed rank sensitivity test (Appendix B) shows that there were no significant underestimation and overestimation effects because of the presence of hidden biases. In Table V, the lower bound of the test indicates that the livestock density was considerably more sensitive to unobserved confounding selection effects at $\Gamma = 1.40$ since the cut-off of the gamma value is 1.50 at 5% level of significance. However, as some studies (Rosenbaum, 2005) have explained, underestimation due to a hidden bias has often occurred in an intervention programme and is not a critical problem. The problem is when there is overestimation because this can lead to change of model and wrong decisions. Furthermore, there is no significant difference between the treated and control groups in livestock density (Table V). It can be concluded that the majority of the livelihood factors were quite insensitive to unobserved biases. Our model is also relatively free of observed and unobserved biases. We therefore conclude that participation in small-scale irrigation has a positive and significant effect on most of the livelihood indicators such as total income, total assets, total expenditure, expenditure on health and education, and expenditure on improved agricultural inputs.

CONCLUSIONS

The study examines the impact of small-scale irrigation on the livelihood of farm households in Northern Ethiopia. We use propensity score matching to address the problem of selection bias that is frequently encountered in observational studies. The findings of the study show that participation in small-scale irrigation depends on a variety of institutional factors and on the presence of rural services. The local institutions and the rural infrastructure services can improve the awareness of people regarding irrigation. The share of poor and food insecure in the study area was found to be lower among treated households (20%) than among control households (30%). Furthermore, it was shown that expansion of small-scale irrigation can be an important strategy to increase income, build-up assets, increase total expenditure, and spend more income on improved agricultural technologies. The Rosenbaum test found the PSM estimates to be insensitive for unobserved heterogeneities. Thus, since the effect of small-scale irrigation on most of the livelihood indices was found to be positive, investing in such irrigation schemes seems to be an appropriate developmental policy of the government. However, as we can learn from previous studies, the adoption rate of small scale irrigation has remained low. As a result, we conclude that local institutions should be technically and financially empowered, and social and physical services should also be expanded to rural areas to arouse farm households to adopt small scale irrigation.

Nevertheless, the focus of the study was exclusively on the positive effects of small-scale irrigation but didn't consider the negative effects. Costs (initial and operation) that can adversely affect the positive effects were not investigated. In the past empirical studies, however, have already indicated several negative effects of small-scale irrigation. For example, some studies in Ethiopia, Mauritania, Namibia, South Africa and Zimbabwe (Makombe and Sampath, 1999; Kamara *et al*., 2002; Fiebiger *et al*., 2010; Comas *et al*., 2012; Ulsido *et al*. 2013; Ulsido and Alemu 2014) indicated a negative return of smallholder irrigated farming due to high construction cost and limited output markets. The studies also found adverse environmental effects of small-scale irrigation including soil salinity, soil acidity and water logging along with increases in some communicable and non-communicable diseases. This implies that there is a possibility that the positive effects of the small-scale irrigation can be offset by the negative effects. Therefore, this study suggests the following points for further investigation (1) looking at the negative effects on the environment and health, for example, death, malaria, salinity, and water logging (2) conducting an economic (cost-benefit) feasibility analysis (3) assessing the water use efficiency and management of small scale irrigation schemes. In that way, the overall net effects of small-scale irrigation on the economy in general and the households in particular could be estimated.

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NOTES

[1] In an experimental framework, treatment can be based on random assignment while, in an observational framework, treatment is based on self-evaluation or self-selection.

[2] Access to information from different sources such as TV, mobile, radio or other media. Since access to information improves awareness and motivates farmers to adopt technological innovation, we assigned 1 for farm households who have access to alternative information sources and 0 otherwise.

[3] Distance to rural services represent the average distance to various social and physical infrastructure services such as primary schools, health centres, veterinary clinics, bank offices, post offices and telephone booths.

[4] Rural associations refer to local institutions such as peasant associations, women's associations, cooperative societies, political groups, youth associations and informal groups. These associations can enhance farmers' awareness and understanding of technological innovation and other issues. Accordingly, this study assigned 1 for households who were members of rural associations before they started the irrigation and 0 otherwise.

[5] TLU (tropical livestock unit) is an international measurement unit for animal resources. 1 TLU equals 1 camel, 0.7 cow, 0.8 ox, 0.1 sheep/goat, 0.5 donkey, 0.45 heifer/bull, 0.7 mule/ horse, 0.2 bee colonies or 0.01 chickens (Randela *et al*., 2000).

[6] The farmland in Ethiopia is customary measured by *tsimad*, where thestandard conversion factor is four *tsimad* to approximately 1 ha.

[7] Adult equivalence scale captures the age and sex-based difference in earning and consuming capacities of the farm households. This is computed as an adult male and female (15–60 years) is assigned 1; male above 60 years is 0.67; female above 60 years 0.60; child (10–14 years) is 0.50; child (4–9 years) is 0.30 and children below 3 years are economically insignificant (Randela *et al*., 2000).

[8] Internationally, people who earn less than 1.25 US$ day^{-1} are considered poor and food insecure. Accordingly, this study puts in the poor category those households who earned less than 16.5 birr day^{-1} during the survey period (the official exchange rate: 1 US$ = 13.2 birr).

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APPENDIX A. MATCHING ALGORITHMS

Nearest neighbour estimator (NNE)

The control and treatment subjects are randomly ordered and then the treated subject is selected along with a control subject with a propensity score closest in value to it. It is a minimization process of the absolute difference between the estimated propensity scores for the control and treatment groups (Khandker *et al.*, 2010). Given the condition that $C(i) = Min_j \left| P_i - P_j \right|$ and $\omega_{ij} = \frac{1}{N_i^c} if\, j\varepsilon C(i) \&\ \omega_{ij} = 0 Otherwise$

$$ATT_{NNE} = \frac{1}{N^T} \sum_{i\varepsilon T} \left[Y_i^T - \sum_{j\varepsilon C(i)} \omega_{ij} Y_j^C \right]$$

where $C(i)$ represents the group of the control subjects j matched to treated subjects i (on the estimated propensity score); P_i is the estimated propensity score for the treated subjects i; and P_j is the estimated propensity score for the control subjects j.

Radius matching estimator (RME)

Every treated subject is matched with a corresponding control subject that is within a predefined interval of the treatment subject's propensity score. It imposes a tolerance level on the maximum propensity score distance. The recommended radius size equals $0.25\delta P$ (one-quarter of the standard error of the estimated propensity) (UNDP, 2009).

$$\text{If } C(i) = \left\{P / \left|P_i - P_j\right| < r\right\} \text{ and}$$

$$\omega_{ij} = \frac{1}{N_i^C}\, if\, j\varepsilon\, C(i)\; and \quad \omega_{ij} = 0, otherwise \text{, then}$$

$$ATT_{RME} = \frac{1}{N^T}\sum_{i\varepsilon T}\left[Y_i^T - \sum_{j\varepsilon C(i)} \omega_{ij} Y_j^C\right]$$

Stratification matching estimator (SME)

It divides the data (the common support of propensity score) into five strata because this can remove 95% of the bias associated with covariates. The impact (ATT) is the mean outcome difference between the treated and control group of each stratum and is estimated as below. AD_q^S is the average difference of block q; $I(q)$ is the set of units in block q; and N_q^T and N_q^C are the number of treated and control units in block q. The estimator of ATT is computed as the average of the AD of each block (Stern *et al.*, 2012).

$$ATT_{SME} = \sum_{q=1}^{Q} AD_q^S \frac{\sum_{i\varepsilon I(q)} D_i}{\sum_{\forall i} D_i} \quad where \; AD_q^s = \frac{\sum_{i\varepsilon I(q)} Y_i^T}{N_q^T} - \frac{\sum_{j\varepsilon I} Y_j^C}{N_q^C} \tag{10}$$

Kernel matching estimator (KME)

It uses a weighted average of all individuals in the comparison group to make the counterfactual effect. The weights are calculated based on the distance between each individual from the comparison group and the treated observation of which the counterfactual is estimated. The kernel matching ATT estimator is given below. $G(.)$ is a kernel function and h_n is a bandwidth parameter. The choice of the bandwidth parameter is important because it defines the fitness of the model or the outcome value. The variance and the bias of the estimation should be considered at the same time as choosing the bandwidth parameter (Caliendo and Kopenig, 2008; Khandker *et al.*, 2010).

$$ATT_{KME} = \frac{1}{N^T}\sum_{i=\varepsilon T}\left\{Y_i^T - \frac{\sum_{j\varepsilon C} Y_j^C G\left(\frac{P_j - P_i}{h_n}\right)}{\sum_{k\varepsilon C} G\left(\frac{P_k - P_i}{h_n}\right)}\right\}$$

APPENDIX B. STANDARDIZED MEAN DIFFERENCE AND SENSITIVITY ANALYSIS

Table B1 Covariates and p-score balancing statistic report (standardized mean difference)

Variable	Mean treated	Mean control	% bias	p-value
Male household head	0.71	0.68	8.0	0.468
Married proportion	1.47	1.49	−4.8	0.690
Household age	44.74	45.21	−2.8	0.769
Household size	6.78	6.99	−6.9	0.536
Literate household head	0.51	0.50	2.3	0.813
Membership in rural association	0.81	0.79	7.6	0.391
Access to financial credits	0.64	0.80	−19.6	0.046
Landholding size	2.71	2.62	5.0	0.673
Distance to district markets	103.08	98.89	6.9	0.535
Access to information sources	0.70	0.69	−1.6	0.883
Distance to rural services	74.11	73.55	2.1	0.850
Distance to all-weather roads	24.07	23.56	2.1	0.856
Distance to farmers' training centres	64.81	62.79	7.8	0.481

Table B2. Rosenbaum sensitivity analysis test for Wilcoxon signed rank *p*-value (upper and lower bound significance selection effect)

Outcome variables	Gamma value	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80
Livestock density	Positive	0.004	0.010	0.025	0.031	0.045	0.051	0.065	0.086	0.180
	Negative	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Income earning	Positive	0.001	0.005	0.019	0.023	0.036	0.041	0.048	0.061	0.065
	Negative	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Food consumption	Positive	0.001	0.015	0.024	0.034	0.041	0.049	0.057	0.078	0.092
	Negative	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Total expenditure	Positive	0.001	0.016	0.017	0.020	0.029	0.038	0.047	0.056	0.071
	Negative	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.006	0.006
Schools and health expenditure	Positive	0.011	0.011	0.027	0.031	0.042	0.050	0.055	0.063	0.070
	negative	0.011	0.017	0.018	0.010	0.027	0.045	0.045	0.051	0.063
Improved input expense	Positive	0.006	0.007	0.018	0.029	0.034	0.044	0.049	0.059	0.067
	Negative	0.006	0.007	0.007	0.007	0.008	0.009	0.024	0.035	0.041
Asset holdings	Positive	0.000	0.006	0.006	0.012	0.019	0.031	0.037	0.046	0.073
	Negative	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Gamma is log odds of differential assignment to treatment due to unobserved factors.