Impact of modern irrigation on household production and welfare outcomes: Evidence from the PASIDP project in Ethiopia*

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Abstract

Irrigation systems have been shown to substantially improve farmers' productivity, and thus help alleviate poverty. Our study provides an example of such investment, the Participatory Small-Scale Irrigation Development Programme in Ethiopia. Combining a primary household survey with geographical data, we estimate the impact of the project on agricultural production and households expenditures using a novel identification strategy. Beneficiaries gain from the project through improved crop yields, which raise revenues, and allow switching from relying mainly consuming their own produce to purchasing greater amount of food from the market. Though we rule out that the project may have targeted farmers based on their agricultural performance, summary statistics indicate notable differences between beneficiaries and non-beneficiaries, an indication that the project might have systematically targeted farmers with certain attributes. Systematic targeting is often favored either to ensure the highest rate of success, or to deliver the project to those who may need it the most, but may limit the generalizability of the project in relation to any efforts to scaling up.

JEL Codes: O13, Q15, Q16

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1 Introduction

What are the returns to public investments in irrigation infrastructure systems? A number of studies have documented that public investments in agriculture, which have been designed and rolled-out to suit local conditions and contexts, may help increase agricultural productivity and resilience capacity of the same group (Asfaw et al., 2012; Azzarri et al., 2015; Minde et al., 2008; Duflo and Pande, 2007). Investment in irrigation facilities illustrates a special example of improving the agricultural performances of farmers in the developing world by raising productivity (Hussain and Hanjra, 2004). Although the returns to investments in irrigation can be potentially high, the World Bank (2007) reports that irrigation coverage in Sub-Saharan Africa (SSA) remains low (World Bank, 2007). Given the low level of irrigation coverage in SSA, a strong case could be made for investing in the expansion of investments in irrigation projects across SSA as a means of improving agricultural productivity, and thereby subsequently contributing to rural poverty alleviation (You et al., 2011).

The goal of this study is to assess the impact of the Participatory Small-Scale Irrigation Development Programme (PASIDP) in rural Ethiopia.[1] Within the context of irrigation systems in Ethiopia, previous studies have shown that irrigation contributes to increases in agricultural productivity, improve food security levels, and reduction in the dependency on food-for-work program participation (Amacher et al., 2004; Esrado, 2005; Van Den Berg and Ruben, 2006; Tesfaye et al., 2008; Bacha et al., 2011; Aseyehegu et al., 2012; Yami, 2013). While finding positive impacts of irrigation is evocative, these existing studies present a weak identification strategy, where the presence of a valid counterfactual to attribute the impact of the project on the outcomes of interest is questionable. This study aims to fill this gap in the literature and investigates the impact of a locally-adapted irrigation project (PASIDP), which was introduced in a participatory manner within the context of Ethiopia, by using a rigorous counterfactual-based estimation approach.

The PASIDP project focuses on developing small-scale modern irrigation schemes in drought-prone, food-deficit areas of Ethiopia.[2] Between 2008 and 2015, the project was mainly responsible for building new and upgrading existing small-scale irrigation schemes in several locations of Ethiopian highland and lowland zones. Our analysis uses primary household-level survey data from PASIDP beneficiary and non-PASIDP beneficiary households across 20 *kebeles* in four regions of Ethiopia.[3] Specifically, the study investigates whether such public investments in small-scale irrigation schemes can generate impacts on production (as measured by agricultural yields and revenues) and welfare of beneficiary households, with the latter being measured using household expenditure levels.

One key challenge of evaluating the impact of an irrigation project is the estimation bias due to the non-random placement of the project, and the self-selection of beneficiaries into receiving the project. The location of an irrigation scheme is likely to be correlated with geographical suitability, village or community characteristics, and pre-existing local conditions such as access to markets or roads. For instance, projects may be implemented in areas that are expected to perform strongly, such as in villages with good access to markets and roads, or may have targeted beneficiaries based on factors that indicate the highest need, such as villages or communities with high prevalence of poverty or drought. Self-selection into treatment is another common empirical problem when a project is introduced in a participatory manner. Specifically, PASIDP employed a participatory approach to promote community involvement, and required the formation of water user associations (WUA's) and the payment of subscription fees to be a member of the group. In this context, a household's participation in the project may be correlated with their underlying unobserved characteristics such as perceived expected returns of modern irrigation, which may simultaneously be linked with their outcomes such as yields or revenues.

Our data come from a primary household survey conducted in 2015. We supplement the household survey with observational data on geographical attributes. In the absence of a valid instrument (Duflo and Pande, 2007), or a regression discontinuity design (Lee and Lemieux, 2010) to assign households into each treatment status, we use a non-experimental design. We control directly for observable household-level characteristics and geographical attributes that might be correlated with the project's targeting strategy or the household's decision to participate in the project. To ensure that the treatment and the control groups in our sample are comparable, the identification strategy foresaw an extensive beneficiary mapping exercise of the households in all kebeles in our sample to establish a sampling frame and determine which households were using different forms of irrigation sources, and allocate them into mutually exclusive treatment and control groups.[4] We follow the multivalued treatment effects approach to estimate the impact of the PASIDP project on its beneficiaries (Cattaneo, 2010). This approach allows us to provide pairwise comparisons among the outcomes of PASIDP beneficiaries, those of who use traditional irrigation, and those of who rely mainly on rainfall. Moreover, it allows us to quantify the additional benefit of having access to modern irrigation relative to traditional forms. We supplement the multivalued treatment effects approach by using the instrumental variable (IV) approach to account for the endogenous nature of program placement.

We observe significant and positive effects on crop revenues and yields of PASIDP beneficiaries and households using traditional irrigation compared to the rainfed control group. Results provide evidence of positive effects of both modern and traditional irrigation schemes on crop yields and revenues, with estimated effects proving consistently positive across all crop yields and revenue quartiles. Households receiving benefits from the project and households using traditional irrigation also have lower values of crop consumption from their own production, but have higher levels of food expenditures compared to that of the households using rainfed agriculture. However, we find no significant impact of the project on expenditures of non-food items. Our IV results also exhibit qualitatively similar results, which help confirm the strength of our multivalued treatment effects results. Further, to ensure the robustness of our results, we perform a number of robustness checks to validate our estimates. Results from the robustness checks confirm that our estimates are robust according to several specifications tested.

There are at least three contributions of this study to the literature on rural agricultural development. First, empirical works using a rigorous impact evaluation methodology to estimate the impact of agricultural projects are small in number (Winters et al., 2011). This is particularly important for policy as international organizations including the World Bank and the Inter-American Development Bank (IDB) have also noted the limited number of counterfactual-based empirical studies evaluating the impact of agricultural projects, and thus any additional contributions to this literature would be beneficial for designing rural development policies (Inter-American Development Bank (IDB), 2010; World Bank, 2010). Our study contributes to a small but growing number of studies that adopt the non-experimental approach to account for the non-random placement of irrigation projects and selection into participation. Thus, this study complements the literature which documents the impact of infrastructure projects on agricultural outcomes (Jacoby, 2000; Jacoby and Minten, 2009; Duflo and Pande, 2007), especially on irrigation projects (Del Carpio et al., 2011; Dillon, 2011b,a).

Second, our findings provide evidence on the impact of an irrigation project on household welfare. Although empirical studies have found modern irrigation to have a positive impact on agriculture and poverty amongst small-scale farmers (Hussain and Hanjra, 2004; Lipton et al., 2003; Smith, 2004), most of these studies that assess the impact of irrigation investments do not contain either a control group or a random assignment of individuals or communities to receive irrigation projects. In the instances where the studies contain a counterfactual group to assess impact, Del Carpio et al. (2011) evaluate the impact of an irrigation rehabilitation project in Peru. They find that large landowners benefit from the project due to higher their income from land ownership. For small landowners, the benefit also includes increased agricultural production. Dillon (2011b) finds that households with access to irrigation have higher household expenditures than those of households without access to irrigation in Mali. Moreover, irrigation beneficiaries accumulate more assets in the form of livestock, and are more likely to share food with non-beneficiaries. However, existing studies in this literature provide limited evidence of the mechanisms through which having access to irrigation generate benefits to its beneficiaries. Our study contributes to this literature by testing directly for the channels through which irrigation can help households increase their total value of agricultural production and household consumption. Specifically, we test whether PASIDP beneficiaries have higher crop yields, use higher levels of cash inputs, cultivation area, or increase the number of crops grown per season.[5]

Finally, the empirical results from the analysis provide lessons on the project's implementation, which will serve as the basis for scaling up the project to similar geographical settings and targeted beneficiaries in the future.[6] This is particularly important in terms of policy, especially if the project is projected to be scaled up. If there is evidence of systematic targeting of projects, then the lessons drawn from the results of the analysis may suffer from external validity, and may limit the potential to inform the scalability of the project in the future.

The rest of this paper is organized as follows. In the next section, we outline the details of the PASIDP project, along with the conceptual framework related to the impact of the PASIDP project on agricultural production and household welfare. In Section 3, we present descriptive statistics of the households in our sample. In Section 4, we describe the identification strategy used to estimate the impact of the PASIDP project on household production and welfare outcomes. Section 5 presents the estimation results from the multivalued treatment effects approach. Section 6 reports the outcomes from a number of robustness checks, conducted in order to test the sensitivity of our results. Section 7 concludes the paper.

2 The PASIDP Project

2.1 Project Information

Ethiopia's geographical setting and climatic attributes contribute to a higher average amount of rainfall than the rest of SSA (Kassahun, 2007). However, its agricultural sector is constantly plagued by frequent drought and soil degradation (Matouš et al., 2013). These idiosyncratic shocks to agricultural production are closely linked to the persistence of poverty in rural Ethiopia. Low coverage of irrigation infrastructures also exacerbates the presence of poverty amongst rural farmers, especially among the poorest of the poor (Del Carpio et al., 2011; Escobal, 2005).

As part of Ethiopias second generation Poverty Reduction Strategy Paper (also referred to as the Plan for Accelerated and Sustainable Development to End Poverty: PASDEP), the PASIDP project was launched. The project received its main financial support (approximately 70% of the total cost) from the International Fund for Agricultural Development (IFAD) as a grant and a highly concessional loan. The remaining cost of the program was financed by the Government of Ethiopia (GoE), and by the beneficiary households through Water Users' Association (WUA) subscription fees. Ethiopia's Ministry of Agriculture and Natural Resources (MoANR) was the main implementation unit of the project, responsible for coordinating the project activities with the regional implementation institutions in the four regions covered by the project. The project was specifically designed to have the local WUA's be responsible for the construction, operation, and maintenance activities of the modern irrigation schemes. This is mainly to create a sense of ownership among the WUA members, incentivizing them to be more committed to maintaining the installed and upgraded facilities.

The PASIDP project was approved in 2008, and completed in 2015. During this time, approximately 121 irrigation schemes were constructed and the total land area under irrigation increased by more than 12,000 hectares. The activities implemented by the project reached more than 62,000 beneficiary households in four regions (Amhara, Oromia, SNNPR, and Tigray) of Ethiopia.[7] The project targeted mainly food-deficit, drought-prone, and densely populated woredas (or districts) covered under the Productive Safety Net Programme (PSNP), but are not covered by the Agricultural Growth Program (AGP). Figure 1 presents the locations of the irrigation facilities constructed and upgraded as part of the PASIDP project.

[Figure 1 around here]

In addition to its focus on irrigation scheme development, project activities also include institutional development (forming WUA's, training WUA leaders, providing technical and capacity strengthening activities to WUA members), and agricultural development (various training activities related to agricultural production), mainly through the WUA's.[8] While the analysis in this study focuses on the small-scale development component of the project interventions, we also account for the other two components of the project.

2.2 Conceptual Framework

The activities offered by the PASIDP project include irrigation infrastructure, institutional, and agricultural development interventions. The interventions are expected to help improving agricultural production and household consumption outcomes of the beneficiaries in the following order. First, the PASIDP project staff is mandated to help form the WUA within each community selected to receive the project activities. Second, WUA leaders and members receive capacity building and training activities from the project staff. Third, assuming that the capacity building and training activities perform well, PASIDP beneficiaries should have improved knowledge and information about agricultural production practices.[9] Finally, the irrigation schemes are built in the project communities, and WUA leaders and members receive the necessary training sessions to learn how to operate, maintain, and repair the irrigation schemes in their community.

A number of hypotheses may be formulated to test for the possible channels through which a well-functioning irrigation infrastructure system, coupled with the project activities provided to the WUA's and other capacity building and training interventions, may contribute to improving the well-being of its beneficiaries (Dillon, 2011b). Access to irrigation may help increase farmers' production by raising crop yields through greater and more stable supply of water for agriculture (Hussain and Hanjra, 2003, 2004). Irrigation also enables farmers to increase the use of other cash inputs complementary to irrigated water such as improved seeds, fertilizer, or pesticides (Evenson and Gollin, 2003), as well as expand the cropping area (Huang et al., 2006). It can also allow farmers to start growing market-oriented crops apart from traditional subsistence crops, which supports diversification of income sources (Binswanger and Von Braun, 1991; Smith, 2004). The literature has also noted other possible mechanisms, including reduced water scarcity due to improved water allocation (Prasad et al., 2006), increased market access (Gidwani, 2002), increased demand for labor resulting in higher wages (Narayanamoorthy and Deshpande, 2003; Von Braun, 1995), reduced seasonal price variation (Lipton et al., 2003), and increased risk diversification (Barrett et al., 2001).

In this study, we test for the evidence of impact on the following outcomes: crop yields (as measured by total output per land area), level of input use (as measured by the level of expenditures on cash inputs namely improved seeds, fertilizer, and pesticides), cultivation area (as measured by the total harvested area), and crop diversification (as measured by the number of crops grown in a season).[10] Unfortunately, due to data availability, we cannot explore other possible mechanisms which might be underlying the observed changes in outcomes mentioned in the previous paragraph, which is a limitation of our study.

3 Data and Setting

The dataset in this study comes from a dhousehold survey conducted by the Ethiopian Institute of Agricultural Research (EIAR). The full sample consists of 1,531 households in 20 kebeles and four regions of Ethiopia. Primary data collection took place between March and May 2015. To calculate the sample size required for the analysis, we set the parameters at 95% confidence level, with a 0.03 precision level, and computed the final sample with probability proportional to the total population size of the 20 kebeles (Yamane, 1967).

Given the lack of sufficient project information, a number of qualitative interviews mainly key-informant interviews (KII's) were conducted in rural Ethiopia in PASIDP project areas to gain additional knowledge about the project implementation. Our information suggests that modern irrigation users (direct PASIDP beneficiaries) are mainly farmers whose agricultural plots are located within the command area of an irrigation scheme, while traditional irrigation users and those who rely on rainfall agriculture are those with the plots outside the command area. Land ownership in Ethiopia is centrally allocated to the households by the government, and formal land transactions are prohibited. In our sample, most of the households in the sample had been assigned the land long before the start of the project.

Our qualitative information suggested that the agricultural setting in each kebele is relatively similar across the villages in the same kebele. The homogeneous characteristics include farm size (mostly small farms), agricultural production (main crops cultivated), agro-climatic conditions (vegetation index, rainfall, and precipitation), and distance to markets and paved roads. As a result, it is reasonable to select the comparison or control group from another kebele may not be appropriate in our setting since the conditions facing farmers may be significantly different.

The household survey used a two-stage stratified sampling approach to select in the households to be in the sample as part of the data collection activities. In the first stage, kebeles with completed and functioning PASIDP irrigation schemes were selected from the full list of all PASIDP irrigation schemes at the time of survey. In the second stage, a beneficiary mapping exercise was conducted to obtain the numbers of households in each kebele using each source of irrigation (modern irrigation, traditional irrigation, and rainfed agriculture). Then, proportional sampling was conducted based on the total number of households using each irrigation source in each kebele.

[Table 1 around here]

In our full sample, there are 766 PASIDP modern irrigation households (50.0%), 438 traditional irrigation households (28.6%), and 327 rainfed agriculture households (21.3%).[11] In Table 1, we report the number of households sampled from each kebele based on their source of irrigation. It is worth noting that the number of households in the sample from Oromia and SNNPR are small (representing only 8.5% and 9.6%

of the full sample). This is because there were smaller number of functioning irrigation schemes in both regions relative to those of Amhara and Tigray at the time of our survey. The survey collected detailed household-level characteristics, demographic information, socio-economic status, agricultural production from the current crop year (February 2014- January 2015), and the previous crop year (February 2013- January 2014). In addition, the survey asked the households to report their asset ownership back to five years preceding the time of the survey to use as baseline information.[12]

[Table 2 around here]

Table 2 reports basic household-level characteristics of the households in our sample. The heads of households using traditional irrigation are more likely to be male compared to the households in the other two groups. However, they seem to be similar in terms of age and education level across all three groups. Households using traditional irrigation have larger family size than those in the other two groups on average. While households in the three groups are similar in terms of asset ownership at baseline (using recalled information), their ownership of productive assets at baseline exhibits statistical difference. Households with PASIDP irrigation are located at lower elevation than households in the other two groups. They receive lower precipitation than households under traditional irrigation but similar precipitation to households using rainfed agriculture. They have slightly larger land holding than households using traditional irrigation, but similar to that of rainfed agriculture households. Finally, on average they spend less time traveling to the nearest market than households under rainfed agriculture, but more time than households using traditional irrigation.

[Table 3 around here]

In terms of outcome variables, our analysis separates outcomes into intermediate outcomes (production decision and input use), and final outcomes (value of crop production and household expenditures). For the intermediate outcomes as reported in Table 3 Panel A, households using both PASIDP or traditional irrigation have higher average crop yields than households relying on rainfed agriculture. During the current crop year, households in all three groups allocate similar areas to crop cultivation and growing similar number of crops. PASIDP and traditional irrigation users have higher farm inputs expenditures on improved seeds and pesticide than households under rainfed agriculture, but there is no significant difference in terms of fertilizer investments across the households in all three groups. The main types of crop grown by the households in our sample are teff, wheat, maize, barley, sorghum. Some households grow root crops, vegetable, or fruits as well apart from the main staple crops. We present some additional summary statistics of crop yields (broken down by crop types) in Table 11 in Appendix A.

Summary statistics provide considerable differences in the final outcomes for the households across the three groups, as presented in Table 3 Panel B. The total value of crop production (both sold and consumed by the household) for PASIDP households are higher than that of the households in the other two groups. However, there is no significant difference in terms of total value of crop production between households using traditional irrigation and rainfed agriculture. When specifically considering total crop revenue, PASIDP irrigation users earn significantly higher than households in the other two groups. On the other hand, the value of crop consumed from own production is higher for households under rainfed agriculture. Regarding household expenditures, PASIDP irrigation users have higher expenditures on food than households in the other two groups. However, households in all three groups have similar levels in terms of total household expenditures, and expenditures on non-food items.

The statistics of the three groups in our sample based on their treatment status reported in Tables 2-4 exhibit considerable systematically significant differences. In particular, on average households in each treatment status are different in terms of asset ownership and geographical attributes. Without a real baseline dataset to control for pre-existing household attributes, the extent to which the treatment effects estimates would achieve internal validity may be limited. Therefore, we acknowledge that the results obtained in the analysis need to be interpreted with caution. Further, these differences in the characteristics of the households might imply systematic targeting of the project implementation. If systematic targeting were present, then any attempt to draw lessons from the analysis of this project as the basis to scale up the activities implemented in this project may have to be considered carefully. Similar to several other impact evaluation exercises conducted ex-post, the limited amount of documentation about the project details prevents researchers from ruling out the possibility of systematic targeting due to the implementation of the project.

4 Identification Strategy

4.1 Construction of Counterfactual

Central to establishing a valid counterfactual is the similar characteristics of the treatment and the control groups,s and the similar conditions faced by both groups before the project had taken place. Given the nature of study which is an ex-post impact evaluation using cross-sectional data, a direct test of such similarities between the treatment and the control groups is not possible. While, the household-level descriptive statistics presented in Table 2 indicate that there is some evidence that the characteristics of the households across three groups are statistically significant, several necessary steps are necessary to ensure that the three groups of household in our sample (PASIDP irrigation, traditional irrigation, and rainfed agriculture) are as similar as possible in terms of household-level characteristics and agro-climatic conditions.

First, an extensive beneficiary mapping exercise in the form of a reconnaissance survey was conducted to gather information about poverty level, agricultural production system, agro-ecological zone, and source of irrigation of the households within the 20 kebeles in our sample. Second, our sample was selected to ensure that households belonging in each treatment status are similar in terms of poverty levels, agro-climatic conditions, and agricultural production system. The sample selection is based on extensive interview consultations with project officials and focal persons from the project management unit (PMU) and the development agent (DA) office both at the kebele level and at the woreda level.

Much as we attempt to construct the counterfactual to control for selection on observable attributes and ensure sizable common support between the households in all treatment levels, we still need to make a number of critical assumptions, which are crucial for our identification strategy. First, while we account for selection on observables by controlling for a number of observed characteristics that may affect the participation into treatment, we cannot rule out the possibility that there may be some unobserved characteristics that might bias our results. Second, we cannot rule out the possibility of spillovers from PASIDP irrigation users to traditional irrigation users. As a result, our estimates provide of the impact of the PASIDP project may underestimate the true effect of the project. Third, we do not have information about the functionality of the irrigation schemes or the intensity of treatment due to the project. Therefore, we are unable to account for differential treatment intensity that households in each kebele. Fourth, we cannot directly test for the presence of pre-existing conditions that may drive the heterogeneity of treatment effects. However, we believe that by providing the estimates of both the conditional means and quartiles of the potential outcome distribution for both estimators, we can shed some light about the potential heterogeneity of treatment effects due to the PASIDP-supported irrigation schemes.

4.2 Multivalued Treatment Effects

Given the setup of our survey, which classifies households in the sample into three categories based on their source of irrigation (modern irrigation, traditional irrigation, and rainfed agriculture), we follow the multivalued treatment effects approach by Cattaneo (2010) to estimate the effects of investments in small-scale irrigation schemes due to the PASIDP project. This method allows researchers to estimate the treatment effects when there are more than two levels of treatment among the individuals in the sample. Further, it allows researchers to compare the treatment effects of the project on outcomes between each pair of treatment level. In our setting, our estimation strategy allows us to estimate the additional benefit of having access to modern agriculture (the PASIDP project) on top of having access to just traditional irrigation.

We follow the description of the identification strategy in Azzarri et al. (2015), which describes the estimation of the multivalued treatment effects (Cattaneo, 2010). As the first step, we construct the conditional probability model to predict the likelihood of households i ($i = 1, ..., N$) being in each treatment level ω according to their irrigation status (source of irrigation: 0 if rainfed agriculture, 1 if traditional irrigation, and 2 if PASIDP irrigation). Thus, we can write down this likelihood function as follows:

$$T(\omega) = \begin{cases} 1 & \text{if } \mathbf{\Gamma}'_{\boldsymbol{\omega}}\boldsymbol{Z} + \boldsymbol{\epsilon}, \\ 0 & \text{if otherwise,} \end{cases} \tag{1}$$

where $\omega = 0, 1, 2$, $\boldsymbol{Z}$ is an $n \times m$ matrix of household attributes where there are $m (m = 1, ..., M)$ attributes, and $\boldsymbol{\epsilon}$ is the error term. If we assume that the error term $\boldsymbol{\epsilon}$ is i.i.d. and follows the logistic distribution, we can use the multinomial logit model to estimate the probability that household i is in treatment level ω according to the following model:

$$P(W = \omega|\mathbf{Z}) = P(\omega) = \frac{exp(\mathbf{\Gamma}'_{\boldsymbol{\omega}}\boldsymbol{Z})}{1 + \Sigma_{j=1}^{2}\mathbf{\Gamma}'_{\boldsymbol{j}}\boldsymbol{Z}}, \tag{2}$$

where $1, 2, W$ represents the indicator of treatment status, and $\boldsymbol{Z}$ is the matrix containing household-level covariates. Note that according to this specification, we assume that selection is largely based on observable characteristics of the households, and that there is sizable common support between the conditional probability densities of the households in all treatment levels.

Similar to the traditional impact evaluation problem, we define our evaluation problem as a potential-outcome model with three levels of treatment. Suppose each household i receives water for their agricultural production from source ω, the potential-outcome model can be written as follows:

$$y_i = \Sigma_{\tau=o}^{2} T_i(\omega) y_i(\omega) \tag{3}$$

where ω indicates the treatment level that each household belongs to, $T_i(\omega)$ is a dummy variable indicating which is 1 when household i receives irrigation from source ω, and is equal to 0 otherwise, and $y_i(\omega)$ is the outcome of interest if the source of irrigation for household i is ω.

Using a linear specification, we can derive the potential outcome equation in the matrix notation from the potential outcome model as follows:

$$\boldsymbol{Y} = \boldsymbol{B}_{\boldsymbol{\omega}}^{'}\boldsymbol{X} + \boldsymbol{\epsilon}, \tag{4}$$

where $\boldsymbol{Y}$ is an $nx1$ column vector of outcomes of interest, and $\boldsymbol{X}$ is an nxk matrix of observed household-level characteristics which may contain some of the elements in $\boldsymbol{Z}$ where there are k characteristics ($k = 1, ..., K$). Given the potential outcome framework, we can write the vector $\boldsymbol{G_i} = (\omega, y(\omega), \boldsymbol{X})^{'}$ for each household i which assumes to be i.i.d. drawn from the matrix $\boldsymbol{G}$. Thus, we assume that the potential outcome of household i for each treatment level ω, denoted as $(y_i(0), y_i(1), y_i(2))^{'}$ is i.i.d. drawn from $(y(0), y(1), y(2))^{'}$.

Adopting the two-step generalized method of moments approach, Cattaneo (2010) two estimators of the multivalued treatment effects: inverse probability weighting (IPW) and efficient-influence function (EIF). In the first step, both of these estimators estimate the generalized propensity scores. Then in the second stage, they calculate the inverse probability weights to recover the parameter estimates for the potential outcome model in Equation (4). A notable difference between the IPW and EIF estimators is that while the IPW estimator models the assignment of treatment following Equation (1), the EIF estimator includes an augmentation term in the potential outcome model to account for the fact that the model may be specified incorrectly. As a result, the EIF estimator contains the doubly-robust qualification that will yield consistent treatment effects estimates if the model is specified correctly (Cattaneo, 2010; Tan, 2010). In this study, we present two sets of results from both estimators for comparison purposes.

4.3 IV Estimate

As mentioned earlier in the introduction section of this paper, a key challenge in evaluating the impact of an irrigation project is placement bias. That is, the presence of the project might be correlated with the certain unobservable characteristics unknown to the researcher, which might lead to the endogenous placement of the irrigation scheme. For example, the project implementers may choose to place the project in areas where the project has the potential to become successful because there implementation capacity of the local institution is strong. As a result, we instrument for the treatment status of the project by using the membership size of the local WUA in the kebele. The larger size of the WUA membership may mean that the WUA in the community can take advantage of higher amount of fees and labor supply from the WUA members to contribute to the operation and maintenance activities of the irrigation scheme.

To qualify as a valid instrument, the size of the WUA membership must satisfy the exclusion restriction. We argue that using the size of the WUA membership to instrument for the treatment status is reasonable because it is determined by the number of farmers who have plots inside the command area, and the size of the command area is usually determined by the flow of water according to the analyses carried out by water engineers. Therefore, it is unlikely that the size of the WUA membership would be correlated with the outcome variables (i.e. crop yields, crop revenues, or household consumption). As a result, we argue that the only channel through which the size of the WUA membership can affect outcome is only through treatment.

5 Results

5.1 Multivalued Treatment Effects Results

As the first step to estimate the impact of the PASIDP project, we construct the conditional probability model to estimate the likelihood that each household would be in each treatment level (PASIDP irrigation, traditional irrigation, or rainfed agriculture). In our specification, the full list of covariates to predict treatment status includes gender, age, and education level of the household head, household size, asset indices as proxies for wealth (durable items, livestock, farm equipment), elevation, average precipitation, size of land ownership, and time to the nearest market town.

[Figures 2-4 around here]

Figures 2-4 report the conditional probabilities of households being in each treatment level. The estimation results in all three figures illustrate that there exists for considerable common support for the households in all three groups across all treatment levels, even though the level of common support is slightly lower for the likelihood of households using traditional irrigation. Busso et al. (2014) emphasize that if the estimated density contains considerable mass near the values 0 or 1, then under finite sample the IPW and EIF estimators may not perform well. This set of results helps us confirm that there is not much high-density mass at both ends of the distribution across all three treatment levels. Thus, the results show that the three groups in our sample are comparable based on a number of observable characteristics. However, there still can be a number of other characteristics that might have led to selection into receiving irrigation. For example, the geographical suitability of installing irrigation facilities, and the implementation capacity of the local institutions may have led to differential treatment status. Therefore, we cannot rule out the likelihood that there can still be other unobserved characteristics that could have affected the participation in the project.

In the second step, we estimate the conditional means and quartiles of the outcomes of interests (both intermediate and final outcomes) using both EIF and IPW estimators.[13] Further, we calculate the pair-wise comparisons of the estimated parameters of the conditional means and quartiles, which represent the average and quartile treatment effects estimates of the PASIDP project relative to households using traditional irrigation and rainfed agriculture.

We report both the EIF and IPW estimates of the average and quartile treatment effects in Tables 5-8. We also present the 95% confidence intervals from bootstrapped standard errors with 500 repetitions. The treatment effects estimates are considered to be statistically significant at the 0.05 level if the associated 95% confidence interval does not contain the value 0. To investigate the size of the average and quartile treatment effects, we calculate the exponential values of the pairwise differences of the potential outcomes between two treatment levels. The exponential values of the pairwise differences denote the changes (in levels) in the outcomes of interest with respect to the change in treatment status (going from one treatment level to another). Overall, we find that our results from EIF and IPW estimators are qualitatively similar, which confirm that the results we obtain are robust and our models are specified correctly. Thus, all our references to the changes in levels will only refer to the pairwise differences from the EIF estimators.

[Table 4 around here]

In Tables 4 and 5, we illustrate the results for the intermediate outcomes due to the PASIDP project. Table 4 reveals that the average and quartile treatment effects for farm input investments namely improved seeds, fertilizer, and pesticide are consistently insignificant across different quartiles for both estimators. One possible explanation for the insignificant result of the investments in farm inputs is that scarcity of farm inputs available in the market in rural areas of Ethiopia.

[Table 5 around here]

Next, in Table 5, we examine the impact of the project on three other intermediate outcomes: average yield, total cultivation area, and the number of crops grown. We observe positive and significant impact of the project on crop yield (average of all crops across the growing season) at the 95% confidence level. In Column 1, the average crop yield of PASIDP irrigation and traditional irrigation households is statistically higher by factors of 1.97 and 1.19 at the 0.05 level when comparing to rainfed agriculture households. However, we do not observe significant impacts on the total cultivation area, which is not surprising for our context since the arable land area is limited for farmers in our sample. We also do not observe that farmers using either PASIDP or traditional irrigation grow more types of crops than farmers under rainfed agriculture. Thus, the fact that we find significant impact of the project on crop yield but not on the number of crops grown suggests that the irrigation schemes help farmers increase their productivity, but not necessarily allow them to grow more types of crop within the same season. Based on our anecdotal evidence, the presence of the project does not only supply farmers with greater access to water, but also guarantees them with the access to water at the right timing according to their cultivation schedule.

[Table 6 around here]

Table 6 reports the average and quantile treatment effects of the project on household expenditures outcomes. We do not find significant impact of the project on total household spending. On the other hand, when considering only expenditures on food items (based on a seven-day recalled period), PASIDP beneficiaries on average have higher food expenditures relative to rainfed households by factors of 1.25, which are both statistically significant at the 0.05 level. Specifically at the 0.75th quantile, households using PASIDP irrigation spend more on food relative to rainfed households by a factor of 1.51. However, we do not find that household using traditional irrigation on average have higher expenditures than households using rainfed agriculture. The point estimates of the project on non-food expenditures are not consistently significant when using EIF and IPW estimators, and are not consistently significant across different quantiles. Thus, we cannot conclude that the project resulted in a significant increase in household expenditures on non-food items among its beneficiaries.

[Table 7 around here]

The treatment effects estimates on the value of crop production can be found in Table 7. Relative to households under rainfed agriculture, the value of total crop production (both sold and self-consumed combined) among PASIDP beneficiaries is significantly higher by a factor of 1.54, while among the traditional irrigation users the effect is higher by a factor of 1.13, both of which are statistically significant at the 0.05 level (Table 7, Column 1). When considering only the crop revenue from sales, households using PASIDP irrigation earn higher crop revenue than rainfed households by a factor of 2.10, and households using traditional irrigation earn higher by a factor of 1.30 (Table 7, Column 2). Also, we find that the value of crop consumption from own production among the households significantly decreases by factors of 1.33 and 1.57 among the PASIDP beneficiaries relative to the households using traditional irrigation and households under rainfed agriculture.

5.2 IV Results

To supplement our results from the multivalued treatment effects approach, we adopt the IV approach to control directly for the potential endogenous project placement. By using the size of the WUA membership in each kebele to predict the treatment status of the households in our sample, we assume that households that have access to modern irrigation under the PASIDP project in areas where the command area is larger is more likely to experience a strong impact of the project. The first-stage regressions for the specifications presented in Table 8 can be found in Table 12 of Appendix B, which helps confirm that our IV

We present the results from the IV estimates in Table 8, which are qualitative similar to our main results. Specifically, relative to households under rainfed agriculture, household using PASIDP and traditional irrigation have significantly higher crop yields, crop revenues, and per capital food expenditures by 1.084, 2.597, and 0.858 times. The Kleibergen-Paap F-statistics of the estimates reported in Table 8 are 118.649, 118.649, and 114.870, which indicate that the size of maximal relative bias is lower than 10% when compared to the Stock-Yogo weak identification critical values, which helps to ensure that our results do not suffer from bias due to a weak instrument. The statistical significance of the instrument (WUA membership size) helps guarantee that the first-stage regressions can accurately predict the treatment status. As alternative specifications, we present the pairwise IV results (PASIDP vs. traditional, PASIDP vs. rainfed, and traditional vs. rainfed), along with their first-stage regressions in Tables 13 and 14 of Appendix B.

6 Robustness Checks

While finding positive and significant impacts of PASIDP project on its beneficiaries is evocative, there could be a number of reasons that our results may be biased due to possible confounding factors. In this section, we provide two robustness checks for these confounding factors. First, individual unobserved characteristics among the farmers with high (such as outside options) and low (such as ability) agricultural performance may drive the results due to possible targeting strategy of the project implementation. We explore this possibility by removing households with the highest 5% and the lowest 5% in terms of productivity levels within each kebele in our sample and re-estimate the multivalued treatment effects model. Second, we test for the possibility that our results might be contingent on the method we use. Thus, we compare our results from the multivalued treatment effects approach to the results from the more standard matching estimation approach. Note that the results presented in this section are only for the final outcomes (household expenditures and value of crop production).

6.1 Individual Unobserved heterogeneity

One source of concern for the results showing positive and significant impact of the PASIDP project may be driven largely by specific targeting rules of the project. On the one hand, the project might have specifically targeted high-performing farmers to achieve the highest possible impact of the project. On the other hand, it might have targeted low-performing farmers who may benefit from the project the most. Either possibility may limit the generalizability of the project outcomes, and any attempt to scale up the project should be considered with caution (Bandiera and Rasul, 2006; Liverpool-Tasie and Winter-Nelson, 2012).

Since there is insufficient information about the implementation procedure of the project, we use the average crop yield (as measured in kilograms of output per hectare) as a measure of agricultural performance. To test for potential targeting of the project based on agricultural performance which may drive the results and limit the external validity of the project, we exclude farmers who belong to the highest 5% and the lowest 5% in terms of average yields within each kebele from our matched sample[14]. We report the results from these estimates in Tables 15 and 16 of Appendix B. Results from this smaller sample still show positive and significant impact of the project on food expenditures and crop revenues among the households using PASIDP irrigation and traditional irrigation (Table 15, Column 3 and Table 16, Column 3). Thus, we may rule out the concern that the project may have targeted households specifically in terms of agricultural performance, which may drive the results we obtained earlier in Section 5.

6.2 Alternative estimation methods

Another concern which might arise from our empirical approach is whether the positive and significant results of the PASIDP project might be method-driven. To rule out such concern, we compare our main results against two other estimators: inverse probability weighting (IPW) and inverse probability weighting with regression adjustment (IPWRA) estimators after conducting propensity score matching as the first step. IPWRA estimators are considered to be "doubly-robust" for it allows greater flexibility of the model being incorrectly specified (Wooldridge, 2007, 2010).[15]

[Tables 9 and 10 around here]

The results from the traditional matching approach using IPW and IPWRA estimators are presented in Tables 9 and 10. In Column 4 of Table 9, our results indicate that both households using PASIDP and traditional irrigation have higher expenditures on food relative to those of households under rainfed agriculture. Similarly to our main results, Column 4 of Table 10 also reports that comparing to households under rainfed agriculture, PASIDP irrigation households and traditional irrigation households earn higher crop revenues. These two sets of results help us verify that our results are robust across different estimation approaches and communicate consistent findings.

Although the results from the matching method indicate significant and positive impacts of the PASIDP project on average crop yields, crop revenues, and food expenditures among the project beneficiaries, there may still be estimation biases due to any unobservable characteristics at the household level or at the community level. For example, some households may have access to agricultural plots with favorable soil quality while other households may not. Thus, households whose plots contain greater soil quality tend to have greater productivity levels.[16] Similarly, some communities may receive greater exposure to agricultural extension services, which allow them to take advantage of the knowledge provided by the extension agents to increase their agricultural productivity, resulting in higher crop revenues.

We test for the extent to which our estimates may be biased due to the underlying observable characteristics using the Rosenbaum bounds method (Rosenbaum, 2002). By increasing the magnitude of hidden bias, γ, the Rosenbaum bounds report the robustness of the estimates from matching due to unobservable characteristics at various levels of increases in the effect of unobservable characteristics. Table 17 in Appendix B reports the upper bound significance of the Rosenbaum bounds estimates for the results in Tables 9 and 10 by increasing the magnitude of γ up to double, which is considered a high threshold of robustness of results (Aakvik, 2001; DiPrete and Gangl, 2004; Caliendo and Kopeinig, 2008; Dillon, 2011b). The results comparing households receiving PASIDP irrigation and rainfed agriculture are robust for average yields and crop revenues, but are robust to only a 40% increase in γ for per capital food expenditures, a finding similar to one found in (Dillon, 2011a). With regards to the matching results comparing households under PASIDP irrigation and traditional irrigation, the Rosenbaum bounds indicate our results are robust to a certain extent: at least 20% for average yields, and at least 10% for crop revenues and per capita food expenditures.[17] One possible explanation of the Rosenbaum bound results for the comparison between PASIDP and traditional irrigation is treatment heterogeneity in our sample. Two possible sources of treatment heterogeneity may arise in the context of the PASIDP project. First, it is likely that the performance of the irrigation schemes may vary across locations due to differential local capacity to operate and maintain the irrigation schemes. And second, the length of time since the irrigation schemes became operational may indicate the extent to which the WUA members have learned to operate and maintain the irrigation schemes more efficiently over time. However, we do not have reliable data about the functionality or the completion date of the irrigation schemes to control directly for these two possible sources of heterogeneity. Dillon (2011a) also notes a similar explanation for the limited robustness of his findings for some of the outcome variables in his study of an irrigation project in Mali.

7 Conclusion

Small-scale farmers in the developing world face multiple challenges that limit their opportunities to achieve higher agricultural productivity and improve their living conditions. One promising channel to help farmers attain more desirable agricultural outcomes is to increase their access to water, an important input for agricultural activities. Several existing studies have noted the positive and significant benefits of irrigation infrastructures on agriculture. However, the mechanisms through which the access to irrigation may correlate with the observed changes in outcomes are not well-documented. A study by Lipton et al. (2003) provides detailed explanations of several channels through which irrigation may generate benefits to those who have access to it.

Our study also contributes to the growing need of rigorously-conducted impact evaluations of agricultural-related projects made by international financial institutions including the IDB and the World Bank (Inter-American Development Bank (IDB), 2010; World Bank, 2010; Winters et al., 2011). Specifically, our study adds to the small but growing number of counterfactual-based impact evaluations of an irrigation project (Del Carpio et al., 2011; Dillon, 2011b,a). The extent to which the lessons learned from the results documented in this study can be used as a basis to scale up the project might be limited if the project had systematically targeted its beneficiaries based on certain attributes.

Our results document significant impact of the PASIDP project, an irrigation development project taken place in Ethiopia between 2008 and 2015. Relative to households using rainfed agriculture for their crop production, we find that households using PASIDP and traditional irrigation on average have higher crop yields, but the effects are not significant on other intermediate outcomes including investments in farm inputs (improved seeds, fertilizer, and pesticide), size of cultivation area, or number of crops grown. Further, in terms of final outcomes, the effects are positive and significant mainly for crop revenue and household food expenditures, but PASIDP beneficiaries consumer lower values of crops from their own production. Apart from using the multivalued treatment effects approach to estimate the impact of the PASIDP project, our IV estimates also provide qualitatively similar results, illustrating significant impacts of the project. These results support the logical framework that an irrigation project may help farmers improve their well-being by raising their agricultural productivity. However, due to data limitation of a cross-sectional dataset, we are not able to control directly for any time-varying unobservable characteristics that may drive our results such as changing market conditions or agro-climatic factors.

The findings in this study are important for policy implications in at least two perspectives. First, while we have ruled out the possibility that the project targeted specifically more productive farmers, we cannot rule out that the project may have been designed to target selected local communities based on a number of observed attributes. If such targeting rule were true, it might hinder the generalizability of the results obtained from this study to advice future effort to scale-up the project in regions where pre-existing conditions are very different. Second, the sampling strategy of the household survey used in this study does not allow us to estimate spillovers due to the program. Due to the nature of the irrigation project, the presence of spillovers is highly likely. Estimating the presence of spillovers, when they exist, may help emphasize the additional benefits of an irrigation project beyond the benefits to its direct beneficiaries. Such finding may help motivate future research into the mechanisms through which an irrigation project may generate the additional impact to indirect beneficiaries, and highlight the need to collect supplementary data to help disentangle the true effect due to the project from the other impacts due to either targeting strategy or spillovers.

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Notes

[1]In this paper, we use the terms PASIDP irrigation and modern irrigation interchangeably to refer to the small-scale irrigation infrastructure systems supported by the PASIDP project.

[2]The PASIDP project also contains two other components: institutional development (through capacity building trainings of WUA leaders and members) and agricultural development (provision of extension services to smallholder households).

[3]A kebele (or historically known as a peasant association) is a local administration unit in Ethiopia, similar to a ward or a sub-district.

[4]The beneficiary mapping exercise was conducted in the form of a reconnaissance survey. More details about this beneficiary mapping exercise is provide in Section 3.

[5]Although our study tests for three possible mechanisms through which an irrigation project can contribute to changes in agricultural production and household consumption levels of its beneficiaries, we are aware that there may be other possible mechanisms that may help contribute to the changes in the outcomes as well. We acknowledge this limitation in our study, and we discuss in greater detail about the other possible mechanisms can be found in Section 2.2.

[6]The project is scheduled to be scaled up as the Participatory Small-scale Irrigation Development Programme Phase II (PASIDP II) starting from late 2016.

[7]Southern Nations, Nationalities, and Peoples' Region, Ethiopia

[8]The small-scale irrigation development component of the project takes up 68% of the total project budget. The agricultural development component takes up 17% of the total budget, and the institutional development component takes up 15% of the total budget.

[9]The capacity building and training activities offered by the PASIDP project include activities related to vegetable and fruit agronomy, integrated pest management (IPM), post-harvest loss prevention, seed multiplication, improved stove use, and home gardening.

[10]Our anecdotal evidence indicates due to cash constraints and limited storage space, it is unlikely that farmers would overinvest in the cash inputs for their farms in each growing season.

[11]The steps through which we undertake to arrive at the matched sample used in our analysis are described later in greater detail in Section 4.1.

[12]Without a true baseline dataset, we have to rely on recalled information to reconstruct baseline information. However, we acknowledge the limitation that recalled baseline information may suffer from measurement error due to memory and from perception bias due to the expectation of project performance.

[13]These results are not reported in the paper, but will be available upon request.

[14]These households account for 13% of the sample in our analysis.

[15]The results presented use the kernel option in the matching routine. We also use the five-nearest neighbor matching as the first step, and we obtain qualitatively similar results. The results are not presented here, but are available upon request.

[16]While we acknowledge that soil quality is an important determinant of agricultural productivity, this information is unavailable in our dataset. We acknowledge that this is a limitation of the study.

[17]The full set of Rosenbaum bound results are available upon request.

Tables

Table 1: Sample size by irrigation source

			Number of households			
Region	Woreda	Kebele	(1) PASIDP	(2) Traditional	(3) Rainfed	Total
Amhara	Sekela	Kevasa	31	44	11	86
	Jabi Tihnan	Jimmat Yenkonima	36	17	7	60
	Dangila	Gisa Kansen	67	16	0	83
	Guangua	Lunt Degera	17	37	30	84
	Guangua	Dangusa	31	40	0	71
	Kobo	07 (Abuarie)	96	13	7	116
	Kobo	03 (Amaya)	117	23	8	148
	Basona	Angolela	11	8	61	80
Oromia	Deder	Burka Golu	25	25	6	56
	Adola	Chenbe	11	8	6	25
	Oda Bultum	Galessa	6	3	13	22
	Munesssa	Damu Dimbiba	16	2	11	29
SNNPR	Demba Gofa	Tozha Sipe	43	4	8	55
	Meskan	Yetebo	27	31	33	91
Tigray	Enderta	Mahibere Genet	26	45	29	100
	Tselmti	Wudihet	25	15	50	90
	Ahiferom	Edaga Arbi	57	31	0	88
	Mereb Leke	May Weyni	28	24	10	62
	Adwa	Laely Lugumti	79	47	8	134
	Tanqua Abergelle	Negede Birhan	14	1	29	44
Total			766	438	327	1,531

Source: EIAR (2015)

Table 2: Household-level descriptive statistics

	Treatment status						
	(1) PASIDP	(2) Traditional	(3) Rainfed	Overall	(1) vs. (2)	(1) vs. (3)	(2) vs. (3)
Descriptive characteristics							
Gender of head (=1 if male)	0.868	0.934	0.887	0.891	***		**
Age of head (years)	45.132	45.342	44.037	44.958			
Education of head (years)	2.923	3.080	2.783	2.938			
Household size (head count)	5.570	5.957	5.517	5.669	***		***
Durable asset index (value)	0.491	0.441	0.528	0.484	***	***	***
Livestock asset index (value)	0.905	1.014	0.959	0.948	*		
Productive asset index (value)	1.907	2.005	1.935	1.941	*		
Elevation (km.)	1.790	1.916	1.928	1.856	***	***	
Mean precipitation (m./year)	1.016	1.107	0.987	1.036	***		***
Land holding (hectares)	1.131	1.035	1.070	1.091	**		
Time to market (min.)	108.943	101.167	118.413	108.741	*	*	***
N	766	438	327	1,531			

Source: EIAR (2015)

Note: Statistical significance at * < 0.1; ** < 0.5; *** < 0.01

Table 3: Household-level intermediate outcomes

	Treatment status						
	(1) PASIDP	(2) Traditional	(3) Rainfed	Overall	(1) vs. (2)	(1) vs. (3)	(2) vs. (3)
A. Intermediate outcomes							
Improved seed purchases (ETB)	432.503	297.196	120.932	327.246		***	***
Fertilizer purchases (ETB)	1,497.911	1,579.089	1,343.350	1,488.123			
Pesticide purchases (ETB)	126.375	106.879	34.099	101.089		***	***
Mean crop yield (kg./ha.)	12,269.217	7,097.578	2, 475.121	8,697.795		**	***
Mean cultivation area (ha.)	0.674	0.657	0.748	0.685			
No. of crops grown (past year)	2.740	2.616	2.725	2.702			
N	766	438	327	1,531			
B. Final outcomes							
Per cap. total expenditures (week, ETB)	231.944	227.429	196.749	223.000			
Per cap. food expenditures (week, ETB)	76.951	62.228	51.757	67.376	**	***	*
Per cap. non-food expenditures (week, ETB)	153.45	158.919	142.798	152.727			
Value of crop produced (year, ETB)	11,245.393	7,416.323	5,898.302	9,007.881	*	**	
Value of crop sold (year, ETB)	9,242.478	4,793.445	2,402.215	6,508.682	**	***	***
Value of own crop consumed (year, ETB)	2,691.468	2,886.200	3,647.807	2,951.439		***	
N	766	438	327	1,531			

Source: EIAR (2015)
Note 1: Statistical significance at * < 0.1; ** < 0.5; *** < 0.01
Note 2: 1 Ethiopian birr (ETB) = 0.05 US$ in 2015

Table 4: EIF and IPW estimates of average and quartile treatment effects, intermediate outcomes

	Improved seed purchases (ETB)						Fertilizer purchases (ETB)						Pesticide purchases (ETB)					
	(1) EIF			(2) IPW			(3) EIF			(4) IPW			(5) EIF			(6) IPW		
	Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.	
Average treatment effects																		
Traditional vs. Rainfed	0.256	-0.203	0.716	0.163	-0.296	0.623	-0.007	-0.174	0.161	0.035	-0.132	0.203	0.444	-0.348	1.236	0.319	-0.473	1.111
PASIDP vs. Rainfed	0.278	-0.133	0.689	0.223	-0.189	0.634	0.065	-0.091	0.222	0.091	-0.065	0.247	0.437	-0.348	1.221	0.360	-0.424	1.145
PASIDP vs. Traditional	0.022	-0.183	0.226	0.059	-0.145	0.263	0.072	-0.079	0.223	0.056	-0.095	0.207	-0.007	-0.264	0.251	0.041	-0.217	0.298
0.25 quartile treatment effects																		
Traditional vs. Rainfed	0.461	-0.501	1.422	0.444	-0.518	1.406	-0.116	-0.355	0.124	-0.078	-0.318	0.161	-0.138	-0.778	0.503	-0.259	-0.899	0.382
PASIDP vs. Rainfed	0.367	-0.598	1.332	0.367	-0.598	1.332	-0.117	-0.307	0.072	-0.103	-0.293	0.086	-0.014	-0.639	0.610	-0.107	-0.731	0.517
PASIDP vs. Traditional	-0.094	-0.387	0.200	-0.077	-0.371	0.216	-0.002	-0.234	0.231	-0.025	-0.258	0.207	0.123	-0.188	0.435	0.152	-0.160	0.463
0.50 quartile treatment effects																		
Traditional vs. Rainfed	0.154	-0.507	0.814	0.131	-0.530	0.792	0.090	-0.116	0.297	0.110	-0.097	0.317	0.506	-0.125	1.137	0.388	-0.243	1.019
PASIDP vs. Rainfed	0.154	-0.442	0.749	0.154	-0.442	0.749	0.211	0.042	0.381	0.225	0.055	0.394	0.318	-0.323	0.960	0.265	-0.377	0.907
PASIDP vs. Traditional	0.000	-0.263	0.263	0.023	-0.241	0.286	0.121	-0.062	0.304	0.115	-0.068	0.298	-0.188	-0.603	0.227	-0.124	-0.539	0.291
0.75 quartile treatment effects																		
Traditional vs. Rainfed	0.179	-0.233	0.590	0.158	-0.254	0.569	0.051	-0.144	0.246	0.090	-0.104	0.285	0.548	-0.149	1.244	0.436	-0.260	1.133
PASIDP vs. Rainfed	0.259	-0.116	0.634	0.259	-0.116	0.634	0.108	-0.091	0.307	0.141	-0.059	0.340	0.604	-0.083	1.290	0.537	-0.150	1.224
PASIDP vs. Traditional	0.080	-0.147	0.307	0.101	-0.126	0.328	0.057	-0.086	0.201	0.050	-0.094	0.194	0.056	-0.328	0.440	0.101	-0.283	0.485
N	823			823			1,336			1,336			529			529		

Note: All standard errors are bootstrapped with 500 repetitions. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 5: EIF and IPW estimates of average and quartile treatment effects, intermediate outcomes (cont.)

	Mean crop yield (kg./ha.)						Mean cultivation area (ha.)						No. of crops grown (past year)					
	(1) EIF			(2) IPW			(3) EIF			(4) IPW			(5) EIF			(6) IPW		
	Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.	
Average treatment effects																		
Traditional vs. Rainfed	0.762	0.590	0.934	0.779	0.607	0.951	-0.035	-0.238	0.167	-0.044	-0.247	0.158	-0.114	-0.275	0.048	-0.117	-0.278	0.044
PASIDP vs. Rainfed	0.992	0.847	1.136	1.009	0.865	1.153	-0.096	-0.195	0.004	-0.098	-0.198	0.001	-0.064	-0.220	0.091	-0.074	-0.229	0.081
PASIDP vs. Traditional	0.230	0.083	0.376	0.230	0.084	0.377	-0.061	-0.265	0.144	-0.054	-0.258	0.150	0.050	-0.095	0.195	0.043	-0.102	0.188
0.25 quartile treatment effects																		
Traditional vs. Rainfed	0.553	0.390	0.716	0.553	0.390	0.716	-0.063	-0.129	0.003	-0.063	-0.129	0.003	-	-	-	-	-	-
PASIDP vs. Rainfed	0.735	0.610	0.861	0.735	0.610	0.861	-0.001	-0.084	0.082	-0.001	-0.084	0.082	-	-	-	-	-	-
PASIDP vs. Traditional	0.182	0.048	0.317	0.182	0.048	0.317	0.062	-0.005	0.129	0.062	-0.005	0.129	-	-	-	-	-	-
0.50 quartile treatment effects																		
Traditional vs. Rainfed	0.734	0.578	0.889	0.742	0.586	0.897	-0.004	-0.174	0.166	-0.004	-0.174	0.166	-	-	-	-	-	-
PASIDP vs. Rainfed	1.090	0.945	1.236	1.090	0.945	1.236	0.000	-0.133	0.133	0.000	-0.133	0.133	-	-	-	-	-	-
PASIDP vs. Traditional	0.357	0.188	0.526	0.349	0.180	0.518	0.004	-0.096	0.104	0.004	-0.096	0.104	-	-	-	-	-	-
0.75 quartile treatment effects																		
Traditional vs. Rainfed	0.877	0.663	1.091	0.955	0.741	1.169	-0.004	-0.174	0.166	-0.188	-0.300	-0.075	-	-	-	-	-	-
PASIDP vs. Rainfed	1.124	0.971	1.276	1.202	1.050	1.355	0.000	-0.133	0.133	-0.188	-0.320	-0.055	-	-	-	-	-	-
PASIDP vs. Traditional	0.247	0.050	0.444	0.247	0.050	0.444	0.004	-0.096	0.104	0.000	-0.085	0.085	-	-	-	-	-	-
N	1,531			1,531			1,531			1,531			1,531			1,531		

Note: All standard errors are bootstrapped with 500 repetitions. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 6: EIF and IPW estimates of average and quartile treatment effects, final outcomes

	Per cap. total expenditures (ETB)						Per cap. food expenditures (ETB)						Per cap. non-food expenditures (ETB)					
	(1) EIF			(2) IPW			(3) EIF			(4) IPW			(5) EIF			(6) IPW		
	Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.	
Average treatment effects																		
Traditional vs. Rainfed	0.153	-0.009	0.316	0.215	0.052	0.377	0.076	-0.062	0.215	0.090	-0.049	0.229	0.122	-0.059	0.304	0.199	0.017	0.381
PASIDP vs. Rainfed	0.179	0.044	0.314	0.228	0.093	0.363	0.264	0.141	0.388	0.273	0.150	0.397	0.115	-0.056	0.286	0.174	0.004	0.345
PASIDP vs. Traditional	0.025	-0.115	0.165	0.013	-0.127	0.153	0.188	0.068	0.307	0.184	0.064	0.303	-0.007	-0.156	0.141	-0.025	-0.173	0.124
0.25 quartile treatment effects																		
Traditional vs. Rainfed	0.213	-0.128	0.553	0.259	-0.081	0.600	0.000	-0.202	0.202	0.059	-0.143	0.261	0.094	-0.095	0.282	0.157	-0.031	0.345
PASIDP vs. Rainfed	0.180	-0.059	0.418	0.213	-0.025	0.452	0.208	-0.024	0.439	0.267	0.036	0.499	0.120	-0.034	0.274	0.148	-0.006	0.303
PASIDP vs. Traditional	-0.033	-0.340	0.274	-0.046	-0.353	0.261	0.208	0.009	0.407	0.208	0.009	0.407	0.026	-0.133	0.186	-0.009	-0.168	0.151
0.50 quartile treatment effects																		
Traditional vs. Rainfed	0.144	-0.070	0.359	0.220	0.006	0.435	0.096	-0.119	0.310	0.111	-0.104	0.325	0.234	-0.124	0.593	0.306	-0.052	0.665
PASIDP vs. Rainfed	0.158	-0.044	0.360	0.232	0.030	0.434	0.175	-0.013	0.363	0.187	-0.001	0.375	0.216	-0.110	0.542	0.299	-0.027	0.625
PASIDP vs. Traditional	0.014	-0.169	0.197	0.012	-0.171	0.195	0.079	-0.109	0.267	0.076	-0.112	0.265	-0.019	-0.263	0.225	-0.007	-0.252	0.237
0.75 quartile treatment effects																		
Traditional vs. Rainfed	0.181	-0.076	0.438	0.303	0.047	0.560	0.295	0.122	0.468	0.302	0.129	0.475	0.066	-0.216	0.348	0.167	-0.115	0.449
PASIDP vs. Rainfed	0.253	0.053	0.453	0.324	0.124	0.524	0.450	0.249	0.651	0.458	0.257	0.659	0.063	-0.120	0.246	0.129	-0.055	0.312
PASIDP vs. Traditional	0.072	-0.098	0.242	0.021	-0.149	0.190	0.155	0.005	0.305	0.156	0.006	0.306	-0.003	-0.271	0.265	-0.038	-0.307	0.230
N	1,443			1,443			1,450			1,450			1,519			1,519		

Note: All standard errors are bootstrapped with 500 repetitions. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 7: EIF and IPW estimates of average and quartile treatment effects, final outcomes (cont.)

	Value of crop produced (ETB)						Value of crop sold (ETB)						Value of own crop consumed (ETB)					
	(1) EIF			(2) IPW			(3) EIF			(4) IPW			(5) EIF			(6) IPW		
	Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.	
Average treatment effects																		
Traditional vs. Rainfed	0.482	0.245	0.718	0.517	0.281	0.754	0.628	0.295	0.961	0.676	0.343	1.009	-0.133	-0.445	0.179	-0.072	-0.384	0.240
PASIDP vs. Rainfed	0.598	0.368	0.828	0.639	0.409	0.869	0.882	0.563	1.201	0.938	0.619	1.257	-0.476	-0.762	-0.190	-0.439	-0.724	-0.153
PASIDP vs. Traditional	0.117	-0.067	0.300	0.122	-0.061	0.305	0.254	0.003	0.505	0.262	0.011	0.513	-0.342	-0.538	-0.147	-0.366	-0.562	-0.171
0.25 quartile treatment effects																		
Traditional vs. Rainfed	0.443	0.133	0.753	0.436	0.127	0.746	0.411	0.028	0.793	0.430	0.048	0.812	0.017	-0.223	0.258	0.035	-0.205	0.276
PASIDP vs. Rainfed	0.505	0.242	0.768	0.515	0.252	0.777	0.585	0.234	0.936	0.673	0.322	1.024	-0.068	-0.336	0.200	-0.068	-0.336	0.200
PASIDP vs. Traditional	0.062	-0.166	0.290	0.078	-0.149	0.306	0.174	-0.227	0.575	0.243	-0.158	0.644	-0.085	-0.382	0.211	-0.104	-0.400	0.193
0.50 quartile treatment effects																		
Traditional vs. Rainfed	0.257	0.072	0.442	0.273	0.089	0.458	0.642	0.366	0.917	0.642	0.366	0.917	-0.034	-0.169	0.100	0.000	-0.135	0.135
PASIDP vs. Rainfed	0.375	0.220	0.530	0.394	0.239	0.549	0.818	0.564	1.072	0.830	0.575	1.084	-0.053	-0.201	0.095	-0.020	-0.168	0.127
PASIDP vs. Traditional	0.118	-0.042	0.278	0.121	-0.039	0.281	0.176	-0.070	0.423	0.188	-0.059	0.435	-0.019	-0.104	0.067	-0.020	-0.105	0.065
0.75 quartile treatment effects																		
Traditional vs. Rainfed	0.429	0.221	0.638	0.511	0.303	0.719	0.993	0.779	1.208	0.993	0.779	1.208	-0.154	-0.372	0.064	-0.090	-0.307	0.128
PASIDP vs. Rainfed	0.576	0.365	0.788	0.658	0.447	0.870	1.188	0.966	1.411	1.188	0.965	1.411	-0.144	-0.345	0.057	-0.086	-0.287	0.115
PASIDP vs. Traditional	0.147	-0.083	0.377	0.147	-0.083	0.377	0.195	-0.028	0.418	0.195	-0.028	0.418	0.010	-0.128	0.148	0.003	-0.135	0.141
N	1,474			1,474			1,474			1,474			1,474			1,474		

Note: All standard errors are bootstrapped with 500 repetitions. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 8: IV estimates of average treatment effects

	Crop yields (kg./hectare)	Crop revenue (ETB)	Food exp. (ETB)
	(1) IV	(2) IV	(3) IV
IV results			
Treatment status	1.084***	2.597***	0.858***
	(0.142)	(0.412)	(0.158)
Kleibergen-Paap F-stat.	118.649	118.649	114.870
N	1,530	1,530	1,449

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Standard errors in parenthesis. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 9: Robustness check: IPW and IPWRA estimates of average treatment effects

	Val. of crop prod. (ETB)		Val. of sales (ETB)		Val. of own cons. (ETB)	
	(1) IPW	(2) IPWRA	(3) IPW	(4) IPWRA	(5) IPW	(6) IPWRA
Kernel matching						
Traditional vs. Rainfed	0.493***	0.507***	0.665***	0.546***	-0.236	0.199
	(0.161)	(0.154)	(0.222)	(0.201)	(0.182)	(0.175)
PASIDP vs. Rainfed	0.663***	0.718***	0.918***	0.936***	-0.496***	-0.424**
	(0.141)	(0.140)	(0.174)	(0.163)	(0.167)	(0.167)
PASIDP vs. Traditional	0.004	0.004	0.109	0.116	-0.397***	-0.362***
	(0.091)	(0.093)	(0.125)	(0.120)	(0.139)	(0.137)
N	739	739	524	524	739	739

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Standard errors in parenthesis. All outcome variables are in the logarithmic scale, and are monetary values in Ethiopian birr. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 10: Robustness check: IPW and IPWRA estimates of average treatment effects

	Total exp. (ETB)		Food exp. (ETB)		Non-food exp. (ETB)	
	(1) IPW	(2) IPWRA	(3) IPW	(4) IPWRA	(5) IPW	(6) IPWRA
Kernel matching						
Traditional vs. Rainfed	0.195**	0.204**	0.140	0.177*	0.151	0.175*
	(0.090)	(0.087)	(0.098)	(0.092)	(0.106)	(0.100)
PASIDP vs. Rainfed	0.236***	0.224***	0.281***	0.253***	0.190**	0.207**
	(0.074)	(0.070)	(0.080)	(0.078)	(0.088)	(0.083)
PASIDP vs. Traditional	0.001	-0.003	0.138*	0.109	-0.023	-0.007
	(0.069)	(0.069)	(0.078)	(0.077)	(0.081)	(0.079)
N	688	688	689	689	725	725

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Standard errors in parenthesis. All outcome variables are in the logarithmic scale, and are normalized by the household size (per capita). Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Figures

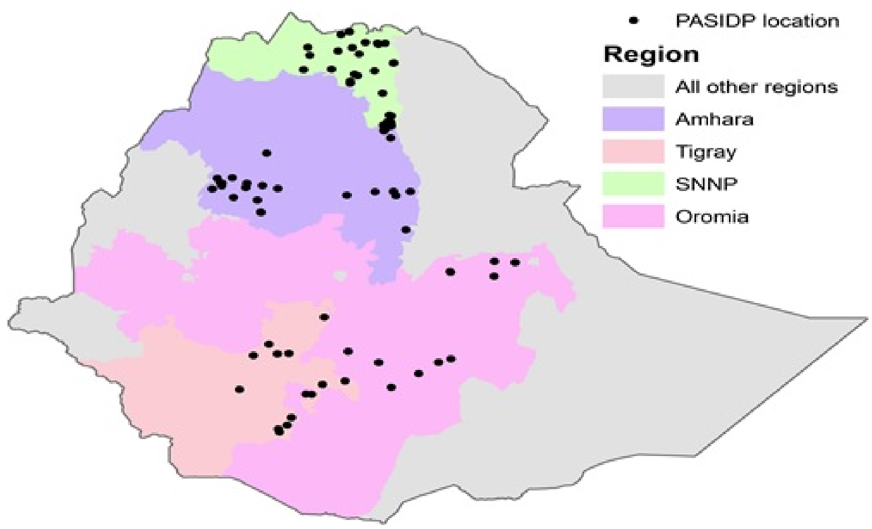

Figure 1: PASIDP small-scale irrigation locations (Source: IIASA)

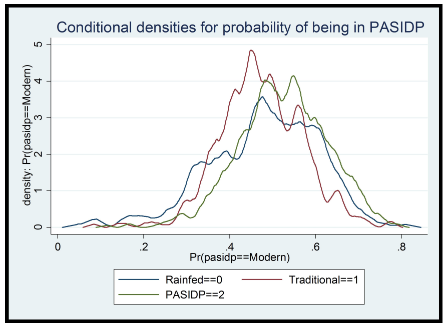

Figure 2: Conditional probabilities for being in PASIDP irrigation

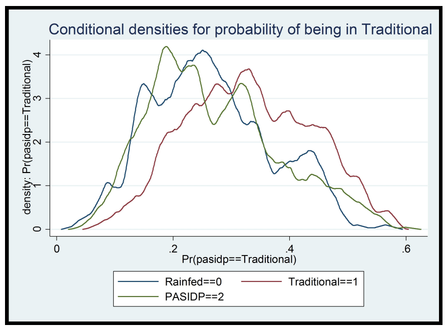

Figure 3: Conditional probabilities for being in traditional irrigation

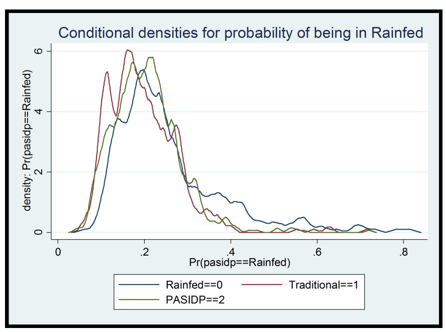

Figure 4: Conditional probabilities for being in rainfed agriculture

Annex A: Additional Tables and Results

Table 11: Yield estimates by crop type

	Treatment status						
	(1) PASIDP	(2) Traditional	(3) Rainfed	Overall	(1) vs. (2)	(1) vs. (3)	(2) vs. (3)
Average yields by crop type (kg./hectare							
All crops	7,200.161	4,518.342	2,293.99	5,385.037	**	***	***
All grains	2,710.826	1,945.278	2,084.476	2,358.033	***	***	
All cereals	2,669.262	1,910.949	1,987.272	2,306.655	***	***	
Teff	589.867	485.076	302.614	498.534	**	***	***
Wheat	365.652	392.764	591.627	421.674		***	***
Maize	1,653.389	1,281.216	1,017.034	1,410.998	***	***	*
Barley	190.042	210.481	547.145	272.162		***	***
Sorghum	1,149.695	517.598	525.335	835.505	***	***	
Vegetables	1,370.538	813.593	50.478	929.257	**	***	***
Roots	3,623.991	2,704.928	342.635	2660.207	**	***	***
Fruits	333.485	255.474	0.979	240.148			***
Other permanent crops	1,598.948	602.947	310.755	1,038.864			
N	766	438	327	1,531			

Source: EIAR (2015)
Note: Statistical significance at * < 0.1; ** < 0.5; *** < 0.01

Table 12: IV results: First stage IV estimates

	Treatment status	Treatment status	Treatment status
	(1) OLS	(2) OLS	(3) OLS
Covariate			
No. of WUA members	0.311***	0.311***	0.312***
	(0.289)	(0.289)	(0.030)
Gender of head (=1 if male)	-0.127*	-0.127*	-0.134**
	(0.069)	(0.069)	(0.069)
Age of head (years)	0.002	0.002	0.002
	(0.002)	(0.002)	(0.002)
Education of head (years)	0.013**	0.013**	0.014**
	(0.006)	(0.006)	(0.007)
Household size (head count)	0.022**	0.022**	0.024**
	(0.011)	(0.011)	(0.011)
Durable asset index (value)	0.327***	0.327***	0.340***
	(0.093)	(0.093)	(0.096)
Livestock asset index (value)	-0.083***	-0.083***	-0.092***
	(0.026)	(0.026)	(0.026)
Productive asset index (value)	0.024	0.024	0.027
	(0.026)	(0.026)	(0.026)
Elevation (km.)	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Mean precipitation (m./year)	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)
Land holding (hectares)	0.054**	0.054**	0.047*
	(0.028)	(0.028)	(0.028)
Time to market (min.)	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
R-square	0.098	0.098	0.102
N	1,530	1,530	1,449

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Standard errors in parenthesis. The number of WUA membership variable is in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 13: Alternative specification: IV estimates of average treatment effects

	Crop yields (kg./hectare)	Crop revenue (ETB)	Food exp. (ETB)
	(1) IV	(2) IV	(3) IV
IV results			
Traditional vs. Rainfed	1.032**	1.456	1.330**
	(0.458)	(1.567)	(0.660)
Kleibergen-Paap F-stat.	16.455	16.455	14.793
N	764	764	718
PASIDP vs. Rainfed	2.191***	5.914***	0.281***
	(0.274)	(0.070)	(0.080)
Kleibergen-Paap F-stat.	112.855	112.855	109.397
N	1,093	1,093	1,046
PASIDP vs. Traditional	2.536***	6.008***	2.679***
	(0.629)	(1.717)	(0.697)
Kleibergen-Paap F-stat.	28.414	28.414	26.830
N	1,203	1,203	1,134

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Standard errors in parenthesis. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 14: Alternative specification: First stage IV estimates

	Trad. vs. Rainfed	PASIDP vs. Rainfed	PASIDP vs. Trad.
	(1) OLS	(2) OLS	(3) OLS
Covariate			
No. of WUA members	0.123***	0.188***	0.106***
	(0.030)	(0.019)	(0.021)
Gender of head (=1 if male)	0.106*	0.050	-0.0151***
	(0.064)	(0.042)	(0.046)
Age of head (years)	0.001	0.002*	0.000
	(0.002)	(0.001)	(0.001)
Education of head (years)	0.009	0.010**	0.002
	(0.006)	(0.004)	(0.004)
Household size (head count)	0.0334***	0.020***	-0.007
	(0.009)	(0.007)	(0.007)
Durable asset index (value)	0.540***	0.252***	-0.150*
	(0.081)	(0.062)	(0.066)
Livestock asset index (value)	-0.023	-0.051***	-0.035*
	(0.022)	(0.017)	(0.017)
Productive asset index (value)	1.005	0.017	0.006
	(0.023)	(0.017)	(0.017)
Elevation (km.)	0.000	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)
Mean precipitation (m./year)	0.000***	0.000**	-0.000**
	(0.000)	(0.000)	(0.000)
Land holding (hectares)	-0.040	0.018	0.068*
	(0.026)	(0.018)	(0.020)
Time to market (min.)	-0.000**	-0.000**	0.000*
	(0.000)	(0.000)	(0.000)
R-square	0.119	0.120	0.090
N	764	1,093	1,203

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ Standard errors in parenthesis. The number of WUA membership variable is in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 15: Robustness check: EIF and IPW estimates of average and quartile treatment effects

	Per cap. total exp. (ETB)						Per cap. food exp. (ETB)						Per cap. non-food exp. (ETB)					
	(1) EIF			(2) IPW			(3) EIF			(4) IPW			(5) EIF			(6) IPW		
	Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.	
Average treatment effects																		
Traditional vs. Rainfed	0.082	-0.106	0.270	0.163	-0.025	0.352	0.040	-0.138	0.219	0.056	-0.122	0.235	0.062	-0.125	0.249	0.165	-0.022	0.352
PASIDP vs. Rainfed	0.091	-0.040	0.223	0.160	0.029	0.292	0.225	0.052	0.398	0.238	0.065	0.411	0.011	-0.162	0.183	0.097	-0.076	0.269
PASIDP vs. Traditional	0.009	-0.143	0.160	-0.003	-0.155	0.148	0.185	0.029	0.340	0.182	0.026	0.337	-0.052	-0.179	0.076	-0.069	-0.196	0.059
0.25 quartile treatment effects																		
Traditional vs. Rainfed	0.082	-0.302	0.467	0.230	-0.154	0.614	0.007	-0.217	0.230	0.051	-0.173	0.274	0.096	-0.135	0.328	0.115	-0.117	0.346
PASIDP vs. Rainfed	0.027	-0.217	0.271	0.158	-0.086	0.401	0.203	-0.019	0.426	0.246	0.023	0.468	0.027	-0.142	0.196	0.046	-0.123	0.214
PASIDP vs. Traditional	-0.055	-0.344	0.234	-0.072	-0.362	0.217	0.197	-0.005	0.399	0.195	-0.007	0.397	-0.069	-0.262	0.124	-0.069	-0.262	0.124
0.50 quartile treatment effects																		
Traditional vs. Rainfed	0.095	-0.122	0.312	0.176	-0.040	0.393	0.030	-0.276	0.336	0.067	-0.239	0.373	0.138	-0.195	0.470	0.321	-0.012	0.653
PASIDP vs. Rainfed	0.093	-0.112	0.298	0.169	-0.036	0.374	0.137	-0.078	0.352	0.171	-0.044	0.387	0.073	-0.233	0.379	0.203	-0.103	0.509
PASIDP vs. Traditional	-0.002	-0.168	0.164	-0.007	-0.173	0.159	0.107	-0.142	0.356	0.104	-0.145	0.354	-0.065	-0.322	0.193	-0.118	-0.376	0.140
0.75 quartile treatment effects																		
Traditional vs. Rainfed	0.036	-0.298	0.370	0.204	-0.131	0.538	0.264	0.005	0.524	0.289	0.030	0.548	0.021	-0.219	0.262	0.123	-0.117	0.364
PASIDP vs. Rainfed	0.081	-0.200	0.363	0.248	-0.033	0.530	0.415	0.141	0.689	0.436	0.162	0.710	-0.023	-0.250	0.204	0.066	-0.161	0.293
PASIDP vs. Traditional	0.046	-0.176	0.267	0.045	-0.177	0.266	0.151	-0.051	0.353	0.147	-0.055	0.349	-0.045	-0.275	0.185	-0.058	-0.287	0.172
N	1,307			1,307			1,314			1,314			1,319			1,319		

Note: All standard errors are bootstrapped with 500 repetitions. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 16: Robustness check: EIF and IPW estimates of average and quartile treatment effects (cont.)

	Value of crop produced (ETB)						Value of sales (ETB)						Value of own cons. (ETB)					
	(1) EIF			(2) IPW			(3) EIF			(4) IPW			(5) EIF			(6) IPW		
	Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.		Contrast	95% C.I.	
Average treatment effects																		
Traditional vs. Rainfed	0.309	0.039	0.580	0.369	0.099	0.639	0.476	0.169	0.782	0.557	0.251	0.864	-0.168	-0.581	0.244	-0.082	-0.494	0.331
PASIDP vs. Rainfed	0.429	0.189	0.670	0.487	0.247	0.728	0.741	0.515	0.966	0.822	0.597	1.048	-0.454	-0.866	-0.043	-0.395	-0.807	0.016
PASIDP vs. Traditional	0.120	-0.108	0.347	0.118	-0.109	0.346	0.265	0.030	0.500	0.265	0.029	0.500	-0.286	-0.546	-0.026	-0.314	-0.574	-0.053
0.25 quartile treatment effects																		
Traditional vs. Rainfed	0.275	-0.025	0.575	0.296	-0.004	0.596	0.287	-0.177	0.751	0.356	-0.108	0.820	-0.004	-0.260	0.253	0.008	-0.248	0.265
PASIDP vs. Rainfed	0.322	0.101	0.542	0.344	0.123	0.564	0.470	0.079	0.860	0.538	0.148	0.929	-0.008	-0.301	0.285	0.000	-0.293	0.293
PASIDP vs. Traditional	0.046	-0.203	0.295	0.048	-0.201	0.297	0.182	-0.259	0.623	0.182	-0.259	0.623	-0.005	-0.256	0.247	-0.008	-0.260	0.243
0.50 quartile treatment effects																		
Traditional vs. Rainfed	0.164	0.004	0.324	0.175	0.014	0.335	0.545	0.284	0.806	0.624	0.363	0.885	-0.111	-0.314	0.092	-0.034	-0.237	0.169
PASIDP vs. Rainfed	0.281	0.125	0.437	0.300	0.144	0.456	0.693	0.491	0.894	0.757	0.556	0.959	-0.116	-0.297	0.065	-0.040	-0.221	0.140
PASIDP vs. Traditional	0.117	-0.042	0.276	0.126	-0.033	0.284	0.148	-0.083	0.378	0.133	-0.097	0.364	-0.005	-0.146	0.135	-0.006	-0.147	0.134
0.75 quartile treatment effects																		
Traditional vs. Rainfed	0.287	0.009	0.564	0.379	0.102	0.656	0.826	0.599	1.054	0.886	0.658	1.113	-0.220	-0.475	0.035	-0.104	-0.360	0.151
PASIDP vs. Rainfed	0.437	0.209	0.666	0.530	0.301	0.758	1.028	0.801	1.256	1.077	0.849	1.305	-0.182	-0.393	0.028	-0.073	-0.284	0.137
PASIDP vs. Traditional	0.151	-0.066	0.367	0.151	-0.066	0.367	0.202	-0.082	0.486	0.192	-0.092	0.475	0.038	-0.125	0.201	0.031	-0.132	0.194
N	1,390			1,390			1,123			1,123			1,390			1,390		

Note: All standard errors are bootstrapped with 500 repetitions. All outcome variables are in the logarithmic scale. Covariates include household size, sex, age, and education level of the household head, asset-based wealth index at baseline from recalled information (durable, livestock, and productive farm assets), land ownership, elevation, average precipitation during the past five years, and time to the nearest market.

Table 17: Rosenbaum bounds of impact estimates from matching

Gamma	Avg. crop yields (kg./hectare)			Crop revenue (Birr)			Per cap. food exp. (Birr)		
	Upp. bound sig. level	C.I.		Upp. bound sig. level	C.I.		Upp. bound sig. level	C.I.	
Trad. vs. Rainfed									
1	0.000	0.636	0.839	0.000	0.447	0.846	0.017	0.044	0.345
1.2	0.000	0.549	0.947	0.000	0.267	1.017	0.270	-0.096	0.490
1.4	0.000	0.466	1.038	0.007	0.112	1.156	0.747	-0.214	0.608
1.6	0.000	0.399	1.109	0.071	-0.030	1.281	0.962	-0.319	0.714
1.8	0.000	0.346	1.182	0.275	-0.152	1.397	0.997	-0.413	0.807
2.0	0.000	0.290	1.242	0.570	-0.262	1.502	0.999	-0.493	0.890
PASIDP vs. Rainfed									
1	0.000	0.861	1.019	0.000	0.742	1.060	0.000	0.254	0.475
1.2	0.000	0.760	1.125	0.000	0.548	1.253	0.000	0.114	0.614
1.4	0.000	0.677	1.210	0.000	0.386	1.416	0.055	-0.003	0.727
1.6	0.000	0.602	1.288	0.000	0.247	1.559	0.449	-0.108	0.826
1.8	0.000	0.539	1.354	0.002	0.126	1.691	0.878	-0.198	0.912
2.0	0.000	0.481	1.416	0.037	0.014	1.809	0.990	-0.278	0.992
PASIDP vs. Trad.									
1	0.000	0.091	0.255	0.052	-0.002	0.306	0.002	0.085	0.318
1.2	0.081	-0.011	0.356	0.624	-0.183	0.491	0.212	-0.061	0.465
1.4	0.639	-0.103	0.448	0.975	-0.335	0.650	0.823	-0.181	0.588
1.6	0.970	-0.178	0.523	0.999	-0.470	0.790	0.992	-0.285	0.693
1.8	0.999	-0.248	0.591	0.999	-0.589	0.914	0.999	-0.376	0.787
2.0	0.999	-0.310	0.654	1.000	-0.696	1.025	1.000	-0.456	0.870

Note: Rosenbaum bounds are calculated at the 10% significance level.