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Does irrigation have an impact on food security and poverty?

Evidence from Bwanje Valley Irrigation Scheme in Malawi

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ABSTRACT

The purpose of this study was to assess the impact of irrigation on household food security and poverty using a case study of Bwanje Valley Irrigation Scheme in Malawi. Data used in the analysis were collected from 412 households – 169 participants in the irrigation scheme and 243 non-participants. Due to the non-random selection of participants into the irrigation scheme, the study used endogenous switching regression to correct for sample selection bias. Propensity score matching was then used to measure the impact of irrigation on food security and poverty. Daily per capita caloric intake and agricultural income were the proxy measures used to measure food security and poverty, respectively. Despite farmers selling paddy rice at the farm gate on an individual basis and operating in an environment with inadequate water supply, the findings revealed that irrigation had a positive impact on annual agricultural income and daily per capita caloric intake. The impact of irrigation on household annual agricultural income was different among the participants, with those cultivating both rice and maize under irrigation earning more agricultural income than their counterparts growing rice only. The results also showed a positive impact of irrigation on daily per capita caloric intake, with both groups of irrigating farmers realizing similar improved levels of caloric intake over farmers that did not participate in the irrigation scheme. In addition, traditionally marginalized groups – households headed by youth, female-headed households, and low-income households – earned more agricultural income than what they would have earned if they did not participate in the irrigation scheme. The recommendations from the study are that irrigation interventions should be up scaled to other areas with potential irrigable land and should promote the growing of more than one crop. In addition, irrigation schemes should promote bulk marketing of processed rice through contract relationships with institutions (i.e. schools, prisons, hospitals) and private traders.

1. INTRODUCTION

Numerous empirical studies across the world have shown that irrigation has a positive impact on household food security and poverty (Dillon 2007; Mangisoni 2008; Omilola 2009; Gebregziabheri and Namara 2009). With this in mind, many developing countries affected by droughts and floods promote irrigation interventions to reduce poverty and to promote food security. Malawi is one of the countries that has promoted irrigation through the Malawi Growth and Development Strategy (GoM 2011).However, despite large investments in irrigation projects, Malawi continues to suffer from chronic food insecurity due to recurrent droughts and floods. Seven major droughts and more than eighteen floods occurred in Malawi between 1967 and 2008 which affected in total approximately 21.7 million people (Siedenburg et al. 2010; Lunduka et al. 2010). Economically, the country loses US$ 22 million or 1.7 percent of its gross domestic product (GDP) on average each year due to the combined effects of droughts and floods. Severe droughts can lead to more than a 10 percent loss in national GDP (Pauw and Thurlow 2009).

While the studies mentioned above have quantified the positive impact of irrigation on household food security and poverty, many of the authors did not control for sample selection biases in their evaluations. Sample selection bias may arise due to systematic differences in unobserved characteristics between participants and non-participants in an irrigation scheme. For instance, motivated farmers might participate in irrigation and are likely to gain more annual agricultural income and have higher daily per capita caloric intake than their less motivated counterparts. Failure to control for selection bias arising from unobserved characteristics may result in overstated or understated estimates of the impact of irrigation on household income and daily per capita caloric intake. In addition, most of these evaluation studies did not disaggregate their results to examine the impact of irrigation on marginalized households – female headed households, the youth, and low-income households.

Using the Bwanje Valley Irrigation Scheme in Malawi as a case study, the evaluation study reported here goes beyond many of the other studies in the literature on the impact of irrigation on food security and poverty as it controls for sample selection bias and examines the effect of irrigation on marginalized households. Specifically, the study addressed the following three questions:

- Does growing crops under irrigation improve the food security status of participant households? Moreover, for those households that use irrigation, does growing two crops under irrigation versus growing only one crop improve household food security status?
- Does growing crops under irrigation reduce poverty of participant households? For those households that use irrigation, does growing two crops under irrigation versus growing only one crop reduce poverty?
- Do marginalized households benefit from using irrigation? For those groups of marginal households using irrigation, who benefit more or less among the groups?

Addressing these questions provides empirical evidence on the effectiveness of irrigation in improving household food security and reducing poverty. Furthermore, this study provides important insights and lessons for improving the current program of irrigation development in Malawi. In addition, the findings of the study can be used in designing better interventions in the future as existing irrigation schemes are rehabilitated and new ones are constructed.

This study uses propensity score matching (PSM) after controlling for sample selection bias to assess the impact of growing crops under irrigation on annual agricultural income and daily per capita caloric intake and, if irrigation is used, of growing one crop versus growing two crops under irrigation among households farming both with and without irrigation in the Bwanje Valley Irrigation Scheme and the surrounding area. The paper further employed PSM to assess the impact of irrigation and growing one irrigated crop versus growing two crops for female headed households, the youth, and low income households, which are traditionally marginalized groups.[1]

1.1 Background to Bwanje Valley Irrigation Scheme

Bwanje Valley Irrigation Scheme (BVIS) is located in the central region of Malawi within Mtakataka Extension Planning Area on the Lake Malawi lakeshore plain in Dedza district. BVIS was established in January 2000 at a total cost of US$ 15 million and targeted 12,000 households in 14 villages. The scheme covers an area of 800 hectares and benefits over 2,000 smallholder farmers (Diemer 1990; Bolding 2004). BVIS was built with the goal of improving household food security and increasing income levels of beneficiaries through increased agricultural production of rice and other crops such as maize, soybean, and cowpea (GoM 2013). After construction of BVIS, the Japanese International Cooperation Agency financed the further rehabilitation of BVIS in November 2005 at a cost of US$ 320,000. This rehabilitation exercise involved headwork and settling basin rehabilitation, main canal relocation, and land leveling. These works were completed in 2006 (Johnstone 2011).

Initially, BVIS was managed by agricultural extension officers from government. Between 2003 and 2004, however, the farmers on the scheme were organized into a cooperative and assumed all responsibilities for managing the scheme (Johnstone 2011). The management structure of the cooperative is made up of the executive committee, general committee, and sub-committees. The executive committee is the board for the scheme and is made up of 27 farmers from the scheme who provide oversight on scheme operations. The members of the executive committee are voted into office every three years by all farmers participating in the irrigation scheme. The general committee is responsible for managing the day-to-day affairs of the cooperative. This general committee is made up of nine members who hold the positions of president, vice president, secretary, vice secretary, treasurer and four finance committee members who serve two year terms. The general committee is divided into sub-committees. The water management sub-committee is responsible for the operation and maintenance of the scheme. The disciplinary sub-committee is responsible for settling disputes or conflicts amongst members of the cooperative based on established by-laws. The agricultural sub-committee is responsible for the training of farmers in the use of new methods of cultivation and monitoring their performance. The marketing sub-committee is responsible for procuring of inputs to be sold to participants and searching for markets for the rice cultivated in the scheme. The finance sub-committee is responsible for ensuring that the cooperative maintains good financial standing. Finally, the ad hoc land allocation sub-committee was established to reallocate land during the rehabilitation phase in 2006.

According to the design of the scheme, all farmers that helped with scheme construction were allocated land within it by the chiefs. Some villages had more land than others and this allowed the respective village chiefs to allocate a larger portion of the land to their subjects. For instance, some farmers were allocated 2.0 hectares of land and found that they were not able to using all of the irrigated land allocated (Veldwisch et al. 2009). During the rehabilitation of the scheme, an agreement was signed by 1601 farmers in early 2006 to reallocate the land within the irrigation scheme. The work of reallocating the land was facilitated by the Japanese International Cooperation Agency and the ad hoc land allocation sub-committee. This sub-committee was comprised of officials from the Department of Irrigation, chiefs from the area, and representatives from the BVIS cooperative. Under this agreement, all responsibilities for managing the land in BVIS were transferred to the cooperative. This gave powers to the cooperative to allocate the land to farmers and also to dismiss any member if he or she does not abide by the by-laws of the cooperative (Johnstone 2011). BVIS cooperative then allocated 0.4 hectares of land to every member of the cooperative (GoM 2013).

Participation in BVIS is voluntary, provided the farmer lives within the 14 villages targeted by the BVIS and is over the age of 18 years with no criminal record (Johnstone 2011).However, farmers have to abide by the by-laws of the cooperative and pay various fees to the cooperative at the start of each agricultural season in order to participate in the scheme. These fees includes an annual subscription fee of MK 500 (US$ 3.00 in 2012) and water fees at MK 300 per

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[1] Youth are regarded as those beneficiaries less than 35 years of age (African Union 2006), while low income households are those earning less than US$1.25 per person per day (Ravallion et al. 2008).

plot. These are paid to assist in the operation and maintenance of the scheme. In addition, farmers buy shares in the cooperative at MK 1500 per share (GoM 2013).

2. THEORETICAL AND EMPIRICAL STRATEGY

It should be emphasized that participants self-select themselves into BVIS. Hence, it is not possible to directly compare the agricultural income or daily per capita caloric intake of participants and non-participants because of selection bias. This selection bias can be as a result of both observed and unobserved characteristics. This section provides the theory and methods for carrying out a counterfactual analysis in order to control for the selection bias as a result of both observed and unobserved characteristics. The counterfactual analysis estimates the agricultural income or daily per capita caloric intake that individuals would have earned or consumed, respectively, if they did not participate in irrigation. This section starts with a description of the theory behind participation decisions that farmers make using the utility framework. Second, we develop the counterfactual groups based on the farmer's decisions, and, finally, the empirical strategy behind an endogenous switching regression method to correct for sample selection bias is discussed.

The aim of BVIS is to improve food security and increase household income for scheme participants. In this regard, household annual agricultural income and daily per capita caloric intake are the outcome variables used in the analysis here. Household agricultural income is the sum of both income from irrigation and from rain-fed agriculture. Following Hoddinott (1999), per capita caloric intake per day was used as a proxy to measure food security. Due to data quality issues, it was not possible to assess total caloric intake from all foods consumed. Here we use the caloric value of daily per capital consumption of the two main staple cereals, maize and rice, as our measure of food security. Quantities in kilograms of maize and rice that study households reported consuming within the past 7 days were converted into standard caloric conversions – 100 grams of maize is equivalent to 334 calories; while 100 grams of rice, 333 calories. For each household, the total amount of calorie intake from these two cereals for each household was then divided by the household size to obtain daily per capita caloric intake from maize and rice.

Following McFadden (1974), a random utility framework was used to model the participation decision of a household in BVIS. According to the design of BVIS, farmers face a two-stage decision process. In the first stage, farmers voluntarily decide whether to participate or not. Once the first decision is made, farmers then decide on the crops to be grown. Farmers have a choice to grow rice only or to grow rice with a combination of other crops, such as maize, soybean, or cowpea for the sake of increasing agricultural income and promoting food security. In this regard, farmers participate in BVIS if they perceive that irrigation will provide them with more utility than rain-fed agriculture. The general utility function can be expressed as:

$$U_{ij}= U(Y_{ij}, K_{ij}, X_{ij}, Z_{ij}, \varepsilon_{ij}), \quad \text{where } j= 0, 1 \quad \text{and } i = 1, 2, 3, \ldots, N \tag{1a}$$

where U_{ij} denote the utility that household i obtains from choosing crop production alternative j (i.e. j=1 implies participation in BVIS and j=0, implies non-participation in BVIS). This utility is a linear function of agricultural income or daily per capita caloric intake conditional on observed characteristics X and Z corresponding to agricultural income (Y) and per capita caloric intake (K), respectively. X and Z are vectors of observable socio-economic and farm variables of the study households. ε is a disturbance term that is associated with household i and alternative j and accounts for unobserved factors, i.e., social, political, developmental, ecological, or environmental factors.

The decisions to participate and, if so, which crops to grow is observed as a bivariate outcome and is mutually exclusive. Therefore, the general utility function can be expressed as a two stage decision framework as follows:

$$J_i \in j = \begin{cases} 1 \quad if \quad M^* > 0 & \begin{cases} 2 \; if \; N^* > L^* \\ 3 \; if \; N^* < L \end{cases} \\ 0 \; otherwise \end{cases} \tag{1b}$$

where 2 indicate the choice of beneficiaries to grow rice only, while 3 indicates the choice to grow both rice and maize. M^*, N^*, *and* L^* are differences in utility between the two decisions expressed as follows: $M^* = U_{i1} – U_{i0}$; $N^* = U_{i2} – U_{i3}$; *and* $L^*= U_{i3} – U_{i2}$.

Equation (1b) states that farmers will choose to participate in BVIS if irrigation provides more utility than rain-fed agriculture. Farmers then decide on the crops to grow. Thus, farmers will grow rice only if the anticipated utility derived from agriculture income and daily per capita caloric intake is more from growing only rice than that of growing both rice and maize. It is assumed that the decision to grow rice or both rice and maize is influenced by observed socio-economic characteristics of the study households. These include the price of rice; price of maize; gender, age, and educational level of household head; family size, farming experience, and total land size.

From equation (1b), the probabilities that farmers participate in BVIS can be expressed as:

$$\begin{aligned} p_{i1} &= pr(\varepsilon_{i1} - \varepsilon_{i0} < U_{i0} - U_{i1}) \\ p_{i0} &= pr(\varepsilon_{i0} - \varepsilon_{i1} < U_{i1} - U_{i0}) \end{aligned} \tag{2a}$$

The probabilities that farmers who choose to engage in irrigated crop production in BVIS choose to grow rice or to grow rice and maize can be expressed as:

$$\begin{aligned} p_{ia} &= pr(\varepsilon_{i2} - \varepsilon_{i0} < U_{i0} - U_{i2}) \\ p_{ib} &= pr(\varepsilon_{i3} - \varepsilon_{i0} < U_{i0} - U_{i3}) \end{aligned} \tag{2b}$$

As earlier stated, agricultural income (y_{ij}) and daily per capita caloric intake (k_{ij}) are derived from both rain-fed and irrigation agriculture. Therefore, we express these outcome variables as follows:

$$y_{1i} = (1-j)y_{1i} + (j)y_{1i} = X_{1i}\beta_1 + \sigma_1\mu_{1i} \text{ if } j = 1 \tag{3a}$$

$$y_{0i} = (1-j)y_{0i} + (j)y_{10} = X_{io}\beta_0 + \sigma_0\mu_{0i} \text{ if } j = 0 \tag{3b}$$

$$k_{1i} = (1-j)k_{1i} + (j)k_{1i} = X_{1i}\beta_1 + \sigma_1\mu_{1i} \text{ if } j = 1 \tag{3c}$$

$$k_{0i} = (1-j)k_{9i} + (j)k_{0i} = X_{io}\beta_0 + \sigma_0\mu_0 \text{ if } j = 0 \tag{3d}$$

Where β_1 and β_0 are coefficient parameters, σ_1 and σ_0 are standard deviations, while μ_{1i} and μ_{0i} are the random components with $E(\mu_{1i} | x_i) = 0$.

Participation in BVIS is endogenously determined as shown in equations 3a through 3d. In other words, the decision to participate in BVIS is a choice and this choice is influenced by expected agricultural income or daily per capita caloric intake from irrigation and rain-fed agriculture. We let π denote the difference between the outcomes of participants and non-participants expressed as:

$$\pi_y = (y_{i1} - y_{i0}) + (X_{1i}\beta_1 - X_{0i}\beta_0) + (\sigma_1\mu_{1i} - \sigma_0\mu_{0i}) \tag{4a}$$

$$\pi_k = (k_{i1} - k_{i0}) + (X_{1i}\beta_1 - X_{0i}\beta_0) + (\sigma_1\mu_{1i} - \sigma_0\mu_{0i}) \tag{4b}$$

However, due to the non-random selection of participants into BVIS, it becomes unrealistic to take the difference between the outcomes of participants and non-participants in order to measure the impact of BVIS on agricultural income and daily per capita caloric intake. This is the case considering that for any participant, it is impossible to observe the agricultural income and per capita caloric intake simultaneously under two mutually exclusive states of nature (with versus without BVIS). In other words, this creates a missing data problem. In addition, the systematic differences in the observed and unobserved characteristics of participants and non-participants may also yield biased impact estimates, since their characteristics are not balanced.

The missing data problem is eliminated through developing counterfactual outcomes for participants based on observed covariates assuming that the study households were not participating in BVIS. This is expressed as E(y_{1i} | X, j=0) and E(k_{1i} | X, j=0). In addition, a treated outcome was developed for participants based on observed covariates expressed as E(y_{1i} | X, j=1) and E(k_{1i} | X, j=1) as $E(y_{1i} | X, j = 1)$ and $E(k_{1i} | X, j = 1)$. To measure the impact of BVIS on agricultural income and daily per capita caloric intake, the difference between the treated and the counterfactual outcomes was used. This is expressed as:

$$\text{E(Y)=}\ \underbrace{E(y_{1i} | X, j = 1)}_{Treated\quad outcome} - \underbrace{E(y_{1i} | X, j = 0)}_{Counterfactual\quad outcome} \tag{5a}$$

$$\text{E(K)=}\ \underbrace{E(k_{1i} | X, j = 1)}_{Treated\quad outcome} - \underbrace{E(k_{1i} | X, j = 0)}_{Counterfactual\quad outcome} \tag{5b}$$

However, estimation of E(Y) and E(K) conditional on observed covariates in equation (5a) and (5b) leads to a dimensionality problem (Heinrich et al. 2010). In other words, as the number of covariates increases, it becomes cumbersome to identify the observations which are close to each other among participants and non-participants. A solution to this is to use the conditional probabilities commonly referred to as propensity scores (Rosenbaum and Rubin, 1983). Therefore, propensity scores estimated in equation (2a) and (2b) were used. Equation (5a) and (5b) can be re-written as:

$$E(Y)= \underbrace{E(y_{1i} \mid p_{i1})}_{Treated\ outcome} - \underbrace{E(y_{1i} \mid p_{i0})}_{Counterfactual\ outcome} \tag{6a}$$

$$E(K)= \underbrace{E(k_{1i} \mid p_{i1})}_{Treated\ outcome} - \underbrace{E(k_{1i} \mid z, p_{i0})}_{Counterfactual\ outcome} \tag{6b}$$

Equation (6a) and (6b) were estimated using the Propensity Score Matching (PSM) technique following Rosenbaum and Rubin (1983); Caliendo and Kopeinig (2005); and Khandker et al. (2010) .The study also assumed that there may be sample selection bias which, if not addressed, may result in biased E(Y) and E(K). In this regard, the methodology was extended to control for endogeneity and sample selection bias.

To account for selection biases described in the theoretical framework, the choice of participation of the study household and the outcome equations for household agricultural income or daily per capita caloric intake were modeled simultaneously in a two-stage framework using an endogenous switching regression model. In the first stage, the choice equation for participating in BVIS was modeled using equation (1b). In the second stage, farmers face two regimes – to participate, or not to participate – defined in equations 3a through 3d. In order to simultaneously model the selection equation (1b) and outcome equations (3a and 3b), a full maximum likelihood estimation method was used. The method was used because the estimation of the selection and outcome equations using maximum likelihood estimation and two-step least square provides inefficient estimates (Lokshin and Sajaia 2004).

We assumed a trivariate normal distribution, with zero mean and a covariance matrix represented by Σ, i.e., (ε, u_1, u_0) ~ (0, Σ). This assumption was made considering the correlation between error terms in the selection equation and outcome equations, respectively, due to systematic differences in agricultural income or per capita caloric intake with and without BVIS. The covariance matrix Σ is expressed as follows:

$$\Sigma = \begin{bmatrix} \sigma_{\varepsilon}^{2} & \sigma_{\varepsilon 1} & \sigma_{\varepsilon 0} \\ \sigma_{\varepsilon 1} & \sigma_{1}^{2} & . \\ \sigma_{\varepsilon 0} & . & \sigma_{0}^{2} \end{bmatrix} \tag{7}$$

where σ_{ε}^{2} is the variance of the error term in the selection equation (1b), which can be assumed to be equal to 1, since the coefficients are estimable up to scale factor (Maddala 1983); σ_1^2 and σ_0^2 are the variances of the error terms in the outcome functions; and $\sigma_{\varepsilon 1}$ $\sigma_{\varepsilon 0}$ are covariances between u's in the outcome function and ε in the selection equation. The covariance between u_1 and u_0 is not reported since y_1 and y_0 are not observed simultaneously.

Following Lokshin and Sajaia (2004), the full maximum likelihood estimation analytical approach was defined based on the trivariate normal distribution, with zero mean and covariance matrix $\sum$, as follows:

$$\ln L = \sum_{i=1} \{ j_i [\ln \phi(\frac{\mu_{i1}}{\sigma_1}) - \ln \sigma_1 + \ln \Phi(\theta_{1i})] + (1-j)[\ln \phi(\frac{\mu_{i2}}{\sigma_2}) - \ln \sigma_2 + \ln \Phi(\theta_{2i})] \} \tag{8a}$$

where ϕ (.) is the standard normal probability density function, Φ (.) is the standard normal cumulative density function, and:

$$\theta_{ij} = \frac{(\beta Z_j + \rho_j \varepsilon_{ij} / \sigma_j)}{\sqrt{1-\rho_j^2}} \quad j=1,0 \tag{8b}$$

where $\rho_1 = \frac{(u_1\varepsilon)^2}{\varepsilon^2}$ is the coefficient of correlation between u_1 and ε_i; and $\rho_0 = \frac{(u_0\varepsilon)^2}{\varepsilon^2}$ is the coefficient of correlation between u_1 and ε_i. To make sure that the estimated ρ_1 and ρ_0 are bounded between –1 and 1, the estimated σ_j are always positive.

3. DATA SOURCES, DESCRIPTIVE STATISTICS AND ASSUMPTIONS

The study purposively selected BVIS because it is one of the oldest modern irrigation schemes in Malawi. Despite this, the operations and welfare impact of the irrigation scheme have not been evaluated since the completion of the rehabilitation works in 2008.

This study used simple random sampling to come up with a representative sample of 412 households (169 participants and 243 non-participants) to be used in the matching analysis. A household questionnaire was used to capture information from study households on their demographic and socioeconomic characteristics, incomes, asset and livestock ownership, benefits and costs associated with BVIS and rain-fed agriculture, marketing of agricultural produce, access to credit, access to extension services, and food security status in the 2011/12 agricultural season. Both quantitative and qualitative approaches were used to collect the data. Key informant and informal interviews were also used to gather in-depth information on the operation of the scheme.

The descriptive results in Table 3.1 show that there were statistically significant differences in socio-economic characteristics between participants and non-participants, youth and adults, female headed and male headed households, low and high income households. Differences are noticed for variables such as age and gender of household head, family size, total land size, rice yield, maize yield, farming experience, annual agricultural income and daily per capita caloric intake from maize and rice.

Table 3.1—Descriptive statistics of study households

Variables	All study households	Irrigation			Youth		Gender		Income status	
		Non-participants in scheme	Participants growing rice	Participants growing rice & maize	Youth-headed households	Adult-headed households	Male headed households	Female headed households	Low income	High income
Age (years)	40.5 *(0.81)*	41.1 *(1.08)*	37.4 *(1.33)*	40.8 *(1.84)*	28.2 *(0.35)*	52.1 *(0.98)*	38.7 *(1.49)*	40.9 *(0.93)*	41.2 *(1.06)*	38.7 *(1.12)*
Family size	5.1 *(0.09)*	5.0 *(0.11)*	5.6 *(0.19)*	5.4 *(0.24)*	4.8 *(0.11)*	5.6 *(0.13)*	5.2 *(0.10)*	5.1 *(0.19)*	5.0 *(0.11)*	5.5 *(0.15)*
Credit amount (MK)	9,183 *(981)*	10,541 *(1,411)*	8,386 *(1,903)*	5,975 *(1,602)*	8,733 *(1,215)*	9,625 *(1,536)*	6,615 *(1,150)*	10,154 *(1,276)*	8,437 *(1,119)*	10,487 *(1,853)*
Total land size (ha)	0.7 *(0.08)*	0.8 *(0.12)*	0.5 *(0.11)*	0.4 *(0.07)*	0.7 *(0.10)*	0.7 *(0.12)*	0.8 *(0.10)*	0.5 *(0.08)*	0.6 *(0.08)*	0.8 *(0.17)*
Rice yield (kg/ha)	2754 *(52)*	2198 *(65)*	3170 *(122)*	3057 *(119)*	2545 *(80)*	2604 *(68)*	2616 *(63)*	2463 *(93)*	1277 *(31)*	4839 *(95)*
Maize yield (kg/ha)	1395 *(65)*	1514.4 *(96.9)*	1897.5 *(117.6)*	1050 *(55.4)*	837.9 *(20)*	1940 *(123.8)*	1509 *(82.9)*	976.7 *(56.12)*	977.7 *(38.5)*	2169 *(170.4)*
Farm experience (years)	17.3 *(0.65)*	19.5 *(0.93)*	14.3 *(1.03)*	13.8 *(1.19)*	10.2 *(0.49)*	24.3 *(0.98)*	18.3 *(0.79)*	14.6 *(1.08)*	17.4 *(0.87)*	17.2 *(0.94)*
Annual agricultural income (MK)	83,318 *(5,216)*	58,197 *(5,249)*	110,823 *(12,038)*	128,801 *(15,162)*	87,094 *(7,991)*	79,616 *(6,742)*	82,388 *(6,009)*	85,781 *(10,473)*	23,428 *(1,366)*	9,216 *(112,873)*
Daily per capita daily caloric intake from maize and rice	1574.8 *(49.3)*	1447.8 *(45.5)*	1584.4 *(80.2)*	1945.2 *(186.6)*	1725.9 *(78.8)*	1426.5 *(58.1)*	1900.2 *(147.5)*	1451.8 *(36.7)*	1519.7 *(48.2)*	1671.1 *(105.9)*
Male headed households	0.73 *(0.02)*	0.88 *(0.02)*	0.59 *(0.05)*	0.42 *(0.05)*	0.72 *(0.03)*	0.73 *(0.03)*	1.00	0.00	0.70 *(0.03)*	0.77 *(0.03)*
Proportion of household heads with some primary education	0.74 *(0.02)*	0.79 *(0.03)*	0.77 *(0.04)*	0.57 *(0.06)*	0.77 *(0.03)*	0.71 *(0.03)*	0.75 *(0.02)*	0.72 *(0.04)*	0.76 *(0.03)*	0.71 *(0.04)*
Observations	412	243	88	81	204	208	113	299	262	150

Source: own calculations.
Note: Values in parentheses are standard errors.

For irrigation status, the results in Table 3.1 show that there are statistically significant differences between participants growing rice and non-participants. These differences are noticed for variables such as family size, rice yield, maize yield, and annual agricultural income, with higher mean levels for all of these variables in favor of participants growing rice. Statistically significant differences were also noticed for variables such as total land size, farming experience, age and gender of household head in favor of non-participants.

Examining differences between participants growing rice and maize under irrigation and non-participants, the results show that there were statistically significant differences for variables such as family size, rice yield, maize yield, agricultural income and daily per capita caloric intake in favor of participants growing rice and maize. In addition, there were statistically significant differences in variables such as total land size, farming experience, age and gender of household head in favor of non-participants. Despite the non-participants having larger land holdings, the rice yields for both groups of participants were above those attained by non-participants. Informal interviews with non-participants revealed that floods and droughts affected rice yields.

Statistically significant differences for some variables are seen between participants growing rice under irrigation and those growing both rice and maize. Households only growing rice are more likely to be female-headed, have larger total land holdings, and the head is more likely to have gone to school.

Between the youth and adults, the descriptive statistics also showed that there were statistically significance differences in total land size, maize yield, farming experience, and age of household head in favor of adults. However, the descriptive statistics show that there was no significant difference in rice yields, agricultural income and daily per capita caloric intake between the youth and adults.

In term of gender of household head, the descriptive statistics show that there are statistically significant differences in total land size, and maize yield between female and male-headed households in favor of male-headed households. However, it was noticed that there are no statistically significant differences in annual agricultural income and daily per capita caloric intake between male and female-headed households.

Lastly, the descriptive statistics indicate that there are statistically significant differences in family size, total land size, rice yields, maize yields, annual agricultural income and daily per capita caloric intake between high and low income households. The differences were in favor of high income households.

One interesting observation was on access to credit. For all the marginalized groups, the descriptive statistics show that there were no statistically significant differences in the amount of credit obtained. However, it was noticed that individuals paid high interest rates (at least 400 percent). Further probing revealed a similar finding that for every MK1000 (US$5.95) borrowed; a farmer is supposed to pay a bag of rice in return. This practice is commonly referred to as “Chigoboza”. This practice is detrimental to low income households, as they are left in a poverty cycle.

Table 3.2—Pairwise correlation coefficients of selected variables

Variables	Irrigation participation	Agricultural income (MK)	Daily per capita caloric intake
Age of household head	-0.03	-0.05	0.10**
Family size	0.12**	0.09***	-0.06
Credit amount (MK)	-0.09	0.11**	0.10
Land size (ha)	-0.32*	0.26*	-0.04
Rice yield (kg/ha)	0.15	0.78*	0.52*
Maize yield (kg/ha)	-0.05	0.33*	0.10**
Farm experience	-0.19	-0.04	-0.03
Female head of household	-0.42*	-0.01	-0.07
Household head has some primary education	0.00*	-0.09***	0.02
Agricultural income	0.28*	--	0.44 *
Per capita daily caloric intake per day from maize and rice	0.19*	0.08** *	--
Observations	*412*	*412*	*412*

Source: own calculations
Note: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance).

Results in Table 3.2, show that rice and maize yields are positively correlated with agricultural income and daily per capita caloric intake. We also find that participation into BVIS is positively correlated with agricultural income and daily capita caloric intake. The positive correlation indicates that irrigation might increase agricultural income and per capita caloric intake of beneficiaries.

To assess the impact of irrigation on food security and poverty, the PSM technique with probit was used to estimate the propensity scores of households participating in BVIS. However, there is no consensus on what type of covariates should be included in the discrete choice models when estimating propensity scores (Austin, 2011). For this study, variables were chosen that strongly influence participation in the irrigation scheme but weakly influence agricultural income or daily per capita caloric intake. These are described in Annex 1. The study also followed Rosebaum and Rubin's (2002) procedure called blocking, where the propensity scores were divided into blocks among the groups. The blocking was done to improve the balancing of covariates. The propensity scores for the blocks among the groups were not different between irrigation scheme participants and non-participants, thereby satisfying the balancing condition of propensity scores suggested by Becker and Ichino (2002). Following Lee (2006), the standard bias was used to test the balancing condition for the entire blocks due to the non-normality of the data in these blocks.

Another important assumption that also was adhered to is the common support and overlap assumption to ensure that households with the same *X* or *Z* values have a positive probability of being either participants or non-participants (Heckman, LaLonde, and Smith, 1999). In this regard, the common support for participants on the full sample was 0.040 and 0.977, with 8 percent of the sample being outside the common support region. This sub-sample was dropped from the analysis. The common support for participants growing rice was between 0.046 and 0.810, with 5 percent of the 331 households being dropped from the analysis as they violated the tenet of common support. The common support for participants growing both rice and maize was between 0.035 and 0.930, with 33 percent of the 324 households being dropped from the analysis as they violated the tenet of common support. The common support for marginalized participants was between 0.049 and 0.848, with 7 percent of the 412 households being dropped from the analysis as they violated the tenet of common support. In addition, there was a perfect overlap between participants and non-participants.(See Annexes 2 to 5.)

Considering that the common support and overlap condition are met, the balancing of covariates was done between participants and non-participants. Caliendo and Kopeinig (2005) provide several procedures of testing the balancing condition, including standard bias, t-test, joint significance, pseudo-R^2 and stratification. However, the variables used in our probit model were not normally distributed, hence the use of t-test could have led to misleading results (Lee 2006). Therefore, the study used the standard bias to test the balancing condition for the variables which were not normally distributed. After matching, all the variables listed in Annex 6 had a standard bias of less than 20 percent, indicating there was a balance between covariates of participants and non-participants for the groups.[2]

4. EMPIRICAL RESULTS

4.1 The impact of irrigation on poverty

The study assessed the impact of irrigation on poverty using household agricultural income as the outcome variable. Thus, the Average Treatment Effect (ATT) was estimated using equations (6a) and (6b) in the region of common support (see Annex 2 to 5). The ATT's were derived using three matching estimators, namely, nearest neighbor, radius, and kernel matching. The three matching estimators were used to check the consistency of the PSM results. Endogenous switching regression was used to adjust estimates of household agricultural income for sample selection bias. The σ_j and ρ_j coefficients were statistically significant, indicating that endogenous switching was appropriate and that sample selection bias was present (use Annex 7). Table 4.1 shows both bias-adjusted and unadjusted estimates of the ATT from three matching methods. For the sake of brevity, we report in the text primarily the results from nearest neighbor matching only.

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[2] Rosenbaum and Rubin (1985) suggest that a standardized difference that is greater than 20 percent should be considered as "large."

Table 4.1—Average treatment effect for annual household agricultural income for irrigation scheme participants, MK

		Nearest Neighbor		Kernel		Radius	
Treatment	Bias adjustment	ATT	Control Mean	ATT	Control Mean	ATT	Control Mean
Full sample (n =412)	No	90,261* *(12,088)*	29,179	87,047** *(15,153)*	32,392	87,639** *(15,649)*	35,282
	Yes	46,697* *(13,271)*	71,932	42,619 38,808	76,009	42,879 *(31,060)*	81,806
Rice participants (n=331)	No	73,268*** *(21,189)*	41,046	77,365** *(16,028)*	33,457	62,897 *(17,389)*	44,609
	Yes	51,440*** *(29,766)*	27,684	57,941** *(14,511)*	19,342	60,226*** *(14,473)*	19,581
Rice & maize participants (n=324)	No	115,367 *(18,717)*	28,497	114,438** *(19,608)*	26,580	122,990** *(23,091)*	30,627
	Yes	80,600** *(15,808)*	60,015	71,080 *(55,565)*	65,987	78,562*** *(21,174)*	74,234

Source: own calculations

Note: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance). Figures in parentheses are standard errors. ATT = Treated mean - Control Mean

Table 4.1 indicates that there were differences between bias-adjusted and bias-unadjusted estimates implying that the PSM is sensitive to the unobserved characteristics. The bias-adjusted estimates are consistently lower than the estimates obtained when bias is not controlled for. Overall, the bias-adjusted results using nearest neighbor matching on the full sample indicate that participants in the irrigation scheme earned on average MK 46,697 above what they could have earned if they did not participate in BVIS. The results were significant at the 10 percent level. This represents a 65 percent increase in annual agricultural income.

Growing only rice under irrigation increases the average agricultural income of the participating households over those not engaging in any irrigated production by MK 51,440 using the bias-adjusted nearest neighbor matching method. This result is statistically significant at the one-percent level. This represents an increase a 185 percent increase in annual agricultural income. The results indicate that participants growing only irrigated rice earn more agriculture income annually than what they could have earned if they did not participate in the irrigation scheme. The results using nearest neighbor matching were consistent with those of kernel and radius matching.

For participants growing both irrigated rice and maize, there are large differences between the bias-adjusted and bias-unadjusted estimates, with all bias-adjusted estimates being lower than the unadjusted estimates. The bias-adjusted estimate using the nearest neighbor method shows that using irrigation to produce both rice and maize increases the annual agricultural income of participants by MK80,600. The estimate is statistically significant at the 5 percent level. This represents a 134 percent increase in annual agricultural income over what they would have earned if they only concentrated on rain fed agriculture.

Through comparing the estimates from the two groups who grew crops under irrigation, we noticed that growing both rice and maize under irrigation increased agricultural income by 34 percent for the farming household over their counterparts that only grew rice under irrigation. This was because participants growing both rice and maize had maize to consume and a balance of rice to sell, while participants growing rice only had to allocate some of their rice for consumption and some for sale.

4.2 The impact of irrigation on food security

The study also assessed the impact of irrigation on household food security using the three matching estimators. For the sake of brevity we use the results from nearest neighbor matching method. In this regard, daily per capita caloric intake from maize and rice consumption was used as the outcome variable. Table 4.2 shows both bias-adjusted and unadjusted estimates of the ATT from three matching methods.

Table 4.2—Average treatment effect for daily per capita caloric intake from maize and rice, kcal

		Nearest Neighbor		Kernel		Radius	
Treatment	Bias adjustment	ATT	Control Mean	ATT	Control Mean	ATT	Control Mean
Full sample (n =412)	No	284** (167.4)	1101	427*** (91.9)	1012	397*** (85.1)	1041
	Yes	103** (44.2)	1009	109* (26.6)	1101	112*** (42.5)	1000
Rice participants (n=331)	No	281** (138.9)	1120	349*** (82.7)	1052	353*** (79.8)	1062
	Yes	131** (59.9)	1020	105** (35.9)	1044	106*** (34.28)	1044
Rice & maize participants (n=324)	No	467** (235.6)	988	376*** (129.8)	1123	362*** (116.5)	1093
	Yes	122** (60.2)	1069	96.3** (43.6)	1086	133*** (43.4)	1057

Source: own calculations

Note: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance). Figures in parentheses are standard errors. ATT = Treated mean - Control Mean. The per capita caloric intake per day is based on consumption of maize and rice only.

The results in Table 4.2 showed that irrigation has a positive impact on the daily per capita caloric intake of participants. Overall, the bias-adjusted estimate using nearest neighbor matching showed that irrigation increased the daily per capita caloric intake for participants by 103 kilocalories. This represented an average increase of 10 percent more than what participants would have consumed if they did not participate in the irrigation scheme. The results from the nearest neighbor matching method were consistent with the other matching methods.

We also assessed whether farming households growing rice in the irrigation scheme had higher daily per capita caloric intake than what they would consume in they did not participate in irrigation. From the results, both of the estimates from the three matching methods were significantly different from zero statistically. The results using nearest neighbor matching indicate that participants growing rice consumed on average 131 kilocalories from maize and rice more than what they would have consumed if they did not participate in the irrigation scheme. This represents an average increase of 13 percent. The results from nearest the neighbor matching were consistent with the results from the other matching methods.

Similarly, for participants growing both rice and maize under irrigation, the estimate using nearest matching showed that growing more than one crop under irrigation relative to those not growing crops with irrigation led to an increase in daily per capita caloric intake by 122 kilocalories. This result indicates that participants growing rice and maize daily consume 11 percent more calories from maize and rice than what they would have consumed if they did not participate in the irrigation scheme. The results from nearest neighbor matching were consistent with the results from the other matching methods.

Results further indicate that there was no difference in daily per capita caloric intake for those growing more than one crop and those only growing rice under irrigation. As stated earlier, participants only growing rice consumed most of their rice and had little rice to sell when compared with their counterparts growing more than one crop. This is one attributing factor that makes the daily per capita caloric intake to be indifferent between the two groups. These results conforms to those of other studies by Dillon (2007); Mangisoni (2007); Omilola (2009); and Gebregziabheri and Namara (2009) which indicate that irrigation has a positive impact on food security and poverty.

4.3 Do marginalized households benefit from participating in BVIS?

PSM in combination with endogenous switching regression was also used to assess whether marginalized households benefit from participating in BVIS. The study focused on benefits in terms of household agricultural income only. The analysis is run on sub-group data for female headed households, low income households, and youths, as indicated in Table 4.3. However, we use the results from the nearest neighbor matching method to present our findings.

Table 4.3—Average treatment effect for annual household agricultural income for marginalized group member households participating in irrigation scheme, MK

Treatment	Bias adjustment	Nearest Neighbor		Kernel		Radius	
		ATT	Control Mean	ATT	Control Mean	ATT	Control Mean
Full sample (n =412)	No	90,261* *(12,088)*	29,179	87,047** *(15,153)*	32,392	87,639** *(15,649)*	35,282
	Yes	46,697* *(13,271)*	71,932	42,619 38,808	76,009	42,879 *(31,060)*	81,806
Youth (n =194)	No	101,525 ** *(18,145)*	39,614	105,551 *(18,061)*	34,087	115,585** *(19,524)*	35,035
	Yes	58,373 *** *(17,183)*	72,544	58,219*** *(17,865)*	71,445	59,335 *(18,791)*	71,582
Female-headed (n=299)	No	80,352*** *(22,560)*	51,006	93,148** *(16,713)*	38,210	84,034 ** *(17,542)*	45,630
	Yes	55,430*** *(15,789)*	64,154	53,167*** *(15,288)*	65,275	53,167*** *(15,288)*	65,275
Low-income households (n=262)	No	11,523 *(4,482)*	21,405	13,723** *(3,755)*	19,205	11,066*** *(4,031)*	20,950
	Yes	11,405 *(9,124)*	57,178	8,891 *(10,923)*	59,691	10,462 *(9,119)*	58,120

Source: own calculations

Note: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance). Figures in parentheses are standard errors. ATT = Treated mean - Control Mean

The average bias-adjusted ATT for youth estimated using the nearest neighbor method was MK58,373. The ATT was significant at the 5 percent level. This indicates that irrigation has a significant positive impact on the agricultural income of youth-headed households. In other words, the youth benefited from irrigation and earned about 81 percent more annual agricultural income than what they could have earned if they did not participate in the irrigation scheme.

The average bias-adjusted ATT for female-headed households estimated using the nearest neighbor method was MK55,430. The ATT was significant at the one-percent level. Irrigation is shown to have a positive impact on the agricultural income of the female headed households. The female headed households benefited from irrigation and earned about 86 percent more annual agricultural income than what they could have earned if they did not participate in BVIS. In addition, construction of 13 boreholes within the 14 villages as part of the BVIS project is likely to have reduced the time that women spend to fetch water, enticing greater participation from female headed households in agricultural activities within BVIS. The results were consistent with the other matching methods.

The average bias-adjusted ATTs for low-income households estimated using all three methods of analysis were not significantly different from zero statistically. However the unadjusted ATTs using the kernel and radius methods were both statistically significant and positive, indicating that irrigation had a positive impact on agricultural income of the low-income households.

Considering that we used similar observed covariates to derive the propensity scores, it was possible to compare these between the sub-groups. It was noticed that the youth earned more agricultural income than the other marginalized groups. The low-income households earned the least agricultural income among the marginalized groups. However, the significant differences in annual agricultural income earned between the different marginalized groups provides evidence that there are some flaws in the design and operation of BVIS as low-income households are benefiting less than their counterpart traditionally marginalized groups – female-headed households and youth-headed households.

4.4 Insights for improving BVIS operations

The study also used qualitative approaches (key informant and informal interviews) to gain insights and lessons that could be used to improve the operations of the BVIS and to design better interventions. According to Baker (2000), integrating quantitative and qualitative evaluations methods can often be the best vehicle for meeting the information needs of a program.

Availability of adequate irrigation water is the main determinant of whether crops can be produced at least twice a year. Interviews with key personnel of the scheme and farmers were done to understand if there is adequate water supply at BVIS. It was observed that only one-quarter of the scheme was utilized during the dry season due to inadequate water supply. This resulted in few participants growing a combination of irrigated crops. Staff from the scheme management indicated that the construction of new irrigation schemes upstream had resulted in low water supply at

BVIS. This has compromised the ability of BVIS members to grow a combination of crops at least twice a year. This indicates a reversal in the operations of BVIS, as Chidanti-Malunga (2009) indicated that rice was grown in the scheme twice every year. Further probing revealed that guidelines for the granting of water abstraction rights were not adhered to by the irrigation schemes upstream.

In addition, scheme participants growing their crops on the one-quarter of the BVIS area that received water in the dry season also faced problems of water distribution. It was reported by some of the farmers that members of the BVIS water management sub-committee expected to receive bribes from farmers requiring water. If the farmers did not oblige, their crops would not receive water. Thus, scheme participants with higher income are favored to get water to irrigate their crops in the dry season, since they are able to pay members of the water management sub-committee who makes decisions on the distribution of water. This finding concurs with work by Chidanti-Malunga (2009). The problem of water supply has prompted the European Union to finance the construction of a dam to supply adequate water to BVIS during the dry season.

In terms of marketing, it was observed that farmers do not engage in any value-addition with their harvested rice. Hence, they sell it at low prices. Moreover, the BVIS cooperative does not provide a proper market for rice for participants. For instance, the cooperative only sells about one thousand bags of paddy rice out of the 60,000 harvested by scheme participants annually. Most of the paddy rice is sold at low prices of around MK40 per kg at the farm gate to vendors who normally dictate prices. The majority of farmers do not use the cooperative to market their rice due to delays in payment from the rice buyers. Furthermore, it was commonly found through interviews with traders who were buying rice at the BVIS that they sell the rice to schools and hospitals based on agreed contracts. This implies that the traders are taking advantage of the imperfect information on market opportunities and a lack of skills in contractual relationships among the BVIS cooperative members and its leadership. Thus, if cooperatives can strike business partnerships with schools, hospitals and prisons for those institutions to purchase rice directly from the cooperative; member farmers of the cooperative are likely to realize more competitive prices for the rice that they offer for sale. However, the government and other stakeholders will need to provide capacity building to cooperatives in the areas of business partnerships and contract relationships.

Finally, our qualitative studies found that the BVIS cooperative does not provide credit facilities to beneficiaries due to inadequate capital. The annual fees, water fees per plot, and selling shares charged to farmers by the BVIS cooperative have not been reviewed since 2008. It is these fees and charges from which comes the capital for the operation of the BVIS cooperative.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

This study assessed the impact of irrigation on household food security and agricultural incomes using a PSM method using probit in combination with an endogenous switching regression. Overall, the findings revealed that irrigation had a positive impact on household food security and agricultural incomes. However, the impact on daily per capita caloric intake per day was similar among both groups of participants. In contrast, participants growing both rice and maize earned more annual agricultural income than did their counterparts growing rice only. The study also found that marginalized households – female and youth-headed households and low-income households – earned more annual agricultural income than what they would have earned if they did not participate in irrigated crop production.

Evidence from this study elicits several crucial issues that are important to future studies and also to the design, operation, and up-scaling of irrigation projects in Malawi. First, our findings provide empirical evidence that irrigation interventions that allocate uniform pieces of land and construct water facilities for beneficiaries will reduce poverty, as evidenced by the marginalized groups attaining higher income than what they could have earned if they did not participate in BVIS. However, despite the marginalized households benefiting from irrigation, the study found that there are some flaws in the design and operation of BVIS, as low-income households are benefiting less than youth-headed and female-headed households. Evidence from this study of the BVIS also showed that there were some flaws in either the design or operation of BVIS in the areas of marketing, provision of credit facilities, and water supply and allocation.

Several policy recommendations can be drawn from the study findings. First, given that irrigation reduces poverty, irrigation interventions should be extended to other areas in Malawi. However, when expanding irrigation, it is important to consider the growing of a combination of crops such as maize (staple food) and other cash crops, such as rice, as opposed to growing a single crop.

Second, evidence from BVIS shows that there is poor marketing by the irrigation cooperative, as the majority of farmers sell their farm produce to individual traders. It is important for cooperatives to promote bulk marketing of farm produce under contracts with institutions (i.e. schools, prisons, hospitals) or larger private traders (both local and foreign).

Contract relationships will assure supplies and sales over the entire year or growing season and minimize individual selling of farm produce at low prices. However, in order to foster business partnerships and contract relationships, government and other stakeholders should provide capacity building in these areas.

Third, the findings also reveal that the BVIS cooperative does not provide credit facilities to members due to insufficient capital that results from the low charges and fees collected by the cooperative. The study recommends that charges and fees be periodically reviewed according to prevailing market conditions in order to assist the cooperatives to provide credit facilities. It is envisaged that the provision on credit facilities will reduce the "*Chigoboza*" practice.

Finally, evidence from this study shows that BVIS is facing problems of water supply due to the construction of other irrigation schemes upstream. The Ministry of Irrigation and Water Development should strengthen the allocation of water abstraction rights to safeguard older irrigation schemes and minimize the problems of water supply in future irrigation schemes.

The study focused on the direct impact of irrigation on household food security and income. However, considering that rice is sold to traders and consumers in other areas within Malawi, there may be other indirect impacts. Therefore, future studies should also focus on the spillover effects of irrigation interventions. In addition, future research should also analyze the sources of income disparity among the low and high-income households participating in such irrigation schemes.

ANNEXES

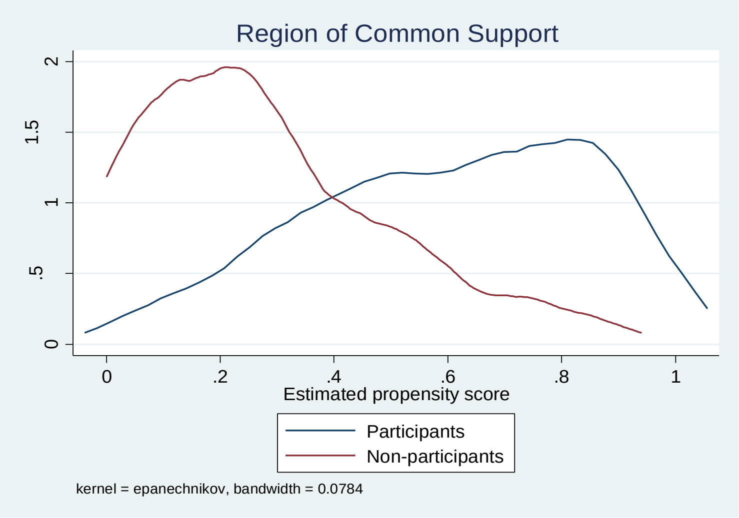
Annex 1 Probit results for propensity score matching

Variables	Participants growing rice only	Participants growing rice and maize	Marginalized groups
Household size	0.188* *(0.0476)*	0.142* *(0.0499)*	0.139* *(0.0369)*
Age	0.009 *(0.0058)*	0.003 *(0.0056)*	NA
Education	-0.966* *(0.1957)*	-0.091 *(0.1728)*	-0.114* *(0.1325)*
Gender	-0.379** *(0.1804)*	-1.222* *(0.1958)*	NA
Land size	-0.380 * *(0.0846)*	-0.778* *(0.1398)*	-0.565* *(0.0743)*
Constant	1.255*** *(0.6854)*	0.661 *(0.5708)*	0.259 *(0.4443)*
Pseudo R^2	0.195	0.362	0.159
Observations	*331*	*324*	*412*

Source: Own calculations

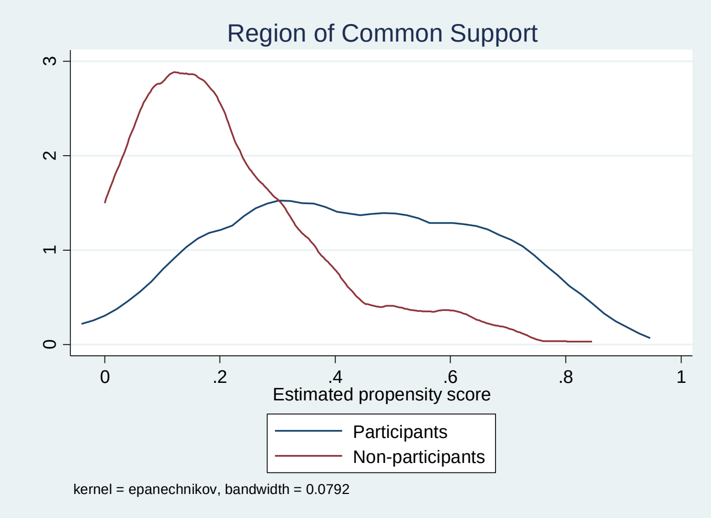
Note: Asterisks represent level of statistical significance: * (10% significance), ** (5% significance), *** (1% significance). Figures in parentheses are standard errors.

Annex 2 Distribution of propensity scores for the full sample



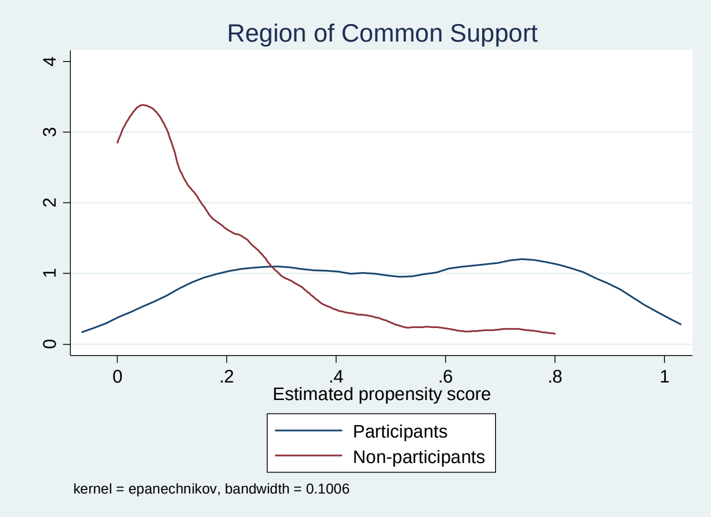
Source: Own calculations

Annex 3 Distribution of propensity scores for participants only growing rice under irrigation



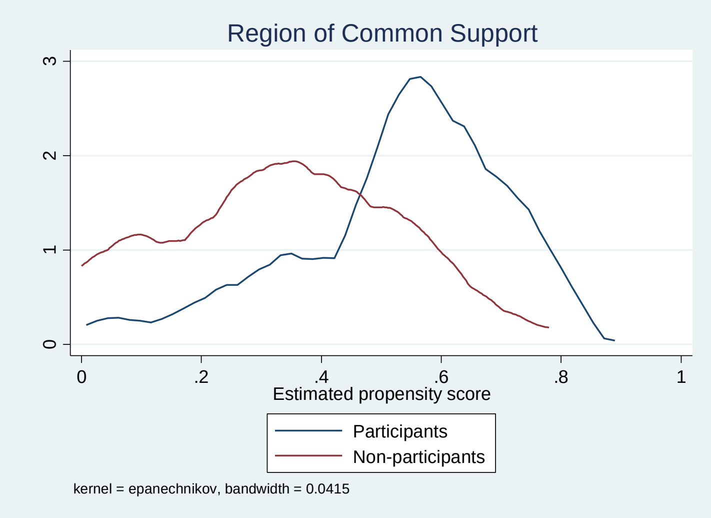
Source: Own calculations

Annex 4 Distribution of propensity scores for participants only growing both rice and maize under irrigation



Source: Own calculations

Annex 5 Distribution of propensity scores for marginalized households



Source: Own calculations

Annex 6 Balancing of observed covariates

Variables	Participant (full sample)			Participant – rice only			Participant – rice and maize			Marginalized groups (full sample)		
	Standardized bias (%) before	Standardized bias (%) after	% bias reduced	Standardized bias (%) before	Standardized bias (%) after	% bias reduced	Standardized bias (%) before	Standardized bias (%) after	% bias reduced	Standardized bias (%) before	Standardized bias (%) after	% bias reduced
Household size	28.6	20.0	27.0	34.4	7.2	79.1	22.1	5.5	75.0	28.2	-17.7	37.3
Age	-13.2	-2.6	79.9	-24.8	11.6	53.3	-2.0	-6.8	-240.5	na	na	na
Gender	-86.7	3.3	96.2	-68.0	7.8	88.6	108.4	1.8	98.3	na	na	na
Education	-3.2	14.4	351.0	-9.9	-4.1	59.2	2.9	-0.9	70.1	-3.2	6.6	-107.9
Land size	-76.7	1.4	98.2	-64.9	-3.3	94.9	-89.9	2.0	97.8	-76.7	-6.3	91.8

Source: Own calculations

Note: 'na' for the marginalized groups shows that age and gender were excluded. This was done in order to satisfy the conditional independence assumption, requiring that the outcome variables must be independent of participation decision conditional on the propensity score.

Annex 7 Checking validity of endogenous switching and presence of sample selection bias

Endogenous Regression		Participants (full sample)		Participants growing rice only		Participants growing rice and maize		Marginalized households (full sample)	
Outcome function	Switching Coefficient	Participants	Non-participants	Non-participants	Participants growing rice only	Non-participants	Participants growing rice and maize	Non-participants	Participants
Agricultural income	σ_j	77.76 *(3.619)*	110.50 *(6.671)*	76.59 *(3.501)*	98.84 *(10.713)*	76.57 *(3.476)*	103.10 *(8.538)*	77.76 *(3.619)*	110.50 *(6.671)*
	ρ_j	-0.20 *(0.176)*	-0.31 *(0.197)*	0.07 *(0.292)*	0.86 * *(0.088)*	-0.035 *(0.289)*	-0.17 *(0.402)*	-0.20 *(0.176)*	-0.31 *(0.197)*
Daily per capita caloric intake	σ_j	7.47 (0.45)	6.81 (0.36)	8.36 (0.70)	6.52 (0.3)	6.51 (0.30)	8.36 (0 .70)		
	ρ_j	0.87 (0.06)	0.55 (0.13)	0.22 (0.23)	0.79 (0.11)	0.22 (0.23)	0.79 (0.11)		
	Observations	*243*	*169*	*243*	*88*	*243*	*81*	*243*	*169*

Source: Own calculations

Note: Significance of σj indicates that the endogenous switch is valid while significance of ρj indicates the presence of sample selection bias. The difference between participants (full sample) and marginalized households (full sample) is that in the latter group, gender and age were excluded in order to satisfy the conditional independence assumption.

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