Impact of Irrigation on Food Security and Nutrition Outcomes Among Rice Farmers in Benin

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Abstract

Investing in irrigation development has been a priority of agricultural policy in Benin since 1960. This has resulted in the development of several irrigation schemes in the country. This study aims to assess the impact of irrigation on food security and nutrition outcomes among rice producers in Benin. It used survey data collected from 690 rice producers including 150 irrigators and 540 non-irrigators in the municipality of Malanville in Benin. An endogenous switching regression model was used to control for the selection bias and endogeneity issues related to the adoption variable. Access to credit, extension services, frequency of farmers-based organisation, access to media, market participation and distance to the irrigation scheme were the main determinants of participation in irrigation scheme. The results also showed positive impact of irrigation on dietary diversity, food consumption score and body mass index. This confirms the potential of irrigation in improving food security and nutrition outcomes among rice farmers in Benin.

Keywords: *Irrigation, food security, nutrition outcomes, rice, impact, Benin*

1. Introduction

Food and nutrition insecurity is still one of the major development issues in Benin. About 20% of households are food insecure (Institut National de Statistique et de l'Analyse Economique (INSAE), 2015a) and those with poor / limit food consumption are on average 23% (World Food Program (WFP), 2014). The daily energy intake of these households does not reach 2,400 kilocalories, a standard set by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). On average, one-third of Benin population suffer from hunger and malnutrition (Alaofè et al., 2016). For instance, chronic malnutrition increased from 32% in 2011 to 34% in 2014 (INSAE, 2015b), while the most affected are those living in rural areas and depend heavily on agriculture as main source of livelihoods. A report by World Food Program in 2014 indicated that households that depend on agriculture are more vulnerable to food insecurity with 21 % of them being food insecure and 48 % were at risk of food insecurity in 2013.

About 70 % of the active population in Benin rely on agriculture for their livelihoods. Like in most developing countries, agricultural productivity is very low in Benin due to poor soil conditions, low use of inputs, poor access to services and low level of investments in infrastructure including irrigation (FAO, 2014; WFP, 2014). Rainfed agriculture is still dominant, exposing farm production to climate change and variability. Moreover, Benin population is constantly increasing at 3.5% growth rate (INSAE, 2013). This high demographic growth rate, particularly in rural areas, increases pressure on food production and worsens food insecurity and malnutrition (Domenech and Ringler, 2013). Hence, it becomes vital to intensify agricultural production to meet the population's food demand. Doing so requires adoption of appropriate technologies. In this regard, empirical evidences (Carruthers et al., 1997; Huang et al., 2006; Domenech and Ringler, 2013) have demonstrated the importance of irrigation technologies in controlling weather risks and improving agricultural productivity. With irrigation, farmers can have several cropping seasons in a year. In the area where rainfall is scarce or poorly distributed, farmers can use irrigation as supplementary water source to cope with dry spells. In the dry season, when rainfed production is not possible, irrigated farm continues to operate and therefore has positive effects on employment[1], incomes, poverty (Hussain and Hanjra, 2004; Hanjra et al., 2009; Burney and Naylor, 2012) and nutritional outcomes (Domenech and Ringler, 2013).

The potential irrigable land area in the country is estimated at 322,000 hectares (ha), of which 205,900 ha is lowland and 117,000 ha account for upland that could be irrigated in the hydrographic units of Ouémé, Mono and Niger. Since 1960, investments in irrigation is a top priority in agricultural policy in Benin with the aim to create the necessary conditions for modern, intensive and competitive agriculture, capable of ensuring the country's food and nutrition security and serving as a foundation for its economy, and for an integrated and sustainable management of available natural resources. Strengthening food and nutrition security, agricultural diversification, increasing productivity and conserving ecological heritage were the main objectives that can influence the management of water resources, and were set in the "Schéma Directeur de Développement Agricole et Rural[3] (SDDAR, 2000)", and "Lettre de Déclaration de la Politique de Développement Rural (LDPDR, 1991)". The first noteworthy actions in irrigation development dates back to the 1970s. With supports from multilateral, bilateral and non-governmental organizations including World Bank (WB), Food and Agriculture Organization (FAO), West African Rice Development Association (WARDA, now Africa Rice Centre), African Development Bank (AfDB) and Chinese technical partners, the government of Benin has constructed several irrigation schemes in the country. As a result of this public collaboration, irrigated land increased from 3,932 ha in 1975 to 9,724 ha in 1990, and to 23,040 ha in 2008 (FAO, 2018; Nonvide et al., 2018). Based on their financial capacity, farmers used several irrigation systems in Benin. Surface irrigation, sprinkler irrigation and drip irrigation are practiced on 46 %, 42% and 12% of the total irrigated area, respectively (FAO, 2005). Canal irrigation is used in all irrigated rice schemes in Benin whereas sprinkler irrigation and drip irrigation are mostly used for vegetable production. Producers often receive technical and financial assistance from the State and Non-governmental Organization (NGOs) involved in the hydro-agricultural purposes.

Recently, the need for irrigation development to achieve high yields and food and nutritional security has been reaffirmed in the Strategic Plan for Agricultural Sector Development (PSDSA) 2025 and in the National Plan for Agricultural Investments and Food and Nutritional Security (PNIASAN) 2017-2021. These plans define the guidelines for the development of irrigation facilities in Benin. These actions are based in particular on (i) support for the promotion of small irrigation scheme for peri-urban agriculture, (ii) support for the establishment of infrastructure and supplementary irrigation equipment for farmers, (iii) the promotion of pilot schemes for other crops, in this case horticultural productions and (iv) support for the development of small scale irrigation for the development of rice production and the promotion of intensive market gardening (MAEP, 2017).

The aim of government policy on irrigation development in Benin is to increase food crop production especially rice which occupies about 50 % of the total irrigated land (FAO, 2018). Rice is one of the main staple food crops retained in the PSDSA-2025 and in the PNIASAN 2017-2021 of Benin to achieve food and nutrition security. The goal is to irrigate 11,000 ha of rice plots (PSDSA-2025). The efficacy of public investment in irrigation in Benin has not been sufficiently addressed. Recent studies have shown the positive effect of adopting irrigation on yield in Benin (Nonvide, 2017, 2018). Other studies analyzed the success factors of the irrigation schemes (Totin et al., 2012; Djagba et al., 2014) and their efficiency (Zannou et al., 2018). So far, the links between irrigation schemes in the country and nutrition security has not been investigated. Exception is the study by Alaofè et al. (2016). This concern was also raised in a review by Domenech (2015) who found that while previous works have shown that irrigation contributes to improving yield and food security, in general, studies have not examined its impacts on nutrition. Thus, little is known on how irrigation policy affects nutritional outcomes among rural households. In addition, mixed evidence was found in the current literature for the impacts of irrigation on nutrition outcomes. In some contexts, positive impacts of irrigation on food security and nutrition outcomes was reported (Dillon, 2008; Nkhata et al., 2014; Pandey et al., 2016; Alaofè et al., 2016) while in other circumstances, no significant relationship was found between irrigation utilization and nutrition outcomes (Hossain et al., 2005; Shively et al., 2012; Hagos et al., 2017).

2. Problem statement

Malnutrition remains an important challenge in the world. In all its forms, malnutrition includes undernutrition (wasting, stunting, and underweight), inadequate vitamins or minerals, overweight, obesity, and resulting diet-related non-communicable diseases (World Health Organization, (WHO, 2018)[4]. About 1.9 billion adults in the World are overweight or obese, while 462 million are underweight (Global Nutrition Report, 2017; WHO, 2018). Malnutrition is more pronounced in developing countries, especially in sub-Sahara Africa (SSA) with 23% of people estimated to be undernourished in 2016 compared to the average of 20% and 11% for Africa and the world respectively (FAO et al. 2017).

In Benin, the nutritional situation also remains very worrying. Chronic malnutrition has increased from 32% in 2011 to 34% in 2016 (INSAE, 2015b; FAO et al., 2017) while prevalence over the threshold of 30% is considered critical by WHO. Severe stunting has a prevalence of 12.4% (INSAE, 2015b). The prevalence of moderate and severe underweight is 18.6% (INSAE, 2015b), while the prevalence of adult obesity is 7.1% in 2014 (FAO et al., 2017). The situation of malnutrition is more critical in rural areas (35.2% compared to 25.8% in urban areas) (MAEP[5], 2017) where access to food sources, health facilities and other infrastructure is very limited. However, Benin has significant agricultural potential to ensure food security and nutrition. By implementing its national food and nutrition policy and increasing access to a diversified diet, the country will have more opportunities to sustainably improve the nutrition and nutritional status of the population. Recently, Benin has launched the National Plan for Agricultural Investments and Food and Nutritional Security (PNIASAN)[6] 2017-2021 which retained rice as a key crop to improving nutrition security. In addition, the PNIASAN 2017-2021 defines the guidelines for the development of irrigation facilities with the aim to develop about 11,000 ha of irrigation scheme for rice production and 300 ha for polyculture. This shows the importance of irrigated rice system in reducing malnutrition in Benin.

This study seeks to provide answers to the following research questions: What is the participation level in irrigation scheme among rice farmers? What factors influence rice farmers' participation in irrigation scheme? And what are the impact of irrigation on food security and nutrition outcomes? By doing this, the study contributes to increase knowledge on the impact of irrigation on nutrition outcomes. It also provides the evidence base to support future irrigation policies to reduce hunger and malnutrition in Benin and in other countries with similar agro-ecological and socio-economic contexts.

3. Objectives

The main objective of the study is to empirically evaluate the impact of irrigation projects on food security and nutrition outcomes among rice farmers in Benin. The key outcomes variables of interest in this study are dietary diversity (DD), food consumption score (FCS) and Body Mass Index (BMI). These variables are used as proxy indicators for food security and nutrition outcomes.

The specific objectives are:

- to estimate the participation level in irrigation system among rice farmers.
- to ascertain the factors influencing farmers participation in rice irrigation system.
- to assess the impact of participation in rice irrigation system on food security and nutrition outcomes.

4. Hypotheses

The key hypotheses to be tested in this study are:

- Socio-economic and demographic factors as well as institutional variables do not influence farmers decision to participate in rice irrigation system.
- Participation in rice irrigation system does not impact food security and nutrition outcomes (DD, FCS, and BMI).

5. Literature review

Several papers have indicated that the development of irrigation can enhance agricultural productivity, increase income and contribute significantly to food security and poverty reduction (Bhattarai and Narayanamoorthy, 2003; Hussain and Hanjra, 2004; Huang et al., 2006; Burney and Naylor, 2012; Bagson and Kuuder, 2013; Sinyolo et al., 2014). But the important question is whether these results improved nutrition. In this regard, previous empirical works have concluded that improvements in farm productivity can be a powerful means to reduce under-nutrition among farmers (Gulati et al., 2012; Pandey et al., 2016). Domenech and Ringler (2013), suggest that irrigation can improve nutritional outcomes through increased yield and availability of food supplies and improved diet both in quantity and quality because it allows smallholder farmers to increase output with the same inputs. However, the potential of irrigation to improve nutritional outcomes depends on various factors including availability of water, type of irrigation technology, access to farm inputs and institutional environment governing access to water (Lipton et al., 2003; Domenech, 2015). An increase in food production due to use of irrigation without improvement of hygienic conditions is not sufficient to improve the nutritional status among rural farmers (Bénéfice and Simondon, 1993). Steiner-Asiedu et al. (2012) suggest that nutritional education is needed to realize the full potential of irrigation in improving nutritional outcomes.

Some empirical assessments (Veronicah et al., 2007; Steiner-Asiedu et al., 2012: Adam et al., 2016; Hagos et al., 2017) were based on a simple comparison test of nutritional outcomes between irrigation project participants and non-participants. In this groups of study, using mean difference tests (t-test and chi-square test) a study by Veronicah et al. (2007) revealed that the prevalence of stunting and underweight (indicators of long-term nutritional deprivation) were higher in non-project households than project households in Kenya. Based on farmers' perceptions assessment, a study by Adam et al. (2016) suggested that small scale irrigation schemes have contributed to improving household nutritional status in Eastern region of Ghana. Using mean difference tests between irrigation users and non-users, Hagos et al. (2017) found that the use of spate irrigation in Ethiopia did not have significant nutritional effects. This finding supports previous studies (Hossain et al., 2005; Shively et al., 2012) that found non-significant impact of irrigation on nutrition outcomes. For example, in Bangladesh, the use of irrigation contributed to increase rice intake, but the food diversity did not increase (Hossain et al., 2005). This shows that increased productivity due to the use of irrigation may not necessary translated into better nutrition, suggesting the need for nutrition-sensitive interventions, such as nutrition education to enhance the impacts of irrigation on nutrition outcomes (Hossain et al., 2005; Hagos et al.; 2017).

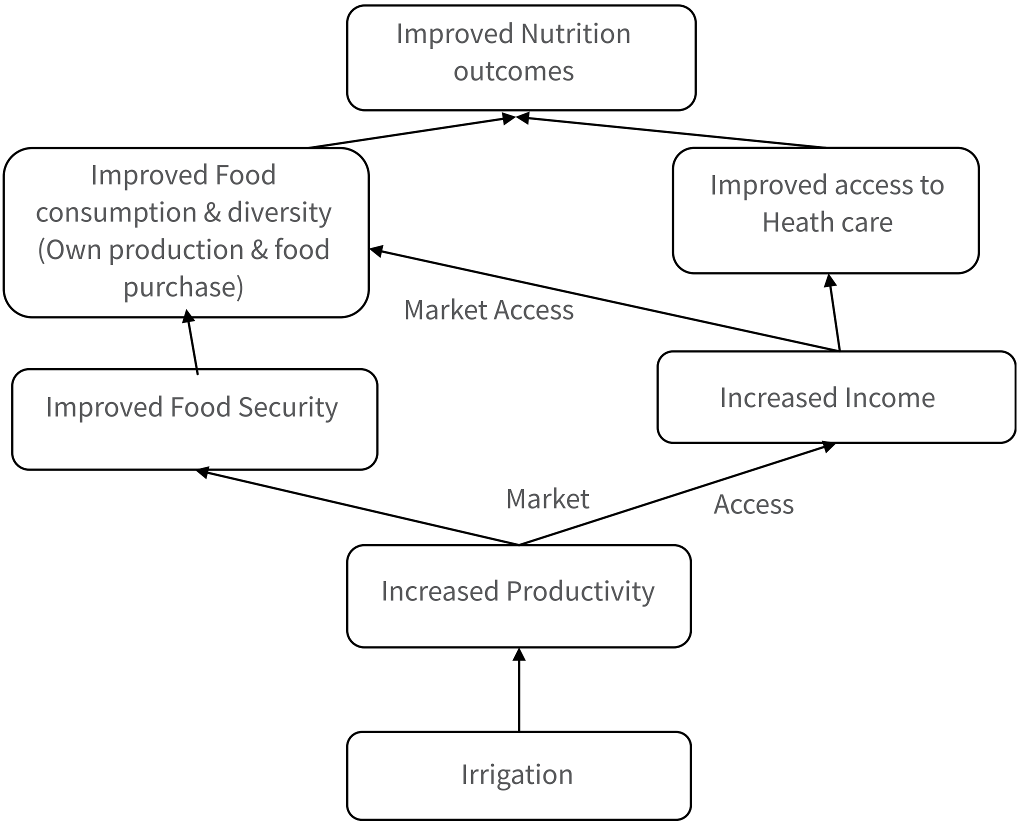
The main weakness of studies based on mean difference tests and perception assessment (Veronicah et al., 2007; Steiner-Asiedu et al., 2012: Adam et al., 2016; Hagos et al., 2017) is the lack of appropriate impact evaluation methods that may deal with the selection bias issue since programme participation is not random. Neglecting this may underestimate or overestimate the impacts of irrigation on nutritional outcomes. To correct this bias, Dillon (2008) employed a propensity score matching and difference in difference techniques with two rounds panel data (1998 and 2006) to analyze the impacts of irrigation in Mali. He found significant positive increases in consumption, agricultural production, and caloric and protein intakes for households with access to irrigation. The daily caloric intake increased by 1,836 calories for irrigators, whereas this decreased by 925 calories for non-irrigators. These findings proved that in an area with low agricultural potential like the arid zone of Mali, agricultural programmes aimed at irrigation can increase nutritional outcomes. Using similar method of analysis (propensity score matching technique) based on a case study of Bwanje Valley Irrigation Scheme in Malawi, Nkhata et al. (2014) found that access to irrigation facilities contributes to increase the daily per capita caloric intake by 10 % for irrigation farmers compared to non-irrigators. Furthermore, based on an experimental design, a study by Alaofè et al. (2016) analyzed the impact of solar-powered drip irrigation using solar market gardens (SMGs) on crop production diversity and dietary diversity in Benin. This study was conducted in four villages including two treatment villages and two matched-pair comparison villages in northern Benin. Solar market gardens were installed in the two treatment villages for women's agricultural groups engaged in horticulture. One year later, the comparison of baseline and endline data between treatment and control villages indicated increases in the variety of fruits and vegetables produced and consumed by farmers' using drip irrigation compared to other groups. The study also revealed that about 57% of the women used their additional income on food, 54% on health care, and 25% on education. This study has shown that solar-powered drip irrigation has the potential to improve nutritional status through direct consumption and increased income.

6. Conceptual framework

Agriculture plays an important role in reducing malnutrition by increasing crops and livestock productivity. Bhagowalia et al. (2012) suggest that agriculture programs that includes irrigation usage, have significant impact on dietary diversity through increasing productivity. Past studies (Lipton et al., 2003; Hussain and Hanjra, 2004; Domenech, 2015) have shown that irrigation can have direct impact on agricultural productivity in three main ways including reduction of crop loss, multiple cropping and expansion of irrigated land. In addition, the promotion of irrigation schemes is often accompanied with institutional supports in term of facilitation to other farm inputs like fertilizers, agrochemicals and improved seed. Therefore, irrigation will likely increase the stability of the food supply which may certainly favor greater food intake. Also, non-farm activities generated through increased demand of farm inputs and supply of outputs may increase the employment opportunities (Hussain and Hanjra 2004; Domenech, 2015), offering more opportunities for farmers to diversify their livelihood sources. This may result in an increase of total income. As income increases, farmers can afford more food for consumption and increase investments in health care (Domenech, 2015; Herforth and Ballard, 2016).

In this study, the impact of irrigated rice production on farmer's nutrition outcomes is considered mainly through two channels (see Figure 1): directly, through own consumption and indirectly, through its contribution to the total income. Yu (2012) argues that rice is a source of nutrition as home consumption, and a contributor of producer's income through sale of surplus production in the market. When combined together, direct consumption of own production and food purchases determine the complete nutritional intake of farmers. Indeed, rice production contributes to income increase through sale of produces in the market. In the particular context of this study where only rice is grown under the irrigation scheme, a better access to market is key to ensure higher incomes for farmers. Several marketing channels exist for rice producers in the municipality of Malanville and especially those operating on the irrigation scheme of Malanville. The State remains the major buyer of rice in the municipality of Malanville. Farmers can also sell their rice in the urban markets or export to the bordering countries such as Togo, Burkina Faso, Niger and Nigeria. Income generated may be used to purchase diverse food stuff rich in nutrition. This may contribute to an improvement of food consumption and diversity. In addition, irrigation farmers can increase investments in health care due to the increased income. All these may contribute to the improvement of farmer 's nutritional status.

Figure 1: Linkages between irrigation and nutrition



Source: Adapted from Hussain and Hanjra (2004) and Domenech (2015)

7. Research methods

As stated in section 3, this study assesses:

(a) the level of participation in irrigation system among rice farmers in Benin;
(b) the factors influencing farmer's decision to participate in irrigation system; and
(c) its impact on food security and nutrition outcomes among rice farmers.

Below the empirical framework and estimation techniques are discussed.

Empirical framework

Estimating index of participation in irrigation scheme

Commonly used approach to assess the adoption rate of new technologies is the simple computation of the percentage of adopters from the survey sample. However, this approach suffers from either "non-exposure bias" or "selection bias". As a result, the population adoption rates are generally biased and inconsistent even when based on a randomly selected sample (Diagne and Demont, 2007; Dibba et al., 2012; Nguezet et al., 2013). To solve this problem, Diagne and Demont (2007) used the average treatment effect (ATE) framework to estimate the potential adoption rate when the population's awareness of the technology is total. However, the potential adoption rate based on awareness alone still underestimates the true potential adoption rate of a new technology because being aware alone is not enough for adoption (Diagne, 2010; Nguezet et al., 2013). One may be aware but have no access to the technology. Nguezet et al. (2013) considered in their analysis both the lack of awareness and access as constraints to technology adoption.

Access to irrigation scheme is an important factor for its participation. The irrigation scheme of Malanville is designed to serve the five districts in the municipality. In the lack of data on awareness of irrigation scheme and to avoid computing a simple percentage of participants from the survey sample, the participation index measured by the intensity of adoption was estimated for individual rice producers with the following formula as adapted by previous studies (Philip et al., 2000; Saka et al., 2005; Adeogun et al., 2008):

$$A_Z = \frac{\sum_{i=1}^{n} L}{\sum_{i=1}^{n} L} \qquad (1)$$

Where: :A_z is the index of participation in irrigation scheme; L_I is the land area under the irrigation scheme and L_T is the total land area grown to rice by farmer *i*.

Analysis of farmer's decision to participate in irrigation scheme

Expected utility theory is the base of technology adoption decision. Therefore, a farmer's decision to participate in irrigation scheme in the municipality of Malanville, Benin can be analyzed within a random utility framework. Let U_{i1} be the utility obtained by a farmer i from participation in irrigation and U_{i0} the utility of non-participation. Let X_i be a vector of farm and farmer characteristics as well as institutional factors influencing participation in irrigation scheme, and ε_i the error term. According to the state of participation, the utility of farmer i can be approximated as follows:

$$\begin{cases} U_{i0} = f(X_{i0}) + \varepsilon_{i0} \\ U_{i1} = f(X_{i1}) + \varepsilon_{i1} \end{cases} \qquad (2)$$

A farmer i will choose to participate in irrigation scheme only if the utility derived from participating is greater than the utility from not participating. Mathematically, a farmer adopts irrigation if $U_{i1} > U_{i0}$. However, the utilities are not observable, the only thing we observe is the farmer decision. The utilities therefore can be expressed in the following latent structure model for participation in irrigation scheme:

$$Z_i^* = \gamma X_i + \varepsilon_i \qquad (3)$$

Where *Zi* is a binary variable for participation in irrigation with value of 1 in the case of participation and 0 in the case of non-participation. *Xi* is explanatory variables selected based on the literature (Dillon, 2008; Nkhata et al., 2014; Alaofè et al., 2016; Hagos et al., 2017). These include socio-economic characteristics such as age, experience in rice production, gender, educational level, off farm activities, access to media, distance to irrigation scheme, and institutional variables such as frequency of farmers based organization (FBO) meeting, access to credit and market participation.

Estimating the impact of participation in irrigation scheme

The outcome variables (food security and nutrition outcomes) are considered as a linear function of the binary variable for participation in irrigation along with the other explanatory variable.

$$Y_i = \lambda X_i + \beta Z_i + \mu_i \tag{4}$$

Where Y_i is the indicators of food security and nutrition outcomes, λ and β are vectors of parameters to be estimated and μ the error term. There is no single way to measure food security and nutrition. The study uses both dietary diversity score (DD) and food consumption score (FCS) approaches to measure food security and Body Mass Index (BMI) as proxy for nutrition status among rice farmers in Benin. The formula for estimating these outcomes are presented in equations E1, E2 and E3 (see appendix) respectively. The DD (equation E1) is defined as the number of different foods or food groups eaten over a reference time period, regardless of the consumption frequency. It reflects access to food variety and caloric availability since it is highly related with food consumption (Ruel, 2003). The FCS (equation E2) combines data on dietary diversity and food frequency over a recall period of the past 7 days. The food frequency provides an estimate of the percentage of individual affected. The FCS has been shown to be associated with various measures that are commonly considered proxy indicators of nutrition security, including food and non-food expenditures, per capita daily caloric availability (Hatløy et al., 2000; Jones et al., 2013; Berti et al., 2004; Carletto et al., 2013). The use of BMI shows whether improvements in access to food also lead to more nutritious diets. The respondent states the frequency of consumption of food groups as shown in Table A1 (see appendix).

The treatment variable and outcomes variables in equation 4 seems to be bi-causal in the sense that participation to irrigation scheme affects food security and nutrition outcomes, but at the same time farmers who adopt the irrigation scheme may be the ones who actually are more food secure and have better nutritional status. This reverse causality creates the endogeneity problem. Moreover, self-selection usually occurs in technologies adoption process. This is the case of participation in irrigation scheme in the municipality of Malanville, as farmers decide themselves to participate or not. Because of some unobservable characteristics (skill, motivation, risk preference, etc.), some producers are likely to adopt irrigation than others. Dealing with these selection bias and endogeneity issues requires proper econometric techniques. Various techniques used in the literature include the Heckman selection model (Tesfaye et al., 2008; Bacha et al., 2011; Nonvide, 2017), the propensity scores matching (PSM) methods (Mendola, 2007; Dillon, 2008; Owusu et al., 2011; Nkhata et al., 2014), the instrumental variables (IV) method (Bezu et al., 2014; Verkaart et al., 2017), and the endogenous switching regression (ESR) model (Di Falco et al., 2011; Asfaw et al., 2012). All these methods are complementary and rely on assumptions[7]. Jalan and Ravallion (2003) argue that the assumption of selection on observables in PSM approach is no more restrictive than eliminating problems of weak instruments with Heckman and IV models. The main advantage of the ESR model is the joint estimation of the selection and outcomes equations through a full information maximum livelihood (FIML) estimator (Carter and Milon, 2005; Asfaw et al., 2012). Other advantage is that the ESR model makes possible to calculate counterfactual outcome. That is, the ESR model will tell us by how much the DD or FCS or BMI of the non-adopter would have improved if he had adopted, and the loss in these indicators for the adopter, had he not adopted. This motivates the use of an endogenous switching regression model.

Estimation techniques: the endogenous switching regression model

Estimation of the ESR model consists of separate estimations for both of irrigators and non-irrigators. This suggests that participation in irrigation scheme becomes the selection criterion indicating which regimes farmer faces. The irrigation participation model is defined by equation (2). This is a probit model predicting factors that affect participation in the irrigation scheme. Following this equation, food security and nutrition outcomes are observed for the two regimes (Maddala, 1983; Di Falco et al., 2011).

Regime 1: $Y_{1i} = \alpha_1 X_{1i} + v_{1i}$ if Zi = 1 (for irrigators) (5)

Regime 2: $Y_{2i} = \alpha_2 X_{2i} + v_{2i}$ if Zi = 0 (for non-irrigators) (6)

Where Yi is the food security and nutrition indicators (DD, FCS and BMI), X_i a vector of explanatory variables influencing farmers' nutrition outcomes, v_i is the random disturbance term for each group. The unobserved variables influencing the likelihood of irrigation participation could also affect the nutrition outcomes, thus, the error term in equation (2) and those in equations (5) and (6) may be correlated posing issues of endogeneity and self-selection. To account for this, equations (2), (5) and (6) were simultaneously estimated using a FIML which remains the most efficient approach (Lokshin and Sajaia, 2004).

Following previous work (Heckman et al., 2001; Carter and Milon, 2005; Di Falco et al., 2011; Asfaw et al., 2012) the ESR model was used to compare the expected nutrition outcomes of irrigators (a) with respect to non-irrigators (b), and to investigate the expected nutrition outcomes in the counterfactual cases (c) that irrigators did not adopt, and (d) that non-irrigators did adopt. These measurements are essential in explaining difference in the nutrition outcomes between the two groups of farmers and possible responses to changes in irrigation policy. Table 1 presents the conditional expectations for nutrition outcomes for the four cases.

Table 1: Conditional expectations, treatment and heterogeneity effects

Sub-sample	**Decision stage**		**Treatments effects**
	Adopt	**Not adopt**	
Adopters	(a) $E(y_{1i}\|Z_i = 1)$	(c) $E(y_{2i}\|Z_i = 1)$	TT
Non-adopters	(d) $E(y_{1i}\|Z_i = 0)$	(b) $E(y_{2i}\|Z_i = 0)$	TU
Heterogeneity effects	BH$_1$	BH^0	TH

Note: (a) and (b) are the observed nutrition outcomes; (c) and (d) are the counterfactual expected nutrition outcomes. TT: Effect of the treatment on the treated; TU: Effect of the treatment on the untreated; BH$_1$: Base heterogeneity effect for adopters; BH$_0$: Base heterogeneity effect for non-adopters; TH: Transitional heterogeneity effect. The treatment effect on the treated (TT) is expressed in equation (7) as the difference between cases (a) and (c):

$$TT = E(y_{1i}|Z_i = 1) - E(y_{2i}|Z_i = 1) \tag{7}$$

Similarly, the treatment effect on the untreated is defined as:

$$TU = E(y_{1i}|Z_i = 0) - E(y_{2i}|Z_i = 0) \tag{8}$$

The study makes difference between the treatment effects and the base heterogeneity effects. The base heterogeneity effect is expressed by equation (9) for the irrigation farmers. This represents the difference between cases (a) and (d).

$$BH1 = E(y_{1i}|Z_i = 1) - E(y_{1i}|Z_i = 0) \tag{9}$$

For the non-irrigators, the base heterogeneity effect is expressed as the difference between cases (c) and (b):

$$BH2 = E(y_{2i}|Z_i = 1) - E(y_{2i}|Z_i = 0) \tag{10}$$

Finally, the transitional heterogeneity effect is calculated (equation 11). This helps to determine whether the impact of irrigation is smaller or larger for adopter and non-adopter relative to the counterfactual scenario, given by:

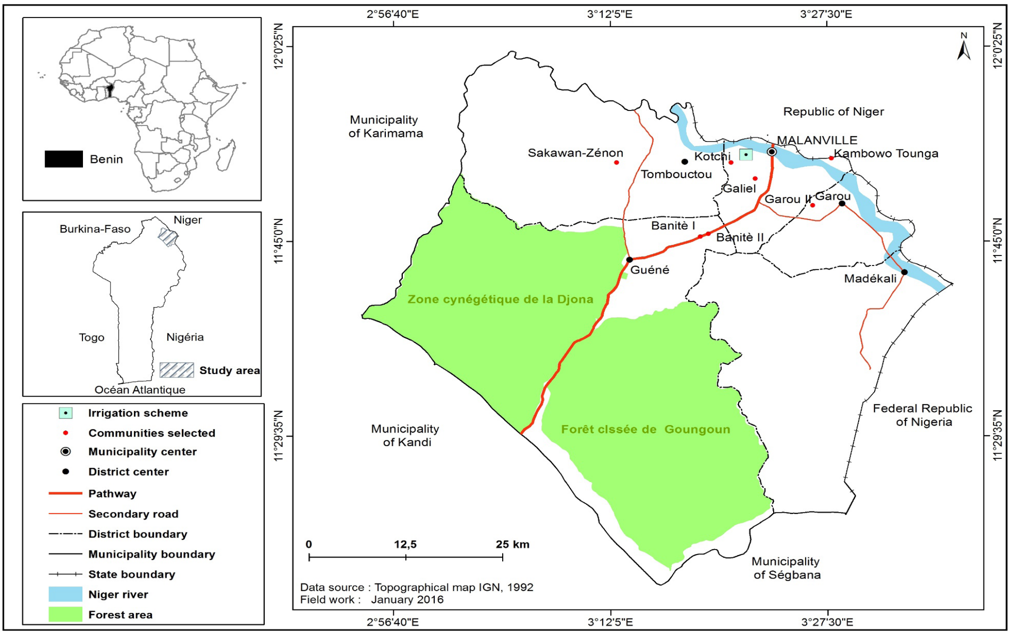
$$TH = TT – TU \tag{11}$$

The analysis was done with the STATA Software. A STATA command “movestay” was used to estimate the endogenous switching regression model by FIML (Lokshin and Sajaia 2004).

Data and descriptive statistics

Data used in this study was collected from individual rice farmers in 2015 in the municipality of Malanville in Benin. The physical location is shown in Figure 2. The data were collected under a sponsored Alliance for Green Revolution in Africa (AGRA) project in the Department of Agricultural Economics of the University of Ghana. It consists of a random sample of 690 rice farmers including 150 irrigators from the irrigation scheme of Malanville and 540 rainfed farmers[8]. The climate in the municipality of Malanville is Sudano-Sahelian with one rainy season which lasts from May to October. The amount of rainfall varies between 700 mm and 1000 mm. This low rainfall has a negative impact on crop production.

Figure 2: Map of study area showing selected communities and irrigation scheme



Majority of the inhabitants are involved in subsistence agriculture with maize, rice, millet, sorghum, cotton, and vegetables, the major crops grown. Other economic activities in the municipality include fishing, livestock rearing, small business, trade and crafts. The municipality is among the municipalities which experienced a highest rate of poverty (48%) in Benin (INSAE, 2013).

The municipality of Malanville was chosen for this study because it is the largest rice producing area in Benin. It is crossed by the Niger River and its tributaries which offer an important opportunity for rice production. Also, the rice irrigation schemes of Malanville is the most important in the country in terms of size and yield. The total irrigable land under the scheme is 516 ha of which 400 ha were used in 2015. The scheme was constructed in 1970. The water used is pumped from the Niger River and distributed into the farms through surface canals. Mono-cropping is practiced with rice produced by approximately 1054 farmers operating on the scheme in 2015. The State is the owner of the irrigated land and participation in the irrigation project is self-selective. Irrigated land size ranges from 0.25 ha to 2 ha. Farmers are classified in groups of 20 to 100 people with a total of 24 groups each leading by a committee of three (3) people. A broad committee of thirteen (13) members is in charge of managing the scheme with a role of ensuring water provision, other inputs and services from primary production to marketing. At the end of the cropping season, each farmer pays, in kind, three bags of 84 kg of rice per 0.25 ha to the committee. The committee is supposed to use a part of the fees collected to ensure the maintenance and rehabilitation of the irrigation system. But in reality, since 1990, the rehabilitation of the irrigation scheme is done every 10 or 15 years by the State.

Table 2 presents the characteristics of irrigation users and non-users. No significant differences were observed between irrigators and non-irrigators for the following variables; education, rice farming experience, engagement in off farm activities, ownership of radio and access to media. Regarding gender, men are more involved in rice production than women. About 81 % of the surveyed irrigation farmers and 72 % of the dry land farmers are male. This is explained by the fact that female farmers in developing countries in general and especially in Benin have limited access to resources particularly land. The mean age of the irrigators was 40 against 42 for rainfed rice farmers implying that relatively young people participate in the irrigation scheme than the older people.

Irrigation farmers used more inputs (fertilizer, herbicide and improved seed) than non-irrigators. For example, they used higher quantity of fertilizer; about 305 Kg per hectare whereas the non-irrigators applied on the average 226 Kg per hectare, which is below the recommended rate of 300 Kg/ha in the municipality of Malanville. There were also significant differences between the two groups of farmers regarding the institutional variables. For instance, the irrigators had more contact with extension agents. About 94 % of them received extension visits as against 49 % of the rainfed rice farmers. All the irrigators and only 31 % of the rainfed rice farmers belonged to rice farmers' organization. About 87 % of irrigators obtained credit in the past year as against 54% of rainfed rice farmers. With respect to the use of improved seed, all the irrigators used improved rice seed as against 44 % of rainfed rice farmers. In the municipality of Malanville, farmers primarily produced rice for market. This is because in this municipality, rice is not a staple food. About 70% of the rice produced is marketed. Irrigation farmers sold higher proportion (76 %) of their rice than that of the non-irrigation farmers (66 %). Also, the share of rice sale in total income is significantly higher for irrigation users (62%) compared to non-users (54%). This figure shows the importance of rice production as source of income in the municipality of Malanville in Benin.

Table 2: Socio-economic characteristics of the respondents

Variable definition	Measurement	Irrigators	Non-irrigators	t-test
Gender (%)	1 = Male 0 = Female	80.67 19.33	72.41 27.59	04.18**
Marital status	1 = married 0 = otherwise	80.67 19.33	92.22 07.78	16.98***
Membership of FBO	1 = Yes 0 = No	98.67 1.33	34.44 65.56	193.86***
Extension services (%)	1 = Yes 0 = No	94.00 06.00	48.89 51.11	98.53
Access to credit (%)	1 = Yes 0 = No	87.33 12.67	54.44 45.56	53.67***
Improved seed (%)	1 = Yes 0 = No	100 00.00	44.07 55.93	149.18***
Access to market	1 = Yes 0 = No	98.00 02.00	92.5 07.5	-2.43**
Off farm activities (%)	1 = Yes 0 = No	66.00 34.00	61.00 39.00	-10.38***
Ownership of phone (%)	1 = Yes 0 = No	35 65	34 66	0.01
Access to media (%)	1 = farmer owns radio or TV 0 = No	74 26	73 27	0.13
Access to health facilities[9]	1 = Yes 0 = No	80 20	57 43	26.69***
Age of the farmers	Years	40.09 (11.00)	42.05 (9.48)	02.15**
Farming experience	Years	16.32 (7.93)	13.51 (7.60)	-3.95***
Education	Number of years of schooling	2.38 (0.322)	2.68 (0.175)	0.79
Frequency of FBO meeting	Numbers of meetings	03.00 (1.17)	01.00 (1.55)	-16.26***
Distance to irrigation scheme	Km	03.34 (1.95)	17.47 (10.83)	15.88***
Off farm income	CFA	20,830 (33,557)	12,180 (36,635)	2.60***
Fertilizer	Kg/ha	305.333 (92.53)	226.20 (79.61)	-10.38***
Herbicide	Liter/ha	02.81 (1.32)	01.75 (1.78)	-06.76***
Market participation	Proportion of rice sold	76.09 (20.62)	66.38 (26.06)	-04.22***
Share of income from rice (%)	Proportion of total income	0.62 (0.017)	0.54 (0.010)	-03.50***

Note: *** $p < 0.01$; ** $p<0.05$. Values in parentheses are standard deviations

As far as food security and nutrition variables (DD, FCS and BMI) are concerned, significant difference was noticed between the two categories of farmers (Table 3).

Table 3: Mean differences in outcomes variables

Variable	Irrigators	Non-irrigators	t-test
Body Mass Index	22.50	25.22	13.14***
Normal weight (%)	83.00	62.00	22.08***
Underweight (%)	03.00	02.00	01.21
Overweight (%)	14.00	36.00	26.30***
Dietary Diversity score	08.17	06.80	-6.54***
Food Consumption Score	69.06	37.53	-2.78***
Poor food consumption (%)	10.67	34.07	5.71***
Borderline food consumption (%)	16.00	0.03	-6.20***
Acceptable food consumption (%)	73.33	62.96	-2.36**

Note: *** significant at 1 %, ** significant at 5 %

The mean BMI is 22.50 for irrigation farmers and 25.22 for non-irrigators. A higher proportion of irrigators (83%) have normal weight as against 62% for non-irrigators. It was also observed that the proportion of non-irrigators (36%) overweight where more than the irrigators (14%). The irrigators had higher dietary diversity than non-irrigators. The irrigators had an FCS of about 69 as against 37 for the non-irrigators. By recording the FCS into a categorical variable using standard cutoff values[10], about 11 % and 34 % of irrigators and non-irrigators respectively were found in the poor food consumption category. About 73 % of the irrigators were in the acceptable food consumption category as against 63 % of the rainfed rice farmers. It is important to mention that farmers in the acceptable food consumption category were more educated and had better access to institutional support services.

8. Results and discussion

Estimation of index of participation in irrigation scheme

The estimated index of participation in irrigation scheme among rice farmers is shown in Table 4. The results indicate that about 18% of land area grown to rice was irrigated in the municipality of Malanville. This is not surprising and reflects the general figure in Benin where only 5% of agricultural lands are irrigated (Bouraima et al. 2015). In addition, less than 8% of the potential irrigable land (322,000 ha) in the country are developed (FAO, 2018).

Table 4: Adoption index for irrigated rice

	Mean	SD
Total rice land area	1.40	1.07
Total irrigated rice land area	0.56	0.30
Adoption coefficient	0.18	0.36

The comparison of participation index (Table 5) revealed no significant difference between educated and uneducated rice farmers. The participation index for non-educated farmers was 18% as against 17% for educated farmers. The analysis also revealed that female farmers had a significantly higher participation rate (20%) compared to male farmers (14%). Farmers who engaged in off farm activities had a higher adoption rate (32%) compared to those who did not (11%). Increased off farm income may provide farmers with resource to support additional cost required by the adoption of irrigation. Access to market increased participation rate of irrigation. Farmers with better access to market had higher participation rate (18%) than those that did not have access (7%). Similarly, farmers with access to credit had higher participation rate (25%) than those that did not have access (6%). A significant difference in participation rate was also observed between farmers who are member of FBO (37%) and the non-member (0.1%). It is also observed a significantly higher participation rate among improved seed users compared to non-users.

Table 5: Participation index across farmers' characteristics

Variables	Participation index	t-test
Gender		
Male	0.14	1.96**
Female	0.20	
Education		
Non educated	0.18	0.08
Educated	0.17	
Off farm activities		
Yes	0.32	-7.04***
No	0.11	
Access to media		
Yes	0.25	- 6.97***
No	0.05	
Market access		
Yes	0.18	-2.06**
No	0.07	
Membership of FBO		
Yes	0.37	-15.49**
No	0.001	
Access to credit		
Yes	0.25	-7.13***
No	0.06	
Use of improved seed		
Yes	0.32	-12.71***
No	0.00	

Note: *** $p < 0.01$; ** $p < 0.05$

Factors influencing participation in irrigation system

A probit model was employed to ascertain the determinants of participation in irrigation scheme. The results are reported in Table 6. The model fits the data well since the Wald test has a p-value less than 1%. This shows that together, all estimated coefficients are statistically significant. The pseudo R2 value is 0.82 which indicates that 82% of the variation in adoption decision is explained by the explanatory variables included in the model while the remaining 18% is being influenced by other variables outside the model but captured by the error term.

Table 6: Probit model estimates of participation in irrigation scheme

Dependent variable Participation in irrigation = 1; 0 otherwise	Adoption model	
	Coeff	dy/dx
Age (in years)	-0.092 (0.066)	-0.0045
Age square	0.0009 (0.0007)	0.000046
Experience (in years)	0.0005 (0.019)	0.000026
Gender (1= Male; 0 = Female)	0.416 (0.313)	0.020
Education (1=Yes, 0 =No)	-0.034 (0.033)	-0.0017
Credit access (1=Yes, 0 =No)	1.568*** (0.273)	0.077
Extension service (1=Yes, 0 =No)	0.748** (0.343)	0.036
Off farm activities (1=Yes, 0 =No)	-0.086 (0.291)	-0.0042
Frequency of FBO meeting (number of meeting in a year)	0.455*** (0.100)	0.022
Access to media (1=Yes, 0 =No)	0.797*** (0.305)	0.039
Market participation (proportion of rice sold)	0.024*** (0.006)	0.0012
Access to health facilities (1=Yes, 0 =No)	0.165 (0.331)	0.0081
Distance to irrigation scheme (in km)	-0.518*** (0.073)	-0.025
Constant	-0.554 (1.571)	--
Log likelihood: -61.393 Wald chi2 (13) = 113.69 Pseudo R2 = 0.83	Prob > chi2 = 0.000	

Note: *** p < 0.01; ** p<0.05 and * p<0.1%. Values in parentheses are standard errors. dy/dx denotes marginal effects.

The main drivers of farmers' decision to participate in irrigation scheme were access to credit, extension services, frequency of FBO meeting, access to media, market participation and distance to the irrigation scheme (Table 6). Farmers with access to credit were more likely to participate in the irrigation scheme. Access to credit increased the probability of participation in irrigation by 7.8%. As explained by Bjornlund and Pittock (2017) and Mdemu et al. (2017) lack of credit prevents farmers from timely access to farm technologies resulting in delaying in farm operations. Contact with extension agents and frequency of FBO meeting play an important role in farmers' decision to participate in irrigation scheme. Access to extension services increased the probability to participate in irrigation scheme by 3.5% while a unit increase in the frequency of FBO meeting increased the likelihood of participation in irrigation by 2.3%. This suggests that learning about modern agricultural technologies may have occurred through extension services and social network (Abdulai et al., 2011; Genius et al., 2014).

The role of information was also very important for participation in irrigation scheme. Farmers with access to media were more likely to use irrigation. Access to media increased the probability of using irrigation by 4.1%. This result suggests that information and communication technologies (ICT) are important for diffusion of agricultural technologies (Kiiza and Pederson, 2012 and Zhang et al. 2016). Farmers' decision to participate in irrigation scheme was positively influenced by market participation which increased the probability of using irrigation by 0.1%. This highlights the importance of marketing channels in using irrigation technologies (Sinyolo et al., 2014). Distance to irrigation scheme turns out to negatively influenced the decision to participate in irrigation scheme. It is likely to decreases the probability of participation in irrigation by 2.5%, suggesting that those farmers who reside near to the irrigation scheme are more likely to participate in irrigation scheme. Conversely, farmers who stay far from the scheme are less likely to use irrigation because of higher costs in terms of time and energy spent to reach the scheme, (Sinyolo et al., 2014). Overall, these results highlight that farmers' decision to participate in irrigation scheme is influenced by information, better access to market, financial resources and farmers' interaction through extension services and FBO.

Assessment of the impact of irrigation adoption on food security and nutrition outcomes

This section presents the results of the endogenous switching regression (ESR) model used to assess the impact of irrigation on food security and nutrition outcomes. The use of the ESR model is validated by the significance of the likelihood ratio test of the independence between equations, and the correlation between error term in the selection equation and those in the outcomes equations. They are revealing that self-selection occurs in the process of participation in irrigation scheme as well as the endogenous nature of participation in irrigation scheme. In these conditions OLS estimates would have been biased.

The two indicators of food security used are dietary diversity (DD) and food consumption scores (FCS). The Body Mass Index (BMI) was used as proxy for the nutrition status of rice farmers. The results of the analysis for each of these indexes are discussed in the subsequent subsections.

Impact of irrigation on food consumption scores (FCS)

Table 7 presents the FIML estimates of the ESR model of irrigation on food consumption among rice farmers. The model has a good fit with explanatory variables as shown by the significance of the likelihood ratio test (p-value < 0.01) of independence between the equations. The estimated coefficient of correlation between participation in irrigation and food consumption score is positive and significantly different from zero suggesting that self-selection occurred in the adoption of irrigation schemes. The results indicate that experience in rice production, access to credit, access to media and market participation were variables that significantly influence food security among irrigation farmers in Benin.

Table 7: Parameter estimates of the impact of irrigation on food consumption

Dependent Variable Ln Food Consumption Score (FCS)	**Outcome model**	
	Irrigators	**Non-irrigators**
Age (in years)	-0.071 (0.080)	0.015 (0.038)
Age square	0.0007* (0.027)	-0.00011 (0.0004)
Experience (in years)	0.027*** (0.010)	-0.019 (0.020)
Gender (1= Male; 0 = Female)	0.039 (0.176)	0.392*** (0.131)
Education (numbers of years of schooling)	0.024 (0.023)	0.050*** (0.014)
Credit access (1=Yes, 0 =No)	1.672***	0.075
	(0.223)	(0.118)
Extension service (1=Yes, 0 =No)	-0.197 (0.331)	1.229*** (0.135)
Off farm activities (1=Yes, 0 =No)	0.160 (0.145)	0.542*** (0.139)
Frequency of FBO meeting (number of meeting in a year)	-0.014 (0.062)	0.105** (0.047)
Access to media (1=Yes, 0 =No)	0.639** (0.266)	0.556*** (0.125)
Market participation (proportion of rice sold)	0.010*** (0.003)	0.003 (0.002)
Access to health facilities (1=Yes, 0 =No)	-0.047 (0.184)	0.907*** (0.125)
Constant	3.267*** (0.873)	1.810** (0.884)
Rho_0	0.102 (0.172)	
Rho_1	0.677(0.200) ***	
Log likelihood: - 1153.51 Wald chi2 (12) = 71.53 Prob > chi2 = 0.000		
LR test of indep. eqns.: chi2 (1) = 7.63 Prob > chi2 = 0.005		

Note: *** p < 0.01; ** p<0.05 and * p<0.1%. Values in parentheses are standard errors.

Experience in rice farming was positively associated with FCS among irrigation farmers. This implies that an increase in farmers experience in rice production contributes to improve food security among irrigation farmers. Access to credit and to media were found to be positively associated with food security. Farm income and engagement in off farm activities also increased food consumption scores among irrigation farmers. These findings suggest that farmers' financial capacity is important for the improvement of food security. Another interesting result is the positive association between market participation and food consumption. As highlighted in the conceptual framework, access to market is one of the main pathways through which irrigation can improve food security and nutritional outcomes since a better access to market is key to ensure higher incomes for farmers. Sinyolo et al. (2014) argue that irrigation is intended to enhance crop production and marketable surplus.

The expected FCS under actual and counterfactual conditions are reported in Table 8. Cells (a) and (b) represent the expected FCS observed in the sample. The expected FCS for farmers that adopted irrigation is higher than the group of farmers that did not adopt. Based on this simple comparison, it can be misleading to attribute the difference in FCS to the adoption of irrigation scheme. In the counterfactual case (c), it is clearly shown that the treatment effect for irrigation adopters is 0.33. This is equivalent to 39.09%[11] difference in the average FCS. In other words, when irrigators did not adopt irrigation, their FCS would have been decreased by 39.09%. In the counterfactual case (d) if non-adopters adopted irrigation scheme, their FCS would have been increased by 19.7%. However, the transitional heterogeneity effect is positive, implying that the effect of irrigation on FCS is significantly greater for farmers who actually did adopt compared to those that did not adopt.

Table 8: Impact of irrigation on food consumption scores: Conditional expectations, treatment and heterogeneity effects

Subsample	Decision stage		Treatments effects
	Adopt (N= 150)	Not Adopt (N = 540)	
Irrigation farmers	(a) 4.25 (0.17)	(c) 3.92 (0.23)	TT = 0.33 (0.023)***
Rainfed rice farmers	(d) 3.75 (0.33)	(b) 3.57 (0.33)	TU= 0.18 (0.020)***
Heterogeneity effects	BH2 = 0.35 (0.023)***	BH1 = 0.50 (0.019)***	TH = 0.15 (0.002)***

Note: *** significant at 1 %; Values in parentheses are standard errors.

The last row of Table 8 which accounts for potential heterogeneity effect in the sample, reveals that farmers who actually adopt irrigation scheme would have higher FCS than farmers that did not adopt in the counterfactual cases (c) and (d). This highlights that there are some important heterogeneity factors that makes the irrigators better off than the non-adopters. Overall, the findings revealed that adoption of irrigation scheme significantly improves farmers' food security status through increases in food consumption score. Other studies found a similar positive impact of irrigation on food consumption (Dillon, 2011; Nkhata et al., 2014). For instance, in

Mali, Dillon (2011) found that adoption of irrigation was associated with increase in consumption per capita.

Impact of irrigation on dietary diversity (DD)

Estimates of the ESR model of irrigation impact on dietary diversity among rice farmers are presented in Table 9. The model has a good fit with explanatory variables as indicated by the significance of the likelihood ratio test (p-value < 0.01) of independence between the equations. The estimated coefficient of correlation between adoption of irrigation and food consumption score is positive and significantly different from zero suggesting that self-selection occurred in the adoption of irrigation schemes. Variables such as experience in rice production, education, off farm activities, market participation and access to health facilities had significant effects on dietary diversity among irrigation farmers in Benin.

Experience in rice farming was positively associated with DD, suggesting that an increase in farmers experience in rice production contributes to improve DD among irrigation farmers. Compared to male being female decrease the probability of being food secure. This is consistent with Felker-Kantor and Wood (2012) and Abdullah et al. (2016). Lack of access to high-quality seeds, fertilizers, credit access, pesticides and marketing services are the major problems which women in developing countries face as a producer (Ibnouf, 2011; Abdullah et al., 2016). Education also has a positive effect on food security implying that education is an important tool for improving food security status of farmers as educated farmers are more likely to be food secure than non-educated. The higher is the level of education, the higher is the likelihood of diversifying consumed food. This result is in line with studies who found that education improves food security status of farmers (Arene and Anyaeji, 2010; Mango et al., 2014; Mutisya et al., 2016). Engagement in off farm activities increase dietary diversity among irrigation farmers. This highlights the importance of farmers' financial capacity for the improvement of food security. A positive association was also found between market access and dietary diversity. This indicates that farmers that have access to market were able to diversify their consumption. Access to health facilities is positively associated with dietary diversity, suggesting that farmers that have access to health facilities are likely to diversify their consumption. This is probably the result of nutrition education received from the health officers.

The expected dietary diversity under actual and counterfactual conditions are reported in Table 10. Cells (a) and (b) represent the observed DD score. The DD was 8.17 and 6.80 for irrigation farmers and non-irrigators, respectively. The difference is about 1.37. It can be misleading to attribute this difference in dietary diversity to the adoption of irrigation scheme. In the counterfactual case (c), the treatment effect for irrigation adopters is 0.30. This is equivalent to 3.8% difference in DD if farmers who actually adopted irrigation scheme did not adopt. In the counterfactual case (d) that farmers who did not adopt irrigation scheme adopted, they would have 0.44 increase (that is about 6.5 % difference in DD) in DD. However, the transitional heterogeneity effect is negative, implying that the impact of irrigation on dietary diversity is significantly smaller for farmers who actually did adopt compared to those who did not adopt. This suggests the implementation of policies to facilitate the adoption of irrigation by non-adopters.

Table 9: Parameter estimates of the impact of irrigation on dietary diversity

Dependent Variable **Dietary Diversity (DD)**	**Outcome model**	
	Irrigators	**Non-irrigators**
Age (in years)	0.019 (0.060)	0.044 (0.050)
Age square	-0.0002 (0.0006)	-0.00033 (0.0005)
Experience (in years)	0.038** (0.015)	-0.0054 (0.011)
Gender (1= Male; 0 = Female)	-0.346	0.548***
	(0.260)	(0.171)
Education (numbers of years of schooling)	0.085*	-0.023
	(0.033)	(0.018)
Credit access (1=Yes, 0 =No)	0.041	0.093
	(0.327)	(0.155)
Extension service (1=Yes, 0 =No)	0.614	0.521***
	(0.495)	(0.176)
Off farm activities (1=Yes, 0 =No)	0.616***	0.697***
	(0.213)	(0.181)
Frequency of FBO meeting (number of meeting in a year)	-0.061	0.011
	(0.092)	(0.059)
Access to media (1=Yes, 0 =No)	-0.135	0.357**
	(0.390)	(0.163)
Market participation (proportion of rice sold)	0.035***	0.011***
	(0.0054)	(0.003)
Access to health facilities (1=Yes, 0 =No)	0.662**	0.158
	(0.274)	(0.163)
Constant	3.360***	3.967***
	(1.286)	(1.156)
Rho_0	-0.223 (0.250)	
Rho_1	0.408(0.203)**	
Log likelihood: - 1356.24 Wald chi2 (12) = 85.86 Prob > chi2 = 0.000		
LR test of indep. eqns.: chi2 (1) = 4.33 Prob > chi2 = 0.037		

Note: *** p < 0.01; ** p<0.05 and * p<0.1. Values in parentheses are standard errors.

Table 10: Impact of irrigation on dietary diversity: Conditional expectations, treatment and heterogeneity effects

Subsample	Decision stage		Treatments effects
	Adopt (N= 150)	Not Adopt (N = 540)	
Irrigation farmers	(a) 8.17 (0.96)	(c) 7.87 (0.56)	TT = 0.30 (0.09)***
Rainfed rice farmers	(d) 7.24 (1.08)	(b) 6.80 (0.54)	TU= 0.44 (0.05)***
Heterogeneity effects	BH1 = 0.93 (0.09)***	BH2 = 1.07 (0.05)***	TH = -0.14 (0.007)***

Note: *** significant at 1 %; Values in parentheses are standard errors.

The last row of Table 10 which accounts for potential heterogeneity effect in the sample, reveals that farmers who actually adopted irrigation scheme would have higher DD than farmers who did not adopt in the counterfactual cases (c) and (d). This highlights that there were some important heterogeneity factors that makes the irrigators better off than the non-adopters. Overall, the findings imply that adoption of irrigation scheme significantly improves farmers' food security status through increase in DD. This finding substantiates that of Alaofè et al. (2016) who found that solar-powered drip irrigation has the potential to increase dietary diversity among vegetable and fruit producers. While these findings agree with many previous studies, they are in contradiction with results by Hossain et al. (2005) and Shively et al. (2012) who found non-significant increases in food diversity among irrigation users.

Impact of irrigation on nutrition outcomes

Body Mass Index (BMI) of farmers is used as proxy for nutrition outcomes. This takes value 1 if a farmer BMI is in the normal range, and 0 otherwise. Since the dependent variable is binary the endogenous switching probit model was estimated using the STATA command "switch_probit" (Lokshin and Sajaia 2011). The results are presented in Table 11. Overall, the model had a good fit with the explanatory variables as shown by the significance of the likelihood ratio test. The estimated coefficient of correlation between participation in irrigation and nutrition indicator (BMI) was negative and significantly different from zero suggesting that self-selection occurred in the process of participation in irrigation schemes. The difference in the BMI equation coefficient between irrigation users and non-users illustrates the presence of heterogeneity in the sample. The BMI function for irrigators was significantly different from that of the non-irrigators.

The results indicate that experience in rice production was significantly associated with the probability of being in the normal BMI range. An additional year of experience in rice production decreases the probability of being in the normal BMI range. Since increasing years of experience is related to increasing age, this is an indication of the fact that adult farmers are more vulnerable to overweight and obesity. Studies by Reas et al. (2007) and Rai et al. (2013) argue that adulthood appeared to be a critical time period at which accelerated weight gain occurred. Access to health facilities was also significantly associated with the likelihood of being in the normal BMI range. This implies that farmers that have access to health facilities are likely to be in the normal BMI range compared to those that did not. This result supports our conceptual framework analysis that improved access to health care are important condition for better nutritional status. The argument is that increased incomes due to participation in irrigation scheme can remove some of the barriers farmers face in accessing health facilities. In line with this, Domenech (2015) argues that irrigation favors investments in health care. However other studies (e.g. Burney et al., 2010) found a non-significant difference in healthcare expenditure between irrigation users and non-users.

Table 11: Parameter estimates of the impact of irrigation on nutritional outcomes

Dependent Variable **BMI (1 if normal weight and 0 otherwise)**	**Outcome model**	
	Irrigators	**Non-irrigators**
Age (in years)	-0.188 (0.117)	0.024 (0.036)
Age square	0.002 (0.003)	-0.00035 (0.00037)
Experience (in years)	-0.047** (0.020)	-0.017 (0.008)
Gender (1= Male; 0 = Female)	-0.157 (0.376)	0.210*** (0.126)
Education (numbers of years of schooling)	-0.010	-0.016
	(0.043)	(0.013)
Credit access (1=Yes, 0 =No)	-0.772	0.054
	(0.615)	(0.114)
Extension service (1=Yes, 0 =No)	0.131 (0.693)	0.307 (0.132)
Off farm activities (1=Yes, 0 =No)	-0.460	-0.147
	(0.315)	(0.132)
Frequency of FBO meeting (number of meeting in a year)	-0.107 (0.131)	0.119*** (0.043)
Access to media (1=Yes, 0 =No)	-0.344	0.206*
	(0.648)	(0.121)
Market participation (proportion of rice sold)	-0.0045 (0.008)	0.0016 (0.002)
Access to health facilities (1=Yes, 0 =No)	0.824**	0.480***
	(0.364)	(0.122)
Constant	7.110***	-0.598
	(0.873)	(0.843)
Rho_0	0.131 (0.194)	
Rho_1	-0.711 (0.327)**	
Log likelihood: - 449.731 Wald chi2 (13) = 106.97 Prob > chi2 = 0.000 LR test of indep. eqns.: chi2 (2) = 8.80 Prob > chi2 = 0.012		

Note: *** p < 0.01; ** p<0.05 and * p<0.1%. Values in parentheses are standard errors.

Table 12 presents the expected BMI under actual and counterfactual conditions. This helps to quantify the impacts of irrigation on nutrition outcomes. As shown in Table 12, the results of the treatment effect on the treated (TT) indicate that irrigation farmers have a 3.9% greater chance of being in the normal BMI range. In addition, the results of the treatment effect on the untreated (TU) suggest that if farmers adopted irrigation this would result in a 34% increase in the probability of being in the normal BMI range. Hence participation in irrigation schemes contributes to improve nutritional outcomes among rice farmers in the municipality of Malanville, Benin. This finding is in line with previous studies that have concluded that irrigation hold great potential for improving nutrition through increasing food production, higher income, enhancing water access and sanitation and hygiene conditions. In Kenya, for instance, enhanced food production as a result of irrigation leads to higher food availability and improved nutritional status (Kirogo et al., 2007; Veronicah et al., 2007). Similarly, a study by Adam et al. (2016) suggested that small scale irrigation schemes have contributed to improving household nutritional status in Eastern region of Ghana. Irrigation is associated with a reduced risk of stunting (height-for-age z-scores) in Malawi (Benson, 2015). However, Hagos et al. (2017) found that the use of spate irrigation in Ethiopia did not have significant nutritional effects, suggesting that increased productivity due to the use of irrigation does not necessarily means a better nutritional status. Interventions such as nutrition education would help to enhance the impacts of irrigation on nutritional outcomes (Hossain et al., 2005; Hagos et al.; 2017).

Table 12. Impact of irrigation on nutrition outcomes: Conditional expectations, treatment and heterogeneity effects

Categories	Observations	Mean	Std. dev
TT	150	0.039***	0.015
TU	540	0.340***	0.135

Note: *** significant at 1 %

9. Conclusion

Water resources are key for agricultural production and for improving welfare of value chains actors. This paper has dealt with the impact of irrigation on food security and nutrition outcomes among rice farmers in Benin. It uses the irrigation scheme of Malanville as case study. Dietary diversity and food consumption scores were used as proxy for food security and BMI for nutrition outcomes. In the methodology, the endogenous switching model is employed to account for observable and unobservable factors which may affect the decision to participate in irrigation scheme. Three important conclusions can be drawn from the results. Firstly, the index of participation in irrigation scheme remains low with a participation rate of 18%. Secondly, the key variables which determine participation decision are access to credit, access to extension services, frequency of FBO meeting, access to media, market participation and distance to the irrigation scheme. Finally, participation in irrigation schemes has a positive and significant impact on food security and nutritional outcomes in the municipality of Malanville. Participation in irrigation scheme increases dietary diversity score by 3.8% and food consumption score by 39.09%. Moreover, it increases the probability of being in the BMI normal range by 3.9%. These findings are particularly important and call for public policies to promote the development of irrigation schemes.

Analysis of the determinants of participation in irrigation scheme also generated interesting results. Farmers’ decision to participate in irrigation scheme is driven by access to information, market participation, better access to market and financial resources. Access to media is an important channel for information sharing, while information plays an important role in determining farmers’ decision. Developing credit market enables farmers to invest in water management tools and to purchase other farm inputs that can support crop production. Farmers should also increase their financial capacity through engagement in off farm activities. For greater impact of irrigation scheme on food security and nutritional outcomes, active market participation is needed. Through market, irrigation farmers can sell their products and afford other nutritious foods. This is key to realize the potential of irrigation scheme among rice farmers in the municipality of Malanville in Benin.

Notes

1. The employment opportunities come from increased demand for farm labour due to additional labour needed for the construction, maintenance and rehabilitation of irrigation facilities.

2. Master Plan of Agricultural and Rural Development

3. Declaration Letter of the Rural Development Policy

4. see http://www.who.int/news-room/fact-sheets/detail/malnutrition

5. Ministère de l’Agriculture, de l’Élevage et de la Pêche

6. Plan National d’Investissements Agricoles et de Sécurité Alimentaire et Nutritionnelle

7. See Jalan and Ravallion (2003) for more information.

8. More details about the survey design can be found in Nonvide et al. (2018)

9. This takes value 1 if farmers reported no constraints in accessing health facilities

10. Following WFP (2008), the typical threshold is 0 - 21 for poor food consumption, 21.5 - 35 for borderline food consumption, and greater than 35 for acceptable food consumption.

11. The treatment effect in this unit is interpreted as percentage difference. Actually, when the outcome variable is log-transformed, multiplying the TT by 100 is an approximation. According to Asfaw et al. (2012) the exact percent difference is given by , where e is exponential e and TT is the average treatment effect provided by the analysis of the log-transformed variable.

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Appendix: Formula for estimating DD, FCS and BMI

$$DD = \sum food\ groups\ consumed \qquad (E1)$$

$$FCS = \sum a_i X_i \qquad (E2)$$

$$BMI = \frac{Weight\ in\ kg}{height\ in\ meters\ squared} \qquad (E3)$$

Where a_i is the weight of each food group, and Xi the frequency of food consumption

Table A1: Food groups and weights

	Food Items	Food Groups	Weight
1	Maize, maize porridge, rice, sorghum, millet pasta, bread and other cereals	Main staples	2
2	Cassava, potatoes and sweet potatoes, other tubers, plantains		
3	Beans. Peas, groundnuts and cashew nuts	Pulses	3
4	Vegetables, leaves	Vegetables	1
5	Fruits	Fruits	1
6	Beef, goat, poultry, pork, eggs and fish	Meat and fish	4
7	Milk yogurt and other diary	Milk	4
8	Sugar and sugar products, honey	Sugar	0.5
9	Oils, fats and butter	Oil	0.5
10	Spices, tea, coffee, salt, fish power, small amounts of milk for tea.	Condiments	0

Source: World Food Programme (2008)

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