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Effect of Adoption of Irrigation on Rice Yield in the Municipality of Malanville, Benin

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***Abstract*:** The paper employed a Heckman selectivity model to determine factors influencing the adoption of irrigation and its effect on rice yield in Benin. Results from probit estimates indicate that farmer's age, gender, extension services, access to credit, market participation, distance to irrigation scheme, use of tractor and fertilizer are factors affecting the probability of irrigation adoption. Results from Heckman second stage estimates show that the adoption of irrigation contributes significantly to rice yield improvement by 57 per cent. For robustness checks of the estimated effect of adoption of irrigation, the propensity score matching method was used. The results indicate that the percentage increase in rice yield due to irrigation adoption varies between 55 per cent and 60 per cent. This confirms the finding of the Heckman estimates. Other variables explaining rice yield are education, extension services, access to credit, market participation, off farm income, use of tractor, labour, and fertilizer. These results imply that besides the adoption of irrigation the provision of complementary services are needed to achieve the objective of productivity improvement.

1. Introduction

Intensifications in rice production in Benin is often driven by an increase in total area planted (Figure 1). Between 2000 and 2014, rice production was highly correlated ($r = 0.98$) with the total cultivated area. It has increased at an annual growth rate of 11 per cent. In the same period, the total area harvested has increased at an average annual rate of 8 per cent. Therefore expanding land area was the main factor for increasing rice production in Benin.

While land resources are fixed, arable land under cultivation cannot be increased indefinitely. The alternative is to improve the yield per hectare through adoption of appropriate agricultural technologies. Irrigation has been identified as key to agricultural productivity improvement (Oramah, 1996; Carruthers *et al.,* 1997; Huang *et al.,* 2006). Irrigation development increases returns to poor households in terms of their physical, human, and social capital and enables smallholders to achieve higher yields and revenues from crop production (Hussain and Hanjra, 2004). Irrigated farms also contribute to the creation of new employment opportunities through higher demand for farm labour due to additional labour needed for the construction and maintenance of irrigation infrastructure. Also during the dry season, when non-irrigated production is not possible, irrigated farms continue to operate and therefore have favourable effects on employment and wages (Hanjra *et al.*, 2009).

There is no formal policy document available for irrigation development in Benin. However, the need for irrigation development in order to achieve high agricultural yields is clearly expressed and defined in the Plan Stratégique de Relance du Secteur Agricole (PSRSA) of Benin 2011–2015. It contains guidelines for improving the use of irrigation facilities in the country. The goal is the control and sustainable access to water for increasing agricultural productivity while safeguarding ecosystems. The main actions to be implemented focused on the support for the development of small schemes for rice development and promotion of intensive gardening, the promotion of pilot facilities for other cultures, the support to the realization of pastoral water development such as small dams, and the development of the major valleys of Ouémé, Niger, Mono, Couffo and Pendjari. The PSRSA places particular emphasis on supporting the rehabilitation and strengthening of management capacity of the irrigation schemes. Despite this, the objective of the rice policy to be self-sufficient in rice production by 2015 was not met. National rice production in 2015 is far below the target of 600,000 MT needed for self-sufficiency in rice production.

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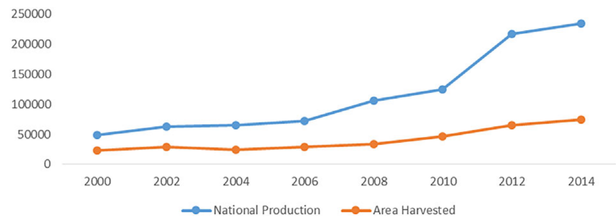
Figure 1: Trend of rice production and area harvested in Benin from 2000 to 2014



Source: FAO (2016).

In this paper, the interest is focused on the following important question for irrigation policy: What informs farmers' decision to participate in an irrigation project? Does irrigation adoption contribute to an improvement in yield among rice farmers in Benin? Analysing farmers' decision whether to adopt irrigation will facilitate the development of appropriate policies for sustainable development of irrigation in Benin. The remainder of the paper is structured as follows. The next section reviews the literature, followed by Section 3 which provides the theoretical framework, the sampling frame and data collection procedure, and the methods of analysis. Results and discussion are presented in Section 4. Finally Section 5 concludes and gives policy implications of the findings.

2. Literature Review

An overview of the literature reveals that several factors inform the decision to adopt an agricultural technology. Most of the pioneering works (Griliches, 1957, 1960; Binswanger, 1974; Dinar and Yaron, 1992) on the technology adoption were more aggregate and have concluded that adoption of technologies is determined by economic attributes such as profit. These studies explained the difference in adoption of technologies between two regions by the difference in the average profit to be realized from the adoption. The rate of adoption tended to be faster for innovations that lead to higher profit and requiring investments that the farmer can undertake. Over time, the adoption works have focused on the individual level. In addition to the economic variables, others factors may influence the technology adoption decision-making process. These include farms' and farmers' characteristics, and institutional variables. Among these variables, level of education, extension services and access to credit were found in the majority of studies (Koundouri *et al*., 2006; Namara *et al.,* 2007; Adeoti, 2009; Abdulai *et al*., 2011; Getacher *et al*., 2013) as main factors explaining the adoption of irrigation. The price of water was also found as a strong determinant for the efficient use of irrigation technology (Caswell and Zilberman, 1985; Moreno and Sunding, 2005). Farmers are very sensitive to the increase in water price which appears to encourage adoption of the most efficient technology (drip) and discourage adoption of the least efficient option (gravity or sprinkler).

Investing in irrigation is one of the most effective ways to develop smallholder agriculture and contribute to poverty reduction through increasing crop yield and income (Huang *et al*., 2006; Domenech, 2015). A study by Dillon (2011) has tested whether the impacts of irrigation in Mali depend on the scale of the scheme. The results indicate that small-scale irrigation has a larger effect on farm production and income compared to the large-scale irrigation scheme. Indeed small-scale irrigation yield impact was estimated at 2.1 to 2.4 MT/ha while large-scale irrigation impact was between 941 kg to 1.1 MT/ha. Huang *et al.* (2006) analysed the agricultural performance in China under the irrigation development. They show that irrigation adoption contributes to the increases in yields and income. Returns are positive in most of the villages that invested in irrigation (Huang *et al*., 2006). This result provides evidence of the role of irrigation in the past and support for future investments in irrigation as a poverty alleviation tool in China.

In contrast to studies (Bhattarai and Narayanamoorthy, 2003; Huang *et al*., 2006; Dillon, 2011; Bacha *et al*., 2011; Domenech, 2015) which had proven the benefits of adoption of irrigation, other literatures have shown mixed results about the impact of irrigation on the livelihood improvement. In south–eastern Nigeria, Urama and Hodge (2004) have tested the differences in returns to factors between irrigation and non-irrigation farmers based on data collected from 1984 to 1998. The result indicates significantly higher yield for irrigation farmers. The returns of farm output to labour and other inputs is higher than the returns to land and water inputs. The partial regression coefficient associated to land and water is negative (–0.92) while the coefficients for labour (0.50) and other variable inputs (0.42) are positive. Based on these results, Urama and Hodge (2004) suggested that agricultural policy in Nigeria should promote access to improved farm inputs rather than focusing on irrigation development. Zhu (2004) demonstrated a non-significant effect of irrigation on food crop (rice, wheat or maize) yield in China between 1979 and 1997. Fan *et al.* (2000) concluded that to reduce poverty in India, the government should invest more on education, road and agricultural research. They demonstrated that government expenditure on irrigation has a modest effect on farm production, poverty and inequality. In Asia in general, and particularly in China and India, Rosegrant and Evenson (1992) and Jin *et al.* (2002) concluded that there was no significant effect of irrigation on farm productivity and poverty reduction.

3. Materials and Methods

3.1 Theoretical Framework

This section presents a model that describes a farmer decision facing the adoption of irrigation under the expected utility maximization theory. This is used in the study for two reasons. First, it is more widely used in technology adoption literature (Caswell and Zilberman, 1985; Koundouri *et al.*, 2006; Genius *et al.*, 2014). And second, in the adoption of irrigation, capital and other financial investments are made based on the farmer's expectation of a net profit or benefit in monetary or physical terms.

The farmer decision is modelled as a discrete choice. The farmer i can decide to participate or not in irrigation project j. The distribution of j is as follows: $j = 0$ for the case of non-participation and $j = 1$ for the case of participation. Let it be assumed that the farmer i produce one single output Q at price$p$. In our case the output is rice. The production function $f(.)$ is assumed continuous and twice differentiable. X is the vector of inputs and r the vector of input prices. All prices are assumed non-random and the farmers are price-takers both in input and output markets. Water (X^{w}) is assumed to be an essential input in the production process. $X^{y}$is the vector of the other inputs such as seed, labour, fertilizer and agrochemicals. Based on the above assumptions, the production function can be written as follows:

$$Q = \mathrm{f}(X^{w}, X^{y}) \tag{1}$$

Then the production function of farmer i before adoption is $Q_0 = f\left(X_0^{w}, X_0^{y}\right)$ and after adoption is $Q_1 = f\left(X_1^{w}, X_1^{y}\right)$. Equation (1) states that the production depends on the availability of water and others inputs. Indeed, water inputs is assumed to be the main factor for agricultural production as it makes the difference between irrigated and rainfed farms. The change in the production function (ΔQ) due to the adoption of irrigation is observed through the following equation:

$$\Delta Q = f\left(X_1^{w}, X_1^{y}\right) - \mathrm{f}\left(X_0^{w}, X_0^{y}\right) \tag{2}$$

The necessary condition for adoption is $\Delta Q > 0$. In other words with the same inputs level the output will increase because of the adoption of irrigation. Or the same output level can be produced with a lower level of inputs.

The farmer's decision to participate in an irrigation project implies an additional investment cost K which in the case of this study includes basically the irrigation water fees, membership fees and other services provided in the scheme. $K > 0$ for the participants and for the non-participants $K = 0$. The profit maximization function of the irrigation farmer is given by:

$$\mathrm{Max}\pi_1 = \mathrm{Max}\left[p\ \mathrm{f}\left(X_1^{w}, X_1^{y}\right) - r_1^{w}X_1^{w} - r_1^{y}X_1^{y} - K_1\right] \tag{3}$$

The first-order condition for irrigation water input derived from Equation (3) is:

$$\frac{\partial \mathrm{f}\left(X_1^{w}, X_1^{y}\right)}{\partial X_1^{w}} = \frac{r_1^{w}}{p} \tag{4}$$

Equation (4) shows that the expected marginal productivity of the water equals the water input price over output price. Formally, the producer decision to participate in an irrigation project will verify the following inequalities:

$$\mathrm{E}[U(\pi_1)] - \mathrm{E}[U(\pi_0)] > 0 \tag{5}$$

Thus farmers adopt irrigation only when this could provide them with an expected utility of profit greater than is the case with out it.

3.2 Study Area and Sampling Technique

Study Area

The study is carried out in Benin in the municipality of Malanville. Malanville is bordered to the north by the Republic of Niger, to the south by the municipalities of Kandi and Ségbana, to the west by the municipality of Karimama, and to the east by the Federal Republic of Nigeria. It covers an area of 3,016 km^2 of which 8,000 hectares is arable land (Figure 2).

The climate is Sudano-Sahelian and the area has only one rainy season which lasts for 5–6 months from May to October with a rainfall range between 700 mm and 1000 mm. This low rainfall negatively affects agricultural production. Malanville is characterized by a high level of food insecurity and poverty (Table 1). The majority of its inhabitants are involved in subsistence agriculture and other economic activities such as fishing, livestock rearing, small business, trade and crafts. The major crops grown are maize, rice, millet, sorghum, cotton, and vegetables.

The municipality of Malanville was chosen for this study because (1) it is the largest rice producing area in Benin, (2) it is crossed by the Niger River and its tributaries which offer an important opportunity for rice production, and (3) also among the rice irrigation schemes developed by the State, the one at Malanville is the most important in terms of size, cropping season, 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 and the water used is pumped from the Niger River and distributed into the farms through surface canals. There are approximately 1,054 rice farmers operating on the scheme in 2015.

Sampling Technique

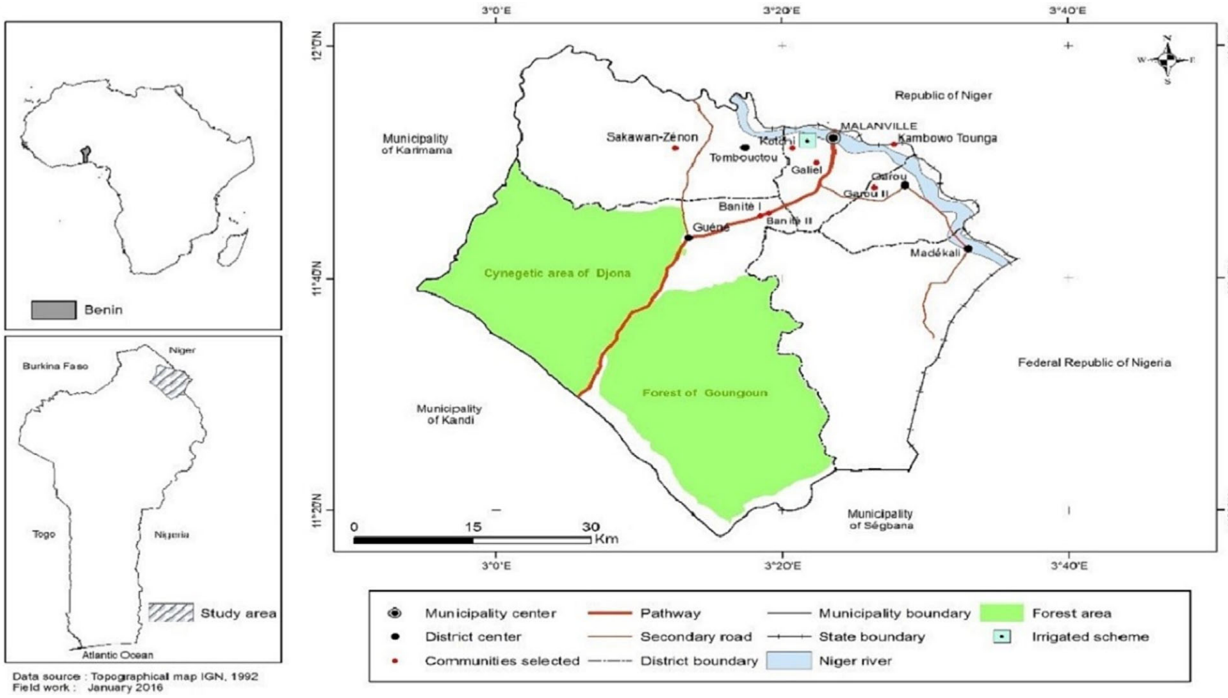
Four districts out of five were selected for the survey based on the distance to the irrigation scheme and on the size of rice production. In each of these districts, two villages, one high rice producing village and one low rice producing village were purposively selected with the help of the extension officers. In total, eight villages within the municipality were covered for the survey. In the practical setting, a list of irrigation farmers was obtained from the committee in charge of the management of the irrigation scheme of Malanville. Irrigation farmers are located in the scheme in groups of 20 to 100 people. From these groups, a proportional sampling technique was used to select 150 irrigation farmers. Further, the dry land farmers were selected from the eight villages covered by the survey. For this group the list of farmers was provided by the chief of the village. Ninety farmers were randomly selected in each high rice producing village and 45 farmers were also randomly selected in each low rice producing village making up to 540 farmers. The total number of respondents interviewed for the survey was 690 rice producers. The data were collected from April to June 2015.

3.3 Methods of Analysis: The Heckman Model of Selection

In projects, where participation is non-random, the problem of selection bias is often encountered in evaluation of impacts. Irrigation participation in the municipality of Malanville is self-selection, therefore estimates of outcome such as crop productivity in an ordinary least squares (OLS) regression will lead to inconsistency and inefficiency estimators. OLS regression will either underestimate or overestimate the impact of access to irrigation depending on whether the irrigation scheme beneficiaries are more or less able to realize the potential benefits of irrigation due to certain unobservable factors (Bacha *et al*., 2011). Moreover the yield difference between irrigation and dry land farmers cannot be attributed to irrigation adoption alone as long as the selection bias problem exists. To overcome the selection bias problem and attempt a robust estimator, the two step regression model suggested by Heckman (1979) has been widely used (Adeoti, 2009; Bacha *et al.,* 2011; Lemba *et al.,* 2013; Sinyolo *et al.,* 2014).

The Heckman selectivity model relies on very strong assumptions such that the unobserved determinants of outcome and selection equations are jointly normally distributed, with zero means, constant variances and a covariance term. It involves two steps procedure. First, the estimation of the selection model and second, the estimation of the outcome equation. The canonical

Figure 2: Map of Benin and municipality of Malanville showing the study sites



specification of the selection model is a probit regression of the following form:

$$Z_i = \sigma + \delta X_i + \mu_i \tag{6}$$

where Z_i is a latent variable representing the likelihood of a farmer i to participate in an irrigation project. X_i is the vector of farms' and farmers' characteristics, and institutional factors that affect the adoption decision. Once the probability of adoption is predicted, the variable called the Mills ratio is calculated as follows:

$$\lambda_i = \frac{\text{Ø}(\rho + \delta X_i)}{\varphi(\rho + \delta X_i)} \tag{7}$$

Table 1: Socio-economic characteristics of the municipality of Malanville

Malanville	
Population (2013)	168,641
Religion (%)	Muslims: 80, Others: 20
Child schooling rate (%)	28.4
Literacy rate (%)	14.1
Main economic activities	Agriculture, fishing, livestock, small business, trade and crafts
Major crops	Maize, rice, millet, sorghum, cotton, and vegetables
Food insecurity (%)	35
Poverty incidence (%)	42.5

Source: Institut National de la Statistique et de l'Analyse Economique (INSAE) (2011, 2013).

where Ø is the density function of a standard normal variable; Ø is the cumulative distribution function of a standard normal distribution and λ_i is the Mills ratio term.

The second step involves the inclusion of the inverse Mills ratio into the productivity equation to test for the existence of selection bias in the model. If the coefficient of the inverse Mills ratio is significant then there is selection bias in the model and the OLS estimates of the outcome equation will be inconsistent and biased. Hence preference will be given to the results from the second stage of the Heckman model as this leads to robust estimators. In the case where the coefficient of the inverse Mills ratio is not significant then this means the absence of selection bias in the data. Therefore the OLS estimates are consistent and unbiased and close to the results from the second step of the Heckman model. The productivity equation is presented as follows:

$$Y_i = \beta_0 + \beta_{1i}X_i + \beta_{2i}Z_i + \beta_3\lambda_i + \mu_i \text{ with } E(\mu_i) = 0 \quad (8)$$

where Y_i is rice yield in kg/ha, X_i is the vector of farm and farmers characteristics, and institutional variables. Z_i is a dummy variable with value 1 for irrigation beneficiary and 0 for non-beneficiary.

4. Results and Discussion

4.1 Socio-economics Characteristics of the Surveyed Rice Farmers

Summary statistics of the socio-economics characteristics of the surveyed rice farmers are given in Tables 2 and 3. Table 2 presents descriptive statistics for the continuous variables from t-test analysis. Table 3 indicates statistics for the categorical variables based on the chi square test. Overall, there are important differences in the socio-economics characteristics between the irrigation and dry land farmers except for the educational level variables. Irrigation farmers are younger than the dry land farmers. There is a gender difference in the participation to an irrigation project. A larger proportion of male (81 per cent) have adopted irrigation. The irrigators have significantly higher yield per hectare than the dry land farmers. This shows how the climatic condition affects the rice production in the municipality of Malanville. The irrigation farmers spend on average about 499 man-days per ha against 283 man-days in rainfed farms. This confirms the fact that more labour is required in irrigated farms than in rainfed farms. While the level of agricultural mechanization is low, there was a significant difference in access to tractor between the two groups of farmers. Table 3 indicates that 11 per cent of the irrigation farmers against 1 per cent of the dry land farmers have used a tractor for land preparation.

There is a significant difference in support services among the farmers (Tables 2 and 3). The irrigators had more contact with extension agents than the dry land farmers. About 87 per cent of irrigation farmers have obtained credit in the past year against 54 per cent of dry land farmers. Also in terms of market participation, irrigation farmers sold a higher proportion of their rice than dry land farmers. This significant difference for the institutional variables is due to the importance that has been given to the development of irrigation in Benin. It is also noticed that irrigators have significantly greater off-farm income (CFA 20,830) than dry land farmers (CFA 12,180).

Table 2: Description of continuous variables

Variable definition	Irrigation farmers (Mean)	Dry land farmers (Mean)	*t*-test
Rice yield (kg/ha)	5726.93	2725.51	−41.71***
Age of the farmer (number of years)	40.09	42.05	02.15**
Frequency of extension visits (number of visits)	03.77	01.25	−16.86***
Proportion of rice sold (%)	76.09	66.38	−04.22***
Off farm income (CFA)	20,830	12,180	−02.60***
Distance from home to irrigation scheme (km)	03.35	17.47	15.88***
Fertilizer application rate (kg/ha)	305.33	226.20	−10.38***
Herbicide application rate (liter/ha)	02.81	01.75	−06.76***
Farm labour (number of man days)	498.19	282.78	−08.23***

*** significant at 1%, ** significant at 5%.
Source: Field survey (2015).

Table 3: Description of categorical variables

Variable definition	Categories	Irrigation farmers (%)	Dry land farmers (%)	χ^2 value
Gender	1 = male	80.67	72.41	4.18**
	0 = female	19.33	27.59	
Use of tractor	1 = yes	11.33	1.11	38.06***
	0 = no	88.67	98.99	
Credit access	1 = yes	87.33	54.44	53.67***
	0 = no	12.67	45.56	
Education	0 = none	66.67	63.89	0.39
	1 = At least primary school	33.33	36.11	

*** significant at 1%, ** significant at 5.
Source: Field survey (2015).

4.2 Factors that Influence Adoption of Irrigation

Estimates of the probit model derived from the first stage of the Heckman model (Table 4) revealed that the model has a good fit with its explanatory variables as the chi square test is significant at 1 per cent. This implies that the exogenous variables are relevant in explaining the likelihood of irrigation adoption. The variables that are statistically significant include the age of the respondent, gender, education, frequency of extension visit, credit access, market participation, distance from home to irrigation

Table 4: Probit regression predicting the likelihood of irrigation adoption

Variables Dependent variable: Adoption of irrigation	Coefficient	Marginal effect	Prob
Age (number of years)	0.742	0.013**	0.024
Age square	–0.0068	–0.0002**	0.008
Gender (male = 1, female = 0)	1.130	0.034**	0.014
Education	0.614	0.018*	0.055
Frequency of extension visit (number of visits)	0.455	0.013***	0.000
Credit access (yes = 1, no = 0)	1.811	0.055***	0.000
Market participation (proportion of rice sold)	0.149	0.00045**	0.012
Distance from home to irrigation scheme	–0.450	–0.013***	0.000
Log of off farm income (income in CFA)	0.018	0.00057	0.569
Use of tractor (yes = 1, no = 0)	4.538	0.139***	0.000
Log of fertilizer (fertilizer in kg/ha)	6.854	0.210*	0.090
Log of herbicide (herbicide in liter/ha)	1.288	0.039	0.834
Log of farm labour per ha (number of man days)	3.750	0.114	0.198
Log of fertilizer × Log of farm labour	–0.528	–0.016	0.324
Log of fertilizer × Log of herbicide	–0.376	–0.011	0.740
Log of fertilizer × Use of tractor	0.036	0.0011	0.961
Log of herbicide × Log of farm labour	0.217	0.0066	0.493
Log of herbicide × Use of tractor	–0.422	–0.012	0.751
Log of farm labour × Use of tractor	–0.119	–0.0036	0.825
Constant	–51.968		
Log likelihood	–39.017		
χ^2	3081.87***		
N	690		

*** Significant at 1%, ** significant at 5% and * significant at 10%.

scheme, use of tractor and fertilizer. The signs of the coefficient of the explanatory variables conform to our expectations and are the same as those of the marginal effects. The results are in line with previous studies by Abdulai *et al.* (2011), Bacha *et al.* (2011), and Sinyolo *et al.* (2014).

Age of the farmers, which is specified as a quadratic, has a significant and non-linear effect on the probability of irrigation adoption. A unit increase in farmer's age increases the likelihood of adopting irrigation by 1.3 per cent, but only up to 55 years, beyond which the likelihood decreases by 0.02 per cent. This implies that as the farmer gets older, the probability of being an irrigator decreases. One explanation is that the older farmers may transfer the ownership of the irrigated land to the younger descendants. There is a positive relationship between the sex of the farmers and the probability to participate in irrigation project. Men are more likely to adopt irrigation than women. This may be due to the high labour demand of irrigated farming. Farmers that have attained at least primary school have higher probability to adopt irrigation than the non-educated farmers. The explanation is that educated farmers may have more ability for adopting a new agricultural technology (Dillon, 2011).

A positive relationship was found between frequency of extension visits and the probability of adoption of irrigation. A unit increase in the frequency of extension visits increases the likelihood of adoption of irrigation by 1.39 per cent, suggesting that learning about new agricultural practices and technologies may have occurred through extension services and social network (Conley and Udry, 2001; Abdulai *et al.,* 2011; Genius *et al.*, 2014). Access to credit affects positively the probability to adopt irrigation. It increases the likelihood of being an irrigator by 5.55 per cent. Therefore improving farmers' access to credit is vital for the irrigation development policy. Table 4 also indicates that participation to market increases the likelihood of adopting irrigation. As farmers are aware that demand for rice consumption exists, they will tend to increase rice supply by adopting new practices. The positive relationship between irrigation adoption and the institutional variables such as access to credit, market and extension services reveals the support given by the government toward the farmers on the irrigation scheme.

As expected, distance from home to irrigation scheme has a negative relationship with the probability of irrigation adoption. Proximity to an irrigation scheme increases the probability of being an irrigator. This may reduce the cost in terms of time and energy spent to reach the scheme and then facilitate the management (Sinyolo *et al.,* 2014). Farmers' engagement in off-farm economic activities increases the probability of using irrigation. The farmer may use the off-farm income as investment in farm activities and could support the costs related to the adoption of irrigation. Farmers that reported practising intensive production have higher probability to adopt irrigation. The variables, use of tractor and fertilizer application rate, have a positive relationship with the probability of adopting irrigation. None of the coefficients of the interaction terms among fertilizer, herbicide, use of tractor, and labour included in the model are not statistically significant.

4.3 Effect of Irrigation Adoption on Rice Yield

Although past studies (Bacha *et al.,* 2011; Sinyolo *et al.,* 2014) have suggested the possible endogeneity between treatment and outcome variables, the Hausman test ($p = 0.35$) reveals the absence of endogeneity between adoption of irrigation and rice yield in this study. Table 5 presents the results of the second stage of Heckman model. Following Sinyolo *et al.* (2014) the variable distance from home to irrigation scheme included in the selection equation was excluded in the outcome equation to satisfy the condition of model identification. This variable influences the likelihood of irrigation adoption but does not affect rice yield. The coefficient of the inverse Mills ratio (lambda) is not significant. This indicates the absence of selection bias in the data. Therefore, the OLS estimates are consistent and unbiased and close to the results from the second stage of the Heckman model.

The Heckman second stage estimates fit the data very well as indicated by the significance of the F-test at 1 per cent. The results show that irrigation affects positively the level of rice yield. The coefficient of the irrigation variable is positive and significant at 1 per cent. Thus irrigation adoption may explain the significant difference in rice yield observed between irrigation and dry land farmers in the municipality of Malanville. Adoption of irrigation contributes to the increase in rice yield at about 57 per cent. This result is consistent with those found in the literature (Huang *et al.,* 2006; Kemah and Thiruchelvam, 2008; Dillon, 2011) and also confirms the expectations that was placed in irrigation for contributing to crop yield improvement. Several studies (Domenech, 2015; Hussain and Hanjra, 2004; Lipton *et al.*, 2003) have indicated that irrigation contributes to crop productivity improvement through reduced crop loss, multiple cropping, and expansion of crop land.

Other determinants of rice yield are education and off-farm income. These variables contribute to the increase in rice yield. The educational level of farmers influences positively the level of productivity. More educated farmers have a higher rice yield. This is in line with our expectation because education enhances the capacity to adapt to change, to understand new practices and technologies (Adeoti, 2009). Thus education improves the ability to face challenges and then increases productivity. The

Table 5: Factors affecting rice yield: Heckman second step and OLS results

Variables	Heckman second stage		OLS results	
Dependent variable: Logarithm of rice yield (yield in kg/ha)	Coefficient	Prob	Coefficent	Prob
Adoption of irrigation	0.568***	0.000	0.561***	0.000
Age (number of years)	–0.0065	0.160	–0.0066	0.154
Age square	0.000082	0.190	0.000082	0.194
Gender (male = 1, female = 0)	0.0179	0.356	0.0173	0.371
Education	0.035**	0.025	0.034**	0.027
Frequency of extension visit (number of visits)	0.0157***	0.001	0.0154***	0.001
Credit access (yes = 1, no = 0)	0.0797***	0.000	0.0799***	0.000
Market participation (proportion of rice sold)	0.00151***	0.000	0.00154***	0.000
Log of off farm income (income in CFA)	0.00330*	0.054	0.00339**	0.048
Use of tractor (yes = 1, no = 0)	0.335***	0.000	0.336***	0.000
Log of fertilizer (fertilizer in kg/ha)	0.088*	0.083	0.091*	0.075
Log of herbicide (herbicide in liter/ha)	0.065	0.519	0.070	0.491
Log of farm labour per ha (number of man days)	0.095**	0.024	0.097**	0.021
Log of fertilizer × Log of farm labour	–0.011	0.144	–0.012	0.138
Log of fertilizer × Log of herbicide	0.0076	0.649	0.0075	0.654
Log of fertilizer × Use of tractor	0.156***	0.000	0.154***	0.000
Log of herbicide × Log of farm labour	–0.092	0.213	–0.013	0.185
Log of herbicide × Use of tractor	0.142	0.178	0.143	0.172
Log of farm labour × Use of tractor	0.092***	0.000	0.090***	0.000
Lambda	0.0050	0.370	–	–
Constant	7.141***	0.000	7.128***	0.000
F-test	123.51***	0.000	128.88***	0.000
R-squared	0.72		0.72	
N	690		690	

*** Significant at 1%, ** significant at 5% and * significant at 10%.

coefficient of the off-farm income variable is positive, implying that farmers with high off-farm income have higher yield. A 1 per cent increase in off-farm income contributes to an increase of 0.3 per cent of rice yield. The explanation is that increased off-farm income is reinvested in the farm.

The institutional variables that affect rice yield are extension services, market participation, and access to credit. In line with the agricultural development theories the extension services variable has a positive effect on rice yield. A unit increase in the frequency of extension visits contribute to an increase in rice yield by 1.5 per cent. Through regular contact with extension agents rice farmers may be able to adopt new farming technologies that will help them to improve their productivity. Market participation also has a positive influence on rice yield. Participation in market is an indication that demand for rice consumption exists. Farmers that have access to market may earn more from the sale of rice and then in turn accrued funds are reinvested in the farm. The positive coefficient of the variable credit indicates that farmers that have obtained credit in the past year have higher yield. This implies that access to credit is vital for productivity improvement.

As expected, the results show a positive relationship between the input variables and the yield. The use of tractor, fertilizer and farm labour are production input variables that contribute to the increase in rice yield. Despite the fact that the level of agricultural mechanization is still low (Table 3 above), farmers that reported using a tractor for land preparation have higher yield compared to those who did not. One explanation is that the use of tractor enhanced rice productivity due to better seedbed preparation. This result confirms the findings of Ghadiryanfar *et al.* (2009); Salam (1981) and Singh (2006). Farm mechanization and high dosage of fertilizer enable agricultural intensification which therefore remains a key policy for yield improvement. This was justified by the positive and significant sign of the coefficient of the interaction terms of the variables fertilizer and use of tractor, and the variables farm labour and use of tractor.

Table 6: Impact of irrigation adoption on rice yield: PSM results

Outcome variable: Logarithm of rice yield

	Number of rice farmers			
Matching method	Treatment	Control	ATT	*t*-test
Nearest neighbour	133	540	0.55 (0.094)	5.83***
Kernel Epanechnikov	133	540	0.58 (0.087)	6.64***
Mahalanobis	150	540	0.60 (0.097)	6.18***

*** Significant at 1%; values in parentheses are standard errors.

For robustness checks of the estimated impact of irrigation on rice yield, the propensity score matching method (PSM) was used. Since there was no confirmation of selection bias and endogeneity in the model, the conditional independence assumption under the PSM is not violated; therefore, the PSM approach is appropriate for estimating the average effect of the adoption of irrigation on rice yield. The idea behind the PSM is to match each irrigation farmer with an identical dry land farmer and then measure the average difference in yield between the two groups after controlling for individual and farm characteristics which may influence the outcome. The common support was imposed in constructing the matching estimates. This reduced the sample size as it drops treatment observations whose propensity score is higher than the maximum or less than the minimum propensity score of the controls. Also the balancing property of the covariates was satisfied. Three matching methods, the nearest neighbour, Kernel Epanechnikov and Mahalanobis, were employed to estimate the impact. Different matching methods were used for the consistency of the results (Dillon, 2011; Sinyolo *et al.*, 2014). Table 6 presents the average treatment effect on the treated (ATT) across the three matching methods.

The results indicate that irrigation adoption has a significant impact on rice yield. The average percentage contribution of irrigation to the increase in rice yield varies between 55 and 60 per cent relative to non-irrigation adopters. The nearest neighbour matching method was used with replacement, and concluded that irrigation adoption contributes to an increase in rice yield of about 55 per cent. On the other hand, the kernel matching method shows that the adoption of irrigation increases rice yield to about 58 per cent. Also, the Mahalanobis matching method reveals that the use of irrigation for rice production contribute to increase yield to about 60 per cent. The PSM estimates support the results of the Heckman model that irrigation adoption has a positive effect on rice yield.

5. Conclusion and Policy Implications

The paper assesses the effect of the adoption of irrigation on crop yield. It uses the Heckman two stage procedure to control for selection bias. The results of the probit estimation show that the variables that influence the adoption of irrigation include the age of the respondent, gender, extension services, access to credit, participation to market, distance from home to irrigation scheme, use of tractor for land preparation, and fertilizer application rate. The Heckman second stage estimates reveal that the adoption of irrigation positively affects rice yield. This view was supported by the PSM results. Hence, irrigation is important for the crop productivity improvement. Other variables that affect rice yield are education, extension services, access to credit, market participation, off-farm income, use of tractor, fertilizer application rate and farm labour. The implication of these findings is that while irrigation adoption is essential for productivity improvement it cannot achieved its goals alone. With complementary farm inputs like fertilizer, agricultural tractor and institutional support services such as extension visits, access to credit and market, the goal of productivity improvement could be achieved. Therefore, policy that will contribute to high crop yield should promote intensive agriculture and mechanization, and also provide institutional support services to the farmers.

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