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A re-examination of the impact of irrigation on rice production in Benin: An application of the endogenous switching model

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Abstract

Irrigation offers important opportunities for enhancing crop yield and production in developing countries. This paper provides a re-examination of the impact of irrigation on rice production in Benin. It employed an endogenous switching model to account for bias due to observable and unobservable factors. The results indicated that the age of the farmer, gender, education, extension services, credit, access to media, ownership of mobile phone, off-farm income, and distance from home to irrigation scheme are factors affecting the probability of the adoption of irrigation. The results also revealed that adoption of irrigation is positively associated with rice productivity improvement. Farm variables such as soil fertility, labor, and fertilizer and herbicide application have a positive effect on rice productivity. Other variables increasing the rice yield were: education, credit, off-farm income, and access to media. These findings suggest that investments in irrigation should be accompanied by the provision of institutional support measures and complementary farm inputs to enhance the impact of irrigation on rice production.

Introduction

Although food security remains one of the higher priorities of the Government of Benin, national food crop production is still insufficient to satisfy the food need of the population. Each year, food deficiency is compensated by imports, with milled rice imports to Benin increasing from 115,000 t in 2002 to 350,000 t in 2013 (United State Department of Agriculture [USDA], 2016). Over the same period the total population has increased annually at a growth rate of 3.5 percent from 6,769,914 in 2002 to 9,983,884 in 2013 and the population growth and dietary changes together have led to an increase in the demand for food, which is a global trend supported by studies on food security (Hanjra & Qureshi, 2010). One way to face the challenge of growth in food demand and reduce food import dependency is to increase agricultural production and productivity. Rice production in Benin increased at an annual rate of 11 percent between 2000 and 2014, while the total area harvested increased at 8 percent (Food and Agriculture Organization [FAO], 2016). This shows that bulk of the gains in food production came from area expansion, also supported by other studies (Abro, Alemu, & Hanjra, 2014; Hanjra, Ferede, & Gutta, 2009). As land resources are limited, the alternative is to increase the output per hectare through adoption of new agricultural practices and technologies. In regard to this, irrigation has been proved as an important tool for agricultural yield improvement (Carruthers, Rosegrant, & Seckler, 1997; Domenech & Ringler, 2013; FAO, 2003; Hanjra, Noble, Langan, & Lautze, 2017; Huang, Rozelle, Huang, Lohmar, & Wang, 2006). The development of irrigation contributes by increasing returns to smallholder farmers in terms of achieving higher yields and revenues from crop production (Hanjra et al., 2009; Hussain & Hanjra, 2004).

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Investments in irrigation in Benin started in 1960. As a consequence, the total land developed for irrigation purposes has increased from 3,932 ha in 1975 to 9,724 ha in 1990, and to 23,040 ha in 2008 (FAO, 2014). This represents less than 8 percent of the potential irrigable land (322,000 ha) and approximately 0.8 percent of the total cultivated area in Benin. The irrigated crops are rice, sugarcane, vegetables, roots, and tubers (Ministère de l'Agriculture, de l'élevage et de la pêche [MAEP], 2009). Rice occupied about half of the total irrigated land in 2008 (FAO, 2014). This shows the importance of rice in Benin's agricultural development policy. Indeed, the need for irrigation development to achieve high agricultural yields is clearly expressed and defined in the Plan Stratégique de Relance du Secteur Agricole (PSRSA) of Benin 2011−2015, which defines the guidelines for improving the use of irrigation facilities in the country. These policies undertaken by the Government for promoting food crop production in Benin led to an increase in rice production from 4,000 t in 1970 to 72,960 t in 2007 and to 234,145 t in 2015; however, the objective of the rice policy to be self-sufficient in rice production by 2015 was not met. National rice production in 2015 was far below the target of 600,000 t needed in Benin for self-sufficiency in rice production. Hence, studies analyzing the impact of adoption of irrigation remain vital for sound policies to support future interventions promoting the development of irrigation in Benin.

This study provides support for continuing investments in irrigation development in Benin. A review of previous studies indicates the positive impact of irrigation on crop yield, food security, and poverty (Bacha, Namara, Bogale, & Tesfaye, 2011; Carruthers et al., 1997; Domenech & Ringler, 2013; FAO, 2003; Hanjra & Gichuki, 2008; Huang et al., 2006; Hussain & Hanjra, 2003; Namara et al., 2010). Other studies have shown that impacts of investments in irrigation on crop productivity and poverty reduction are greater where institutional support measures and complementary policies and infrastructure are available (Fan, Hazell, & Throat, 2000; Hanjra et al., 2009; Hussain & Hanjra, 2003, 2004; Nguyen, Phung, Ta, & Tran, 2017). This study aimed to quantify the effect of irrigation adoption on rice production in the specific context of Benin. It complements earlier studies about the impacts of irrigation development. It also offers a re-examination of the impact of irrigation on rice yield in Benin. Indeed, a previous study (Nonvide, 2017) has shown that the contribution of irrigation in rice productivity improvement in Benin varies between 55 and 60 percent. By employing a Heckman model of selection, the study by Nonvide (2017) does not account for the unobserved factors (farmers' motivation, ability, among others) which may affect the adoption process. This paper builds on previous analysis (Nonvide, 2017) and employs an endogenous switching model which controls bias due to both observable and unobservable factors. The advantage of the endogenous switching model is the use of full information maximum livelihood to simultaneously estimate the selection and outcomes equations. It can also be used to compare the expected outcomes under actual and counterfactual cases (Asfaw, Shiferaw, Simtowe, & Lipper, 2012; Carter & Milon, 2005; Di Falco, Veronesi, & Yesuf, 2011).

Material and Methods

Study Area and Sampling Design

The study was conducted in the municipality of Malanville, Benin. The climate is Sudano-Sahelian with only one rainy season from May to October. The municipality benefits from a low rainfall between 700 mm and 1000 mm. It experiences high levels of food insecurity (35%) and poverty (42.5%) with the majority of its inhabitants involved in subsistence agriculture and other activities such as fishing, livestock rearing, small business, trade, and crafts (Institut National de la Statistique et de l'Analyse Economique [INSAE], 2013). Maize, rice, millet, sorghum, cotton, and vegetables are the major crops grown. The municipality of Malanville is the largest rice-producing zone in Benin. Among the rice irrigation schemes developed by the State, the scheme in Malanville is the most important in terms of size, cropping season, and yield per farmer. The scheme covers 516 ha of which 400 ha were used in 2015. Rice is the only crop grown under the scheme with 1,054 farmers in 2015. The irrigated land size per farmer ranges from 0.25 ha to 2 ha.

The survey covered four districts out of the five in the municipality. District selection was based on the criteria of production and distance to the irrigation scheme. In each of the four districts selected, two villages (one high and one low rice-producing village) were purposively selected. A proportional sampling technique was employed to select the irrigators because they were grouped in 20−100 people. Those practicing rainfed farming were selected within the eight villages covered by the survey. Based on the list of rice farmers, provided by the Chief of the village, a random sample of 90 was obtained from each high rice-producing village. Similarly, 45 farmers were selected in each low rice-producing village. In total, 690 rice producers consisting of 150 irrigators and 540 farmers using rainfed techniques were interviewed from April to June, 2015.

Methods of Analysis

This study was built on the expected utility maximization theory. Under the expected utility framework, farmers adopt irrigation only when this could provide them with an expected utility greater than is the case without it. In line with this, farmers' direct expectation in irrigation participation is the increase in crop yield. The study employed the endogenous switching regression model to achieve an unbiased estimate of irrigation's impact on rice production per hectare, accounting for possible endogeneity of the adoption decision due to unobserved characteristics of farmers. The endogenous switching model involves separate estimations for subgroups of irrigators and rainfed farmers. Therefore, irrigation adoption becomes the selection criterion indicating the regime faced by the farmers. The irrigation adoption function is defined as:

$$D_i = \partial Z_i + \mu_i \quad (1)$$

with $i = 1$ for irrigators and 0 for rainfed farmers, Z_i is a vector of farmers and farm characteristics influencing the decision to adopt irrigation. Following Equation (1), the outcomes are observed for the two groups of farmers (Asfaw et al., 2012; Maddala, 1983):

$$\text{Regime 1}: \; Y_{1i} = \alpha_1 X_{1i} + v_{1i} \quad \text{for irrigators} \tag{2}$$

$$\text{Regime 2}: \; Y_{2i} = \alpha_2 X_{2i} + v_{2i} \quad \text{for rainfed farmers} \tag{3}$$

where Y_i is the rice output per hectare, X_i a vector of exogenous variables affecting the rice yield, and v_i is the residuals.

There is a high likelihood that some unobserved factors affecting the likelihood of adoption of irrigation could also affect the rice yield (outcome variable). Hence, the error term in Equation (1) and the error terms in the outcomes functions (2) and (3) may be correlated. To solve this problem, Equations (1)–(3) were simultaneously estimated using a Full Information Maximum Likelihood (FIML) which remains the most efficient approach. The Stata command "movestay" provides consistent estimation of the endogenous switching model (Lokshin & Sajaia, 2004).

The study also used the endogenous switching model for the comparison of the expected rice yield of the irrigators (a) with respect to the rainfed farmers (b), and to investigate the expected rice yield in the counterfactual cases (c) that the irrigators did not adopt irrigation, and (d) that the rainfed farmers did adopt (Asfaw et al., 2012; Carter & Milon, 2005; Di Falco et al., 2011). These measures are important to explain differences in the rice yield between the two groups and to provide possible responses to changes in irrigation policy. The conditional expectations for rice yield in the cases (a), (b), (c), and (d) are reported in Table 1. Cases (a) and (b) indicate the actual expectations, while the counterfactual expected outcomes are shown in cases (c) and (d).

The effect of irrigation adoption on irrigators is expressed by Equation (4). It is the "treatment effect on the treated" (TT) which is the difference between cases (a) and (c) (Asfaw et al., 2012; Di Falco et al., 2011; Heckman, Tobias, & Vytlacil, 2001):

Table 1
Conditional expectations, treatment and heterogeneity effects

Sub-sample	Decision stage		Treatments effects
	Adopt	Not Adopt	
Irrigation farmers	(a) $E(y_{1i} \vert D_i = 1)$	(c) $E(y_{2i} \vert D_i = 1)$	TT
Dry land farmers	(d) $E(y_{1i} \vert D_i = 0)$	(b) $E(y_{2i} \vert D_i = 0)$	TU
Heterogeneity effects	BH_1	BH_0	TH

Note: (a) and (b) are the observed expected rice yields; (c) and (d) are the counterfactual expected rice yields
$D_i = 1$ if farmers adopted irrigation; $D_i = 0$ if farmers did not adopt
y_{1i} : Rice yield if farmers adopted
y_{2i}: Rice yield if farmers did not adopt
TT: Effect of the treatment on the treated
TU: Effect of the treatment on the untreated
BH_i: Base heterogeneity effect for farmers that adopted ($i = 1$), and did not adopted ($i = 0$)
TH = (TT − TU): Transitional heterogeneity
Source: Adapted from Asfaw et al. (2012); Carter and Milon (2005); Di Falco et al. (2011)

$$TT = E(y_{1i}|D_i = 1) - E(y_{2i}|D_i = 1) \tag{4}$$

Similarly, the difference between cases (d) and (b) is the treatment effect on the untreated (TU) for the rainfed farmers. This is expressed by Equation (5) as:

$$TU = E(y_{1i}|D_i = 0) - E(y_{2i}|D_i = 0) \tag{5}$$

The study differentiates the treatments effects from the heterogeneity effects. For instance, the irrigators may have more or less yield than the rainfed farmers regardless of the fact they adopted irrigation but rather because of unobservable factors that affect the rice yield. This "base heterogeneity effect" is expressed in Equation (6) as the difference between cases (a) and (d) for the group of irrigators (Asfaw et al., 2012; Di Falco et al., 2011)":

$$BH_1 = E(y_{1i}|D_i = 1) - E(y_{1i}|D_i = 0) \tag{6}$$

Similarly, for the group of rainfed farmers, the "base heterogeneity effect" is given by Equation (7) as the difference between cases (c) and (b):

$$BH_2 = E(y_{2i}|D_i = 1) - E(y_{2i}|D_i = 0) \tag{7}$$

Lastly, the study investigated whether the effect of adoption of irrigation is greater or smaller for irrigators or for rainfed farmers if they did adopt. That is the "transitional heterogeneity effect" calculated as:

$$TH = TT - TU \tag{8}$$

Summary statistics of surveyed rice farmers indicated no significant differences were noted between the irrigators and rainfed farmers regarding the educational level, rice farming experience, accessibility to agricultural information, knowledge through the media (radio or TV), use of mobile phone, and perceived soil fertility (Table 2).

Irrigators were younger compared to rainfed farmers. There was a gender difference in the adoption of irrigation. Significant differences were observed in access to extension services, improved seed, credit, and market exists among the farmers. With respect to the farm variables, significant differences were also noted. The irrigators had significantly higher yields per hectare. This shows how the climatic conditions and lack of inputs affect rice production in the municipality of Malanville.

Results and Discussion

Table 3 presents the results of the full information maximum likelihood estimation of the endogenous switching model. The variable, distance to irrigation scheme, used in the adoption equation was excluded in the outcomes functions, to meet the condition of model identification (Nonvide, 2017; Sinyolo, Mudhara, & Wale, 2014). The hypothesis was that this variable affects the probability of adoption of irrigation but does not influence rice yield. Accessibility to the irrigation scheme is key to its adoption. One cannot adopt irrigation if there is no access. However, being closer to the irrigation scheme without adopting it does not affect the rice output.

Table 2
Respondents' socio-economic characteristics

Variable definition	Irrigators (Mean)	Rainfed farmers (Mean)	t-test/χ^2 value
Rice yield (Kg/ha)	5,726.93	2,725.51	−41.71***
Age of the farmer (years)	40.09	42.05	02.15**
Rice farming experience (years)	13.55	13.27	−0.458
Extension services (1 = Yes, 0 = No)	0.94	0.47	102.84***
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 (L/ha)	02.81	01.75	−06.76***
Farm labor (Number of worker days)	498.19	282.78	−08.23***
Off farm activities (1 = Yes, 0 = No)	0.66	0.61	1.34
Gender (1 = male, 0 = female)	0.80	0.72	04.18**
Use of improved seed (1 = Yes, 0 = No)	1	0.43	150.06***
Perception of Soil fertility (1 = Good, 0 = Poor)	0.55	0.53	0.098
Access to credit (1 = Yes, 0 = No)	0.78	0.54	53.67**
Education (1 = At least primary school, 0 = None)	0.33	0.36	0.39
Access to media (1 = farmer owns a radio or a TV, 0 = No)	0.74	0.73	0.138
Ownership of mobile phone (1 = Yes, 0 = No)	0.35	0.34	0.013

***significant at 1%, ** significant at 5%

Estimates of the endogenous switching model (Table 3) revealed that the model has a good fit with its explanatory variables. The Wald test of independence was significant at 5 percent, confirming the sample separation. The coefficient of correlation (Rho_1) between the equations of adoption of irrigation and rice yield was negative and significant at 1%. This implies that the irrigation adoption decision is affected by observable and unobservable factors. The endogenous switching model presents the results of both the adoption and the yield impacts equations. The results regarding the adoption model are not discussed since this was not the primary focus of the paper. However, variables that were statistically significant in explaining the decision to adopt irrigation (Table 3) were: the age of the farmer, sex, education, distance from home to irrigation scheme, extension services, off farm income, ownership of mobile phone, radio, or TV, and access to credit.

The significant determinants of the rice yield in both irrigated and rainfed farming (Table 3) were: education, soil fertility, access to media, and farm labor. Off farm income was the additional variable that contributed to the increase in rice yield in irrigated farming. However, in rainfed farms, access to credit and the fertilizer and herbicide application rates significantly increased rice yield. The educational level of farmers had a positive effect on rice yield. Educated farmers had a higher rice yield because education enhances the capacity to adapt to change and to understand new practices and new technologies (Adeoti, 2009). Hence, education improves the ability to face challenges and then increase productivity. Farmers that perceived their soil as

Table 3
Estimates of the impact of irrigation on rice yield

Variable Dependent variable: Rice yield	Adoption model	Outcome model	
		Irrigation farmers	Rainfed farmers
Age	0.478 (0.11)**	−86.75 (107.36)	−13.21 (10.74)
Age square	−0.004 (0.001)***	1.29 (1.39)	0.16 (0.11)
Gender	0.522 (0.27)*	−80.47 (139.70)	21.89 (32.23)
Education	0.511 (0.26)***	384.91 (155.18)**	77.74 (30.78)**
Extension services	2.056 (0.32)***	−189.44 (181.25)	42.61 (28.51)
Credit access	1.089 (0.25)***	1.99 (125.31)	108.77 (30.22)***
Off farm income	0.00001 (4.88e-06)**	0.001 (0.001)***	0.00006 (0.0003)
Soil fertility	−0.154 (0.26)	1619.13 (107.43)***	735.53 (27.81)***
Ownership of mobile phone	0.773 (0.26)***	−47.11 (127.94)	−63.79 (43.1)
Access to media	1.211 (0.25)***	661.89 (124.53)***	125.71 (29.44)***
Distance to irrigation scheme	−0.497 (0.052)***	–	–
Fertilizer	–	−0.59 (0.91)	0.74 (0.18)***
Herbicide	–	−19.98 (44.39)	36.23 (9.58)***
Farm labor	–	0.39 (0.12)***	0.18 (0.07)**
Constant	−5.502 (2.19)**	6010.125 (2089.53)***	2145.10 (236.4)***
N	690	150	540
Rho_0	0.076 (0.15)		
Rho_1	−0.487 (0.16)***		

Log likelihood: −5134.43; Wald chi2 (13) = 943.73; Prob > chi2 = 0.000
Wald test of indep. eqns.: chi2 (2) = 6.05; Prob > chi2 = 0.048

Note: *** significant at 1%; ** significant at 5% and *significant at 10%; Standard errors in parentheses

Table 4
Average expected rice production per hectare for irrigation and rainfed farmers

Subsample	Decision stage		Treatments effects
	Adopt (N = 150)	Not Adopt (N = 540)	
Irrigation farmers	(a) 5,729.437 (45.03)	(c) 2,982.983 (18.27)	TT = 2,746.455 (26.75)***
Rainfed farmers	(d) 5,847.556 (38.06)	(b) 2,725.522 (15.87)	TU = 3,122.034 (22.18)***
Heterogeneity effects	BH_1 = −118.11 (25.56)***	BH_2 = 257.46 (91.95)***	TH = −375.579 (2.75)***

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

fertile had a higher yield compared to those who perceived the soil as poor. In line with economic theory, the availability of labor was associated with an increase in rice yield. Farmers that owned a radio or TV had higher rice yields, implying that they may be informed on the agronomic practices through the media. Information on both input and output markets may be also found through the media. Furthermore, ownership of a radio or TV is also an indication of wealth; therefore wealthier farmers can invest more in boosting their farm productivity.

Table 4 presents the expected rice yield under the counterfactual analysis for irrigators and rainfed farmers. Cases (a) and (b) are the observed expected rice yield which were 5,729 kg per ha for the irrigators and 2,725.5 kg per ha for the rainfed farmers. A t-test analysis (t = −41.71) between the two groups showed that irrigation farmers had significantly higher rice yields with the difference being 3,001 kg per ha; however, it cannot be attributed to the adoption of irrigation alone. Table 4 also reports the treatments effects of irrigation adoption. In the counterfactual case (c), the irrigated rice yield would have been 2,746 kg per ha less if they did not adopt irrigation. If the rainfed farmers had adopted irrigation (case (d)), they would have produced 3,122 kg more. The last column of Table 4 shows that the transitional heterogeneity effect was negative (TH = - 375.57), implying that the impact of adopting irrigation was significantly smaller for the irrigators than the rainfed farmers. The rainfed farmers would produce 375.57 kg per ha more than the irrigators if they did adopt irrigation. The heterogeneity effects reveals that the rainfed farmers would have produced less than the irrigators in the counterfactual case (c), while producing more in case (d).

The findings of this study suggest that there is a positive relationship between adoption of irrigation and rice yield. Irrigation contributes to increasing rice production by 2,746 kg per ha, corresponding to CFA 466,820 (USD 789.54). This result confirms previous findings by Dillon (2011); Huang et al. (2006), Kemah and Thiruchelvam (2008) who reported that irrigation has paramount importance on crop production. Indeed, irrigation contributes to improving crop yield through reduced losses, multiple cropping, and land expansion (Abro et al., 2014; Hussain & Hanjra, 2003, 2004; Mateos et al., 2010). Irrigation has helped to improve the rice yield in Benin but it is still not widely adopted among farmers. The main factor limiting adoption of irrigation in Benin is the investment cost. A previous study by Nonvide, Sarpong, Kwadzo, Anim-Somuah, and Amoussouga Gero (2017) reported that farmers could not afford the high cost of irrigation, and this is the major constraint faced by irrigated rice farmers in Benin. Indeed, the yield advantage for irrigators over rainfed farmers is combined with an increase in costs due to additional investments related to the adoption. For greater impacts of irrigation on rice production, institutional support is needed to increase farmers' education and knowledge. This may be done through regular training which requires active participation by farmers. Extension agents can help in training farmers. The findings also suggest that irrigation schemes can provide off-farm income opportunities to farmers through increased demand for inputs and supply of outputs (Hussain & Hanjra, 2004). It is therefore important to encourage the surrounding services sectors when promoting irrigation (Diagne, Demont, Seck, & Diaw, 2013).

Conclusion and Recommendation

The paper used an endogenous switching regression model to estimate the impact of irrigation on rice yield in the municipality of Malanville, Benin. The endogenous switching model controls for bias due to the observable and unobservable factors. The results indicated that the variables that influence the adoption of irrigation were: age of the farmer, gender, education, extension services, credit, access to media, ownership of mobile phone, off-farm income, and distance from home to irrigation scheme. The results also revealed that adoption of irrigation positively affects rice yield. Farm variables such as soil fertility, labor, and fertilizer and herbicide application have a positive effect on rice yield. Other variables that increased the rice yield were: education, credit, off-farm income, and access to media. The implication of these findings is that while irrigation is essential for rice productivity improvement there is a need for complementary services, infrastructure, policies, and institutions for greater impacts on production and wellbeing. Therefore, the study recommends that investments in irrigation should be accompanied by the provision of institutional support services and complementary farm inputs. For instance, the facilitation of access to farm inputs such as fertilizer, herbicide, and availability of labor are of great importance to boost rice productivity. The improvement of extension services may provide a source of information and training for the farmers. Accessibility to credit may enable farmers to secure the other inputs in time. The impact of public policy and investments on increasing productivity and wellbeing are well established in the literature but context-specific analysis is needed to support smarter policies in Benin.

Conflict of Interest

No conflict of interest.

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