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Research Article

Impact of Irrigation Ecology on Rice Production Efficiency in Ghana

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Irrigation production is a means by which agricultural production can be increased to meet the growing food demands in the world. This study evaluated the effect of irrigation ecology on farm household technical, allocative, and economic efficiency of smallholder rice farmers. Cross-sectional data was obtained from 350 rice farmers across rain fed and irrigation ecologies. Stochastic frontier analyses are used to estimate the production efficiency and endogenous treatment effect regression model is used to estimate the impact of irrigation ecology on rice production efficiency. The impact of irrigation ecology on technical efficiency is about 0.05, which implies farmers producing under irrigation ecology are more technically efficient in their rice production than those in rain fed production. The impact of irrigation ecology on allocative efficiency is about 0.33, which shows that farmers participating in irrigation farming are more allocatively efficient in their rice production than those in rain fed production. The impact on economic efficiency is about 0.23, meaning that farmers participating in irrigation farming are more economically efficient in their rice production than those in rain fed production. Irrigation ecology has positive impact on production efficiency; hence farmers should be encouraged to produce more under irrigation for increased yield and profit.

1. Introduction

Smallholder farmers in sub-Saharan Africa including Ghana, like those in other developing regions of the world, face a number of constraints that limit their farm productivity and farm income [1]. In many parts of SSA cereal crop yields are estimated to be <1.5 ton/ha while the actual potential is more than 5 tons/ha. The low yields are largely attributable to low use of organic and mineral nutrient resources, which has also resulted in negative nutrient balances [2, 3]. The reasons for these poor yields also include lack of sufficient information about production methods and practices and market opportunities. Their ability to access credit and inputs is limited by the lack of collateral which is an important requirement by most financial institutions.

Studies have shown that technical efficiency measures for Ghana's agriculture are low. Reference [4] found that average profit efficiency for rice farmers in Northern Ghana is 63%, with profit efficiency ranging between 16% and 96%. Reference [5] provided evidence to show that smallholder rice farmers in the Upper East region of Ghana produce, on average, 34% below maximum output. The estimated technical efficiency for smallholder irrigators and nonirrigators was 53% and 51%, respectively, using a simple t-test to compare the significance of their means. The authors of [6], in their study of rice farmers under irrigation in Tono, also concluded that mean technical efficiency estimate for irrigation rice farmers was 0.81, which is an improvement of earlier studies. All these studies used the SFA. These studies did not take into consideration the issue of self-selection that could potentially bias their predictions. This study will use the endogenous treatment-regression model to account for possible endogeneity and self-selection bias.

Table 1: Study regions, districts, and communities.

REGIONS	DISTRICTS	COMMUNITIES
Northern	Tolon	Golinga
Region	Kumbungu	Gbuli, Vogu, Kushebo, Zangbali, Kprim, Yipelgu, Wuba, Dalung, Kumbungu
	Savelugu	Tarikpaa, Duko, Dinga, Gbanga, Nakpanzo
Upper East Region	Bolga Metro	Nyariga, Yorugu, Gowrie, Zaare, Vea, Yebongu, Aguusi
	Kassena Nankana East	Pungu, Kajelo, Yogbania, Chuchulga, Kogwania, Korania, Wuru
Volta Region	South Tong	Sogakope

Efficiency measurement is very important because it has a direct effect on productivity and economic growth. Efficiency studies help firms to determine the extent to which they can raise productivity, incomes, and profit by improving their efficiencies, with the existing resource base and the available technology. Such studies could also support decisions on whether to improve efficiency first or to develop a new technology in the short run. More importantly, enhanced efficiency will not only enable farmers to increase their yield and profit but also give direction for the adjustments required in the long run to achieve food sustainability. The main objective of the study is to assess the impact of irrigation ecology on farm household technical, allocative, and economic efficiencies in Ghana.

2. Materials and Methods

2.1. The Study Area. This study covered Northern, Upper East, and Volta regions of Ghana basically because of their rice production potential in the country, which is mainly savanna. About 80% of total rice production in Ghana comes from these three regions. In Northern region three districts were selected based on their involvement in rice production, namely, Savelugu Municipal, Kumbungu, and Tolon districts. The communities covered are Golinga, Gbuli, Vogu, Kushebo, Zangbali, Kprim, Yipelgu, Wuba, Dalung, Kumbungu, Tarikpaa, Duko, Dinga, Gbanga, and Nakpanzo. In the Upper East, the district covered were Bolga Metro and Kassena Nankana East. The communities are Pungu, Kajelo, Yogbania, Chuchulga, Kogwania, Korania, and Wuru. Volta region had only one district participating in the study which is the South Tongu district with Sogakope as the only community; the details are shown in Table 1.

2.2. Sampling Strategy and Sample Frame. Multiphase (purposive and probability) sampling was used to sample the representative smallholder rice farmers in Northern, Upper East, and Volta regions. The three regions were purposively selected because their production constitutes about 80% of national rice production, and hence results can be generalized to be representative of national situation. Each region was classified into the two production ecologies (irrigation and rain fed ecologies). This procedure allowed us to take a representative sample with characteristics that can be generalized for the entire population which it represents. The population of interest for the study included rice smallholder farmers (SHF) working under irrigation and rain fed production systems in Northern, Upper East, and Volta regions of Ghana; see Table 2.

Table 2: Sample frame.

Region	Production ecology	# farmers
NR	Irrigation	51
	Rain Fed	99
UER	Irrigation	44
	Rain Fed	106
VR	Irrigation	38
	Rain Fed	12
Total		350

2.3. Types, Sources, and Methods of Data Collection. The study used different data collection tools. These included both quantitative methods (questionnaires) and qualitative (participatory rural appraisal tools; focus group discussions, key informants' interviews) methods. Besides that, literature was obtained on existing studies already done on similar subject. Household survey, focus group discussion (FGD), and key informants' (KI) interviews of the smallholder farmers and other actors were carried out. Focus group discussions were carried out with randomly selected rice FBOs working within the project district. This was aimed at collecting qualitative data to support the data gathered by the survey and also serve as a means of triangulation to ensure that the data is of good quality. This was guided by a preprinted checklist tailored to meet the information needs of the study.

Key informants' interviews were also conducted, basically engaging in a conversation with key stakeholders in the district such as MoFA crop officers, scientists from SARI, processors, and aggregators. This was guided by a preprinted checklist. Semistructured questionnaires were administered to multistage purposively and randomly selected farmers within the project district to enable us to obtain data on their livelihoods, which includes production, marketing, credit access, adoption of good agronomic practices, income status, food security situation, farm and farm household demographics, and rice production status.

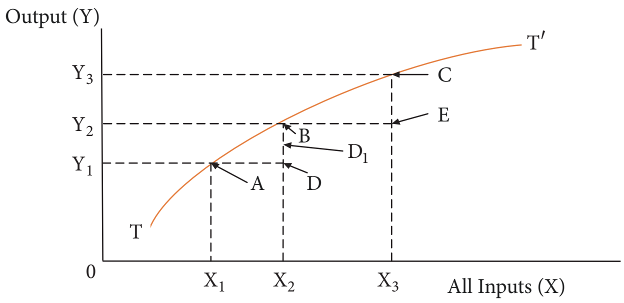

Figure 1: Production frontier.

3. Analytical Framework

The study employed both descriptive and inferential statistical analysis. Descriptive statistics (e.g., mean, minimum, maximums, standard errors of the mean, and standard deviation) were used to summarize and describe 350 rice farmers' survey results. Inferential statistics were used to arrive at conclusions based on probability. Some of the results are presented in tables and others are presented in graphs. SFA was used to investigate and measure rice farmer's production efficiencies, and endogenous treatment effect regression was used to estimate the impact of irrigation ecology on production efficiency.

3.1. Stochastic Production Frontier Analysis. Stochastic production frontier was first developed by [7, 8] and is now widely used and reported in literature to measure farm performance [9–13]. The specification allows for the decomposition of the error term into a nonnegative random variable, u_i, associated with the technical inefficiency (TE) of the i^{th} farm, as well as the normal error term, v_i, which represent the random variation in output due to factors beyond the control of farmers, such as variation in weather patterns, measurement error, or any unspecified input variable. The random error term can be positive or negative, and thus the frontiers vary about the deterministic part of the model, $\exp(x_i\beta)$.

In Figure 1, Rice farm D uses X_2 inputs to produce Y_1 output. If there are no inefficiency effects, the frontier output could be D_1. This is the deterministic part of the frontier (point B); therefore the noise and inefficiency effects are negative. The distance between point D and point D_1 represents inefficiency, while the distance between D_1 and point B represents variation due to random events.

3.2. Specifications of SFA Model for Production Efficiency Estimation

3.2.1. The Production Frontier Function. The production frontier function is specified as

$$Y_i = f\left(X_\text{i}, \beta\right) e^{v_i - u_i} \tag{1}$$

where Y denotes rice output (paddy), X denotes the factor inputs, the subscript i identifies the rice farm, β represents the parameters to be estimated, and e is the error term representing both inefficiency u_i and noise factors v_i. The rice production frontier shows the relationship between farm inputs (labour, fertilizer, seed, etc.) and farm output (rice yield), and the value of β indicates the relative importance (propensity) of each input in influencing the rice production process [11]. A parametric production frontier needs to assume a functional form, and two forms that are relatively easy to derive and commonly used in efficiency analysis are the Cobb-Douglas and the translog production functions.

A Cobb-Douglas stochastic frontier, using the terminology of [14], is defined by

$$\ln\left(y_i\right) = X_i\beta + v_i - u_i \quad i = 1, 2 \ldots n \tag{2}$$

where

$\ln(y_i)$ is the logarithm of the rice output of the ith sample farm (i = 1, 2 . . . 350),

x_i are the logarithms of the input quantities used by the ith farm,

β is a column vector of unknown parameters to be estimated for each covariate,

u_i is the technical inefficiency (TE) of the ith farm and in this study it is assumed to be an independent and identically distributed (i.i.d.) half normal random variable,

v_i is the random error term, assumed to be i.i.d. normal random variable with zero mean and constant variance, σv^2, independent of the u_i.

The technical efficiency of the i^{th} rice farm, in time period t, is given by the ratio of observed output to the maximum potential output, as defined by the frontier.

$$TE = \frac{Y_i^*}{Y_i} = \exp\left(-u_i\right) \tag{3}$$

Where Y_i = the total production frontier, Y_i^* = the stochastic production frontier

3.2.2. The Rice Production Cost Frontier Function. The rice production cost frontier function is specified as

$$C_i = f\left(X_\text{i}, P_\text{i}, \beta\right) e^{v_i + u_i} \tag{4}$$

where C denotes the total production cost observed for ith farmer, X_i is the output quantity for farmer i (rice produced), P_i is the input price vector used for the ith farmer, β is the parameters to be estimated, and e_i is the composite error term representing both inefficiency, u_i, and noise factors,v_i.

$$AE = \frac{C_i^*}{C_i} = \exp\left(u_i\right) \tag{5}$$

where C_i is the total production cost frontier and C_i^* is the stochastic cost frontier. This will give us the allocative efficiency from which economic efficiency will be estimated as

$$\text{EE} = \text{TE x AE} \tag{6}$$

where EE is the economic efficiency.

The maximum likelihood estimation technique is used to estimate the inefficiencies. In addition to estimating the levels of technical efficiency among farmers, the factors influencing efficiency are also being examined under the endogenous treatment effect model.

The endogenous treatment effect model will be used to assess the impact of irrigation ecology on production efficiencies while examining the determinants of production efficency and also irrigation ecology choice decision which is explained in Section 3.3.

3.3. Endogenous Treatment Effect Regression Model (ETERM). The endogenous treatment effect regression model is a linear model that allows for correlation between unobservable factors affecting the treatment equation and those affecting the outcome measures. The idea is to model the treatment effect on the outcome measure as in [15]. This model assumes a joint normal distribution between the errors of the treatment equation and the outcome equation.

3.3.1. The Endogenous Treatment-Regression Model (ETRM) Specification. Estimation of endogenous treatment effect model is a common feature in empirical studies in economics. When the treatment can be categorized by a dichotomous indicator function, its effects are typically estimated via instrumental variables or variants of the control function approach motivated by [16, 17].

The endogenous treatment effects model is a linear model that allows for correlation between unobservable factors affecting household irrigation ecology choice decision and those affecting the household production efficiency measures (technical, allocative, and economic efficiencies). The household technical, allocative, and economic efficiencies are a proportion measure with 0 meaning perfect inefficiency and 1 a maximum efficiency. The idea is to model the treatment effect of household irrigation ecology on the efficiency measures of small scale rice producers. As in [15] we use the endogenous treatment effect regression specification to assess the impact of irrigation ecology on technical, allocative, and economic efficiencies. This model assumes a joint normal distribution between the errors of the selection equation (irrigation ecology) and the outcome equation (the measure of technical, allocative, and economic efficiencies). We specify the outcome model as follows:

$$Eff_i = X_i{}'\beta + \delta IE_i + \epsilon_i \tag{7}$$

where the effect of irrigation ecology ($\mathbf{IE_i}$) on technical, allocative, and economic efficiencies $(\mathbf{Eff_i})$ is expressed. The impact of irrigation ecology on technical, allocative, and economic efficiencies is not captured by the $\boldsymbol{\delta}$, because these households were not randomly assigned to participate in irrigation farming or otherwise but were personal choices of the participants to participate in irrigation farming or rain fed (case of self-selection; self-selection bias arises in any situation in which individuals select themselves into a group, causing a biased sample with nonprobability sampling). Hence, neglecting the potential endogeneity (the problem of **endogeneity** occurs when the independent variable is correlated with the error term in a regression model) of irrigation ecology will produce wrong estimates of the treatment model and will confound the effect of irrigation ecology on household technical, allocative, and economic efficiencies. Household irrigation ecology choice (treatment) is based on the household, individual, community, and farm characteristics $\mathbf{G_i}$, and is modeled as

$$IE_i^* = G_i'\alpha + \mu_i \tag{8}$$

$$IE_i = \begin{cases} 1 & if\ IE_i^* > 0 \\ 0 & Otherwise \end{cases} \tag{9}$$

where $\mathbf{IE_i^*}$ represent irrigation ecology and $\mathbf{X_i}$ and $\mathbf{G_i}$ are covariates that are unrelated to the error terms. $\boldsymbol{\beta}$ and $\boldsymbol{\alpha}$ are the parameter estimates. The assumption is that $\boldsymbol{\epsilon_i}$ *and* $\boldsymbol{\mu_i}$ are jointly normally distributed with mean vector zero and variance covariance matrix $\boldsymbol{\Sigma}$ given as

$$\Sigma = \begin{pmatrix} \sigma_1^2 & \rho\sigma_1 \\ \rho\sigma_1 & 1 \end{pmatrix}. \tag{10}$$

The model can be estimated using the two-step approach or the maximum likelihood approach. This is therefore modeled simultaneously as irrigation ecology model as in (8) and the efficiency model as in (7). Consistent estimates of impact of irrigation ecology decision on their technical, allocative, and economic efficiencies are obtained by accounting for the endogenous participation. The determinants of the efficiencies are jointly determined. The maximum likelihood approach is used to analyse the model.

4. Results and Discussion

4.1. Effect of Irrigation Ecology on Some Factors of Production of Farm Households. According to Table 3, the mean age difference between irrigation farms and rain fed farms is about 0.34 and is not significant. There is also no significant difference in rice production experience between the irrigation farmers and the rain fed farmers. Irrigation farmers are richer than rain fed farmers and this is significant at 1%. There is no difference in the household size and also the available arable lands of the two groups.

According to Table 4 the mean difference in rice farm size of irrigation farmers and rain fed farmers is about 0.34 acres and it is not significant. The mean differences in fertilizer use, seed use, and labour used are 68.47kg, 23.13kg, and 3 persons, respectively, which are all significant. There is no difference in the prices of fertilizer, seed, and labour used. Yield is an important variable in assessing farm level performance and it is evidently clear that irrigation farmers have higher yields than their rain fed farmer colleagues with mean difference of 681.26kg per acre. Total output of irrigation farmers was far more than the output of rain fed farmers with a mean of about 1823.29kg of paddy rice. Output price is not significant indicating that irrigation farmers and their rain fed counterparts receive the same price for their paddy rice. This implies their farm revenues will also be

Table 3: Production ecology effect of means of farm household's characteristics.

Farm household Characteristics	Irrigation (n=133) Mean	Rain fed (n=217) Mean	Mean Difference	Z-statistic
Age of household head	44.71	44.36	0.34	0.28
Farmer experience in years	22.50	24.42	-1.92	-1.73
Wealth of farm household	8385.63	3298.29	5087.34***	4.5
Household Size	7	7	-0.24	-0.7
Total household arable land	5.43	5.41	0.02	0.0447

**** 1% significance level; ** 5% significance level; * 10% significance level.*

Table 4: Production situation under rain fed and irrigation production.

Variables	Irrigation (n=133) Mean	Rain fed (n=217) Mean	Mean Difference	Z-statistic
Rice farm size in acres	2.89	2.66	0.23	0.91
Fertilizer used in kg	283.54	215.08	68.47***	2.63
Seed used in kg	87.32	64.19	23.13**	2.13
Labour used (average number of people who worked)	12	9	3**	2.29
Fertilizer price in GHS	1.73	1.40	0.32	0.48
Seed price in GHS	0.62	0.66	-0.04	-0.92
Labour price in GHS	38.96	41.21	-2.25	-0.47
Yield per acres	1511.41	830.15	681.26***	5.7
Total output kg	3994.67	2171.38	1823.29***	5.06
Output price per kg in GHS	1.40	1.36	0.04	1.47
Total Revenue GHS	2249.68	1148.34	1101.34***	5.52
Total cost of production GHS	572.43	428.09	144.34***	3.95
Gross margins GHS	1677.25	720.25	957.00***	5.4

**** 1% significance level; 5% significance level; * 10% significance level.*

Table 5: Average efficiency measures of the irrigation and rain fed ecologies.

Efficiencies	***Irrigation (n=133)***					***Rain fed (n=217)***				
	Mean	Min	Max	STD	SEM	Mean	Min	Max	STD	SEM
Technical	0.84	0.58	0.94	0.06	0.01	0.83	0.58	0.99	0.07	0.00
Allocative	0.71	0.10	1.09	0.29	0.02	0.61	0.09	1.07	0.29	0.02
Economic	0.61	0.07	1.00	0.32	0.03	0.51	0.07	1.00	0.32	0.02

higher with a significant mean difference of 1,101.34GHS. Cost of production of irrigation farmers is far more than that of the rain fed producers with mean difference of 144.34 GHS. Gross margins mean difference is 957.00 GHS, indicating that irrigation farmers earn more profit than their rain fed counterparts.

4.2. Irrigation and Rain Fed Production Ecologies Analysis. The mean technical efficiency for irrigated and rain fed farms is 0.84 and 0.83, respectively. These imply that irrigated farms can achieve their current outputs with about 16% reduction in inputs used. The mean allocative efficiency of the study is 71% and 61%, respectively, for irrigated and rain fed systems. However, the economic efficiency of farms is 61% and 51% for irrigated and rain fed farms. Farmers in irrigation are producing rice at a better cost minimizing level compared to that of rain fed systems. This implies irrigated and rain fed farms can achieve their current production levels with about 39% and 41% reduction in cost of production. Details are shown in Table 5.

4.3. Mean Differences of Irrigation and Rain Fed Farms. There is significant difference in the allocative and economic efficiency means of irrigated and rain fed farms. This shows that the irrigated farms have higher allocative and economic efficiencies than their rain fed colleagues hence the null

Table 6: Mean differences of irrigation and rain fed farms.

Efficiencies	*Irrigation (n=133)* Mean	*Rain fed (n=217)* Mean	*Mean Difference*	*Z-statistic*
Technical	0.84	0.83	0.01	1.5
Allocative	0.71	0.61	0.09***	2.97
Economic	0.61	0.51	0.09***	2.64

**** 1% significance level; ** 5% significance level; * 10% significance level.*

Table 7: Estimates of the endogenous treatment effect model of impact of irrigation ecology on technical efficiency.

	Technical Efficiency		**Irrigation Ecology**	
Variables	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Improved seed	-0.027	0.017		
Gender	-0.006	0.019	-0.17723	0.37695
Age	0.001*	0.000	-0.00236	0.00831
Educational level	-0.002*	0.001	-0.02381	0.01787
Farmer experience	-0.001**	0.000	-0.01053	0.00866
Wealth of farm HH	0.000	0.000	5E-05***	1.5E-05
Household Size	0.001	0.001	-0.03129	0.02902
Total HH arable land	0.000	0.002	0.02266	0.03297
Rice farm size	0.004	0.003	-0.09362	0.063848
FBO Membership	-0.017**	0.008	-0.06097	0.17115
Fertilizer			0.00091*	0.00054
Seed			0.0016	0.00101
Labour			0.02072**	0.01074
1. Irrigation ecology	0.048**	0.021		
_cons	0.840***	0.033		
/athrho	-0.46942**	0.207234		
/lnsigma	-2.706***	0.061		
rho	-0.438	0.168		
sigma	0.067	0.004		
lambda	-0.029	0.013		
Log likelihood	261.944			
Wald test χ^2 (15)	4.95***			
LR test of independent equations χ^2 (1) 3.84**				

**** 1% significance level; ** 5% significance level; * 10% significance level.*

hypothesis is rejected. However, with regard to technical efficiency, there are no significant differences in their means. The null hypothesis is sustained as shown in Table 6.

4.4. Impact of Irrigation Ecology on Technical Efficiency and Its Determinants. Results of the endogenous treatment effect model on impact of irrigation ecology on technical efficiency are presented in Table 7. The maximum likelihood estimation approach was used to estimate the impact of irrigation ecology on technical efficiency of rice farms. Thus, the results of the selection equation are given in the 4th and 5th columns of Table 7. The results of the outcome equation which represents the impact of contract participation on rice farms technical efficiency are presented in the 2nd and 3rd columns of Table 7.

From the results, the Wald test is highly significant indicating the goodness of fit of our endogenous treatment effect model. This implies there are endogeneity problems; hence the use of the endogenous treatment effect model is justified. The likelihood ratio test of independence of the selection and outcome equations indicates that we can reject the null hypothesis of no correlation between irrigation ecology and technical efficiency. This implies irrigation ecology is negatively correlated with technical efficiency. The estimated average treatment effect (ATE) of participating in irrigation production is 0.05 of the technical efficiency. The impact of irrigation ecology on technical efficiency is about 0.05. This implies farmers participating in irrigation farming are more efficient (0.05 more efficient) in their rice production than those in rain fed production. The estimated correlation between the treatment assignment errors and the outcome errors is (-0.44) indicating that the unobservables that increased technical efficiency also tend to occur with the

Table 8: Estimates of the endogenous treatment effect model of impact of irrigation ecology on allocative efficiency.

	Allocative Efficiency		Irrigation Ecology	
Variables	**Coef.**	**Std. Err.**	**Coef.**	**Std. Err.**
Improved seed	-0.040	0.060		
Gender	0.042	0.093	-0.18091	0.382307
Age	0.001	0.002	-0.00393	0.007909
Educational level	0.006	0.004	-0.01303	0.017019
Farmer experience	0.002	0.002	-0.01424∗	0.008081
Wealth of farm HH	0.000	0.000	3.34E-05∗∗∗	1.15E-05
Household Size	-0.001	0.007	-0.01883	0.027527
Total HH arable land	0.005	0.008	0.021044	0.030328
Rice farm size	0.035∗∗	0.015	-0.08274	0.05944
FBO Membership	0.030	0.041	-0.0174	0.16182
ISFM[3] Adoption	0.026	0.036		
Contract Farming	0.254∗∗∗	0.037		
Fertilizer	0.000	0.000	0.00055	0.00047
Seed	-0.00043∗∗∗	0.000247	0.00141	0.00098
Labour	-0.005∗∗∗	0.002	0.016∗∗	0.00787
1. Irrigation ecology	0.330∗	0.050	0.015587	0.007868
_cons	0.23829	0.1427	0.057237	0.531055
/athrho	-1.34707∗∗∗	0.289909		
/lnsigma	-1.143∗∗∗	0.084		
rho	-0.873	0.069		
sigma	0.319	0.027		
lambda	-0.278	0.044		
Log likelihood	-202.687			
Wald test χ^2 (15)	209.61∗∗∗			
LR test of independent equations χ^2 (1) 5.03∗∗				

∗∗∗ 1% significance level; ∗∗ 5% significance level; ∗ 10% significance level.
[3]Integrated Soil Fertility Management technique

unobservables that discourage choice of irrigation production. The negative sign indicates a positive bias, suggesting that farmers with above average technical efficiency have a higher probability of participating in irrigation production and will prefer to produce under irrigation production.

4.5. Impact of Irrigation Ecology on Allocative Efficiency. Results of the endogenous treatment effect model on impact of irrigation ecology on technical efficiency are presented in Table 8. The maximum likelihood estimation approach was used to estimate the impact of irrigation ecology on technical efficiency of rice farms. Thus, the results of the selection equation are given in the 4th and 5th columns of Table 8. The results of the outcome equation which represents the impact of irrigation production on rice farms technical efficiency are presented in the 2nd and 3rd columns of Table 8.

From the results, the Wald test is highly significant indicating the goodness of fit of our endogenous treatment effect model. This implies there are endogeneity problems; hence the use of the endogenous treatment effect model is justified. The likelihood ratio test of independence of the selection and outcome equations indicates that we can reject the null hypothesis of no correlation between irrigation ecology and allocative efficiency. This implies irrigation ecology is correlated with allocative efficiency. The estimated average treatment effect (ATE) of irrigation production is 0.33 of the allocative efficiency. The impact of irrigation ecology on allocative efficiency is about 0.33. This implies farmers participating in irrigation farming are more allocatively efficient (0.33 more efficient) in their rice production than those in rain fed production. The estimated correlation between the treatment assignment errors and the outcome errors is (-0.87) indicating that the unobservables that increased allocative efficiency also tend to occur with the unobservables that discourage the choice of irrigation production. The negative sign indicates a positive bias, suggesting that farmers with above average allocative efficiency have a higher probability of producing under irrigation.

4.6. Impact of Irrigation Ecology on Economic Efficiency. Results of the endogenous treatment effect model on impact of irrigation ecology on economic efficiency are presented in Table 9. The maximum likelihood estimation approach was used to estimate the impact of irrigation ecology on technical efficiency of rice farms. Thus, the results of the selection

Table 9: Estimates of the endogenous treatment effect model of impact of irrigation ecology on economic efficiency.

Variables	Economic Efficiency Coef.	Std. Err.	Irrigation Ecology Coef.	Std. Err.
Improved seed	-0.022	0.063		
Gender	0.104	0.102	-0.20412	0.37845
Age	0.000	0.002	-0.00242	0.00771
Educational level	0.004	0.005	-0.01636	0.01694
Farmer experience	0.003	0.002	-0.0131	0.008
Wealth of farm HH	0.000	0.000	3.1E-05***	1.1E-05
Household Size	-0.003	0.008	-0.02967	0.02774
Total HH arable land	0.005	0.009	0.01808	0.03016
Rice farm size	0.069***	0.017	-0.0871	0.05974
FBO Membership	0.018	0.044	-0.03796	0.1604
ISFM Adoption	0.028	0.039		
contract farming	0.235***	0.039		
Fertilizer	2.9E4***	0.000	0.00055	0.00046
Seed	-0.001***	0.000	0.00159	0.00098
Labour	-0.007**	0.002	0.01743***	0.00751
1. Irrigation ecology	0.23***	0.034		
_cons	0.047	0.154	0.109085	0.521881
/athrho	-1.3758***	0.232817		
/lnsigma	-1.051***	0.071		
rho	-0.880	0.053		
sigma	0.350	0.025		
lambda	-0.308	0.039		
Log likelihood	-232.204			
Wald test χ^2 (15)	219.82***			
LR test of independent equations χ^2 (1) 10.05***				

**** 1% significance level; ** 5% significance level; * 10% significance level.*

equation are given in the 4th and 5th columns of Table 9. The results of the outcome equation which represents the impact of irrigation ecology on rice farms economic efficiency are presented in the 2nd and 3rd columns of Table 9.

From the results, the Wald test is highly significant indicating the goodness of fit of our endogenous treatment effect model. This implies there are endogeneity problems; hence the use of the endogenous treatment effect model is justified. The likelihood ratio test of independence of the selection and outcome equations indicates that we can reject the null hypothesis of no correlation between irrigation ecology and allocative efficiency. This implies irrigation ecology is positively correlated with economic efficiency. The estimated average treatment effect (ATE) of participating in irrigation production is 0.23 of the economic efficiency. The impact of irrigation ecology on economic efficiency is about 0.23. This implies farmers participating in irrigation farming are more economically efficient (0.23 more efficient) in their rice production than those in rain fed production. The estimated correlation between the treatment assignment errors and the outcome errors is (-0.88) indicating that the unobservables that increased economic efficiency also tend to occur with the unobservables that discourage the choice of irrigation production. The negative sign indicates a positive bias, suggesting that farmers with above average allocative efficiency have a higher probability of producing under irrigation.

Table 10: Summary of impact of irrigation ecology on technical, allocative, and economic efficiencies.

Study Unit	Efficiency Type	Impact	Significance level
Irrigation ecology	Technical	0.05	5% level
	Allocative	0.33	10% level
	Economic	0.23	1% level

Irrigation ecology had significant impact on technical, allocative, and economic efficiencies of rice farms. This impact was more on allocative efficiency followed by economic efficiency and then technical efficiency; see Table 10.

5. Conclusion and Recommendation

5.1. Main Findings of Impact of Irrigation Ecology on Technical Efficiency. The impact of irrigation ecology on technical efficiency is about 0.05. This implies farmers participating in irrigation farming are more efficient (0.05 more efficient) in their rice production than those in rain fed production. The estimated correlation between the treatment assignment errors and the outcome errors is (-0.44) indicating that the unobservables that increased technical efficiency also tend to occur with the unobservables that discourage the choice of irrigation production. The negative sign indicates a positive bias, suggesting that farmers with above average technical efficiency have a high probability of participating in irrigation production and will prefer to produce under irrigation production.

5.2. Main Findings of Impact of Irrigation Ecology on Allocative Efficiency. The impact of irrigation ecology on allocative efficiency is about 0.33. This implies farmers participating in irrigation farming are more allocatively efficient (0.33 more efficient) in their rice production than those in rain fed production. The estimated correlation between the treatment assignment errors and the outcome errors is (-0.87) indicating that the unobservables that increased allocative efficiency also tend to occur with the unobservables that discourage irrigation production. The negative sign indicates a positive bias, suggesting that farmers with above average allocative efficiency have a higher probability of producing under irrigation.

5.3. Main Findings of Impact of Irrigation Ecology on Economic Efficiency. The impact of irrigation ecology on economic efficiency is about 0.23. This implies farmers participating in irrigation farming are more economically efficient (0.23 more efficient) in their rice production than those in rain fed production. The estimated correlation between the treatment assignment errors and the outcome errors is (-0.88) indicating that the unobservables that increased economic efficiency also tend to occur with the unobservables that discourage the choice of irrigation production. The negative sign indicates a positive bias, suggesting that farmers with above average allocative efficiency have a higher probability of producing under irrigation.

5.4. Recommendation. Irrigated farms have higher technical, allocative, and economic efficiencies than their rain fed counterparts; hence we recommend that farmers should be encouraged to participate more in irrigation rice production than in the rain fed production since they are more efficient in their resource allocation.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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