

NERICA Adoption and Impacts on (Performance) Technical Efficiency of Rice Producing Households in Ghana: Implications for Research and Development

B. O. Asante^{1,2*}, A. N. Wiredu^{3,4}, E. Martey³, D. B. Sarpong⁵ and
A. Mensah-Bonsu⁵

¹CSIR-Crops Research Institute, Kumasi, Ghana

²UNE Business School, University of New England, Armidale, Australia

³CSIR-Savanna Agricultural Research Institute, Nyankpala Ghana

⁴Rural Development Theory and Policy, Institute of Agricultural Economics and Social
Sciences in Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany

⁵Department of Agricultural Economics, University of Ghana, Legon, Ghana

Authors' contributions

BOA and ANW designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. EM was in charge of the collection and management of the data. DBS managed and streamlined the analyses of the study and AMB managed the literature searches and edited the manuscript. All authors read and approved the final manuscript

ABSTRACT

In an effort to enhance agricultural development in Ghana, rice producers have witnessed myriads of improved agricultural technology development and dissemination. Notably among them is the Multi-national NERICA Rice Dissemination Project (MNRDP). However the empirical evidence linking these technologies to productivity indicators is limited. This paper uses cross sectional data which were collected from 200 smallholder rice producers from major rice growing districts in Ghana, to examine whether adoption of NERICA rice varieties have impacted on technical efficiency. Taking into account the endogeneity of technology adoption and assuming that impact is heterogeneous across the population, we use propensity score matching approach to estimate average treatment effect (ATE) on technical efficiency. Our analyses reveal an adoption rate of 68 per cent among sample rice farmers. The data further suggest an average technical efficiency of 69.1 per cent. In addition, adoption of NERICA rice varieties has been found to have a positive and significant impact on technical efficiency of rice producing households in the country. Besides NERICA adoption, other factors that significantly influenced technical efficiency include; education, household size, gender and non-farm income. The result also highlights a positive influence of institutions such as NGOs and extension services on technical efficiency. The findings suggest that access to improved varieties is an essential factor to consider in promoting interventions aimed at improving technical efficiency of smallholder rice producers. Further, continuous provision of training through the establishing and strengthening linkages between farmers and these institutions is recommended to enhance the smooth transformation of adoption efforts into efficient rice production among smallholder rice farmers in Ghana.

Keywords: Impact, adoption, NERICA varieties, technical efficiency, average treatment effect (ATE).

ABBREVIATIONS

AfricaRice: Africa Rice Centre, **ARI**: Africa Rice Initiative, **ATE**: Average Treatment Effect, **CSIR**: Council for Scientific and Industrial Research, **DEA**: Data Envelopment Analysis, **FBO**: Farmer Based Organizations, **MNRDP**: NERICA Rice Dissemination Project, **NERICA**: New Rice for Africa, **NGO**: Non-Governmental Organizations, **OLS**: Ordinary Least Squares, **PSM**: Propensity Score Matching, **TE**: Technical Efficiency, **USD**: United States Dollar.

1. INTRODUCTION

Rice is one of the world's most important foods and is the main source of nutrition for more than half of the world population [46]. In Africa, rice has increasingly become a popular food as it is tasty and quick to cook. Its importance it competes effectively with traditional coarse grains and roots and tuber crops. Besides being an important food staple for both rural and urban communities across Ghana, it is the most important cash crop in the communities in which it is produced [6].

In Ghana, domestic demand for rice has not been adequately met by growth in local production. To meet this gap, the country currently imports about 70 per cent of domestic rice requirement accounting for about USD 600 million per annum [24]. Apparently, rice is a key economic commodity in Ghana. It is one of the crops that have a high potential to improve self-sufficiency hence have received reasonable attention by policy makers in the country lately.

Against this background, there have been myriads of development interventions aimed at promoting local rice production and consumption including the Multi-national NERICA Rice Dissemination Project (MNRDP). With the support from of the Government of Ghana the project promoted the New Rice for Africa (NERICA) varieties together with complementary agronomic technologies under the Africa Rice Initiative (ARI), throughout Africa.

Amidst declining land holdings in sub-Saharan Africa, productivity gains has been projected to come from investment in technologies that lead to higher levels of output given the current size of land while ensuring environmental sustainability [30, 37]. In view of this, strategies towards improving productivity and efficiency must include, among others, accelerated adoption of improved crop varieties, increased restoration of soil nutrients through the use of organic and inorganic fertilizers and adoption of improved soil and water conservation technologies in order to reduce erosion and improve soil moisture content [37].

However, in view of the challenges and costs of improving soil nutrients through conservation technologies as well as the use of soil organic and inorganic fertilizers, adoption of improved varieties have been a one of the key ways through which increased in productivity and efficiency among small scale farmers in Ghana can be achieved.

Literatures on the positive impacts of agricultural development interventions on the livelihoods of farm households in Ghana have been documented. These interventions have promoted improved technologies including high yielding crop varieties as well as best-bet agronomic practices. The impacts of these interventions have been channelled through the adoption decision making processes. These adoption decision processes have been analysed extensively with various forms of binary choice and censored regression models [1,

76 3, 4, 18, 23]. Least squares estimates have also revealed significantly higher efficiency and
77 productivity among farmers who adopt and use improved agricultural technologies [36; 45].

78 In most of these studies however, the status of sampled respondents in terms of their
79 participation in the intervention is assumed to be random which in reality is not the case.
80 Parameter estimates from such approach are characterised by selection and endogeneity
81 biases [21, 26, 28]. In addition, there is scanty evidence on the impact of adoption of
82 NERICA rice varieties on efficiency and productivity of rice producing households.

83 Approaches to minimize the bias associated with selection and endogeneity biases are
84 deeply rooted in the concept of counterfactual outcome framework. These methodologies
85 produce consistent estimates of the effect of an intervention/adoption on a randomly
86 selected population, also known as average treatment effect (ATE). This approach has
87 been employed to estimate the actual and potential impacts of the interventions [7, 20, 21,
88 22, 38].

89 The measurement of efficiency draws on the seminal works of Farrell [25] who suggested
90 the efficiency of a firm consisting of two main components as technical efficiency and
91 allocative efficiency. Technical efficiency is a measure of the ability of a firm to obtain
92 maximum output from a set of inputs given the best available technology. Efficiency scores
93 are performance measures or indicators used in evaluating production units including farm
94 households. There are two main approaches for estimating efficiency, parametric and
95 nonparametric [8, 17, 39, 47]. The parametric can broadly be classified into two categories,
96 namely, deterministic frontier models and stochastic frontier models. The most common
97 nonparametric method is data envelopment analysis (DEA).

98 The parametric method of estimation involves econometric modelling of production frontiers.
99 This has been widely applied in the literature [8, 16, 43, 13]. This approach accounts for
100 measurement error in both the output and the stochastic element of production, thereby
101 decomposing the effect of noise from the inefficiency effect. In addition, it allows
102 conventional statistical tests to be carried out. However it is unable to measure efficiency of
103 multi-output cases [8, 9, 17]. The nonparametric DEA does not require a functional form to
104 specify the relationship between the inputs and outputs, and also it has the ability to
105 accommodate multiple-input and multiple-output technologies [9; 17].

106 This paper employed the counterfactual outcome framework and estimated the impact of
107 adoption of the NERICA varieties on technical efficiency of rice farmers in Ghana. It aims at
108 quantifying the impact of adoption of NERICA varieties developed and disseminated to rice
109 farmers on technical efficiency of smallholder farmers in Ghana. In addition, we explore
110 whether establishing and strengthening institutional linkages among farmers to improve
111 technical efficiency of smallholder farmers.

112 The remaining sections of this paper are presented as follows. We present description of the
113 methodology and the study area. It includes a brief overview of the MNRDP in Ghana, data
114 collection methods and the empirical framework. The next two sections present the results of
115 analysis of the empirical findings and the implications of the result. We end with some
116 concluding remarks and policy recommendations.

117

118 **2. METHODOLOGY**

119

120 **2.1 The NERICA Rice Dissemination Project in Ghana**

121 The Multi-national NERICA Rice Dissemination Project (MNRDP) was one of the numerous
122 development interventions that received huge support from the Government of Ghana [35].
123 The MNRDP was part of an overall initiative to promote the New Rice for Africa (NERICA)
124 varieties together with complementary agronomic technologies throughout Africa, the Africa
125 Rice Initiative (ARI). The project was intended to ultimately contribute to poverty reduction
126 and food security among rice producers in the country. The NERICA varieties distributed
127 through the project are mainly NERICA 1 and NERICA 2. For the study, a farmer is said to
128 be an adopter if he/she uses any of these varieties. The NERICA rice varieties combine their
129 high yielding potential, disease resistance and early maturity traits together with a new
130 potential for upland rice cultivation in Ghana [2].

131 In Ghana the project was implemented in 3 pilot rice producing districts namely, Ejura-
132 Sekyeredumase and Hohoe in southern Ghana and Tolon-Kumbungu in northern Ghana.
133 Ejura-Sekyeredumase is located on latitude 070 23' 00.00" N and longitude 010 22' 00.00"
134 W. Hohoe is located on latitude 070 08' 56.54" N and longitude 000 28' 28.56" E. Tolon-
135 Kumbungu is located on latitude 090 25' 51.41" and 010 03' 52.56" W.

136 The project included 3 main components, namely, technology transfer, production support
137 and capacity building. Under technology transfer was participatory evaluation, adaptation
138 and selection of appropriate technology mix. The identified technology mixes were designed
139 to meet the needs of the respective agro-ecological of the targeted districts [35].

140 Production support was in the form of rice production infrastructure such as roads and
141 postharvest facilities, human resource development and inputs and seed supply. While
142 roads and postharvest facilities were to ensure effective market participation, the latter were
143 expected to improved farm level performance. The production and distribution of certified
144 seeds of the NERICA varieties among beneficiary farmers was very crucial for the success
145 of the project. The creating access to NERICA seeds the project in facilitated the adoption of
146 the NERICA varieties. The component on capacity building focused on market integration. It
147 involved sensitization and training of key stakeholders to facilitate the process of market
148 integration.

149 After 5 years of selection, promotions and capacity building, the MNRDP ended in 2010 [35].
150 The success of the MNRDP like all agricultural technology dissemination interventions can
151 be measured by the observed changes in adoption decisions which are further translated
152 into improved farm level performance and the overall wellbeing of beneficiaries [45]. For the
153 MNRDP, adoption of the NERICA rice varieties was assured through the facilitation of
154 access to the seeds. Adoption of the NERICA rice varieties was in turn expected to impact
155 positively on efficiency and productivity among targeted rice producing households in the
156 country.

157 **2.2 Data and sampling technique**

158 The basic information for the analysis was obtained from primary data collected with the aid
159 of objective oriented structured questionnaire. The data described rice producer and
160 production characteristics and access to information. The study was conducted within the
161 project districts in Ghana. A total of 200 rice producing households, 10 per community were
162 systematically selected and interviewed. The selection of the households followed a two-
163 stage systematic random sampling procedure. In the first stage, communities were randomly
164 selected from a list of rice producing communities in the project districts. The second stage
165 involved the selection of farm households from a list of households from the selected
166 communities.

167

168 **2.3 Empirical framework and estimation technique**

169 In this paper, we follow a two-stage impact estimation method. First stage, we use the
170 stochastic frontier estimation analysis to generate technical efficiency scores following
171 Battese and Coelli [10]. Second, the estimated technical efficiency scores are regressed on
172 NERICA adoption alongside other socio-economic, institutional and farm level covariates,
173 which are hypothesised to affect technical efficiency. To accounts for endogeneity in the
174 choice of variety and selection bias, we adopt the propensity score matching approach [5,
175 12, 19, 33] to estimate the impact of adoption on technical efficiency.

176

177 **2.3.1 Estimating technical efficiency**

178 This study applies the parametric approach because the rice producing environment is
179 largely influenced by external factors. This approach specifies some functional form to
180 represent the relationship between output and inputs. A preferred functional form has the
181 properties identified by Coelli et al [17]. Both the A Cobb-Douglas and the transcendental
182 logarithmic (translog) function developed by Christensen et al. [15] satisfies these properties
183 and are widely used in econometric estimation. Both functional forms were considered
184 represent the rice production model. However, a hypothesis test result suggests that
185 translog functional form is not an adequate representation of the data given the assumptions
186 of the translog stochastic frontier model and was therefore not employed in our analyses.

187

188 Following Battese and Coelli [10], Cobb-Douglas production function can be specified as
189 follows:

$$190 \quad \ln Y_i = \beta_0 + \sum_{j=1}^5 \beta_j \ln X_{ji} + V_i - U_i \quad (1)$$

191 , $i=1,2,3,\dots,N$

192 Where the subscript i indicate the i -th farmer in the sample:

193 Y represents the quantity of rice harvested for the sampled farmer (in kilograms)

194 X_1 is the total area of land (in hectares) planted to rice;

195 X_2 is the total labour (in man days) used in rice cultivation;

196 X_3 is the quantity of seeds(in kilograms) used in rice cultivation;

197 X_4 is the quantity of herbicides (in kilograms)used in rice cultivation;

198 X_5 is the quantity of fertilizers (in kilograms) used in rice cultivation;

199 The V_i^s are the random errors, assumed to be independent and identically distributed as
 200 $N(0, \sigma^2)$

201 The U_i^s are the non-negative technical inefficiency effects assumed to be independently
 202 distributed among themselves and between the V_i^s , such that U_i^s is defined by the
 203 truncation of the $N(\mu_i, \sigma^2)$ distribution, where μ_i is defined by a set of other explanatory
 204 variables that are hypothesized to influence technical efficiency. The magnitude of the effect
 205 of these factors will then be explored when analyzing the determinants of technical
 206 efficiency.

207 The variables included in the technical efficiency model are area, labour, seeds, fertilizer and
 208 herbicide. These variables are major inputs used in rice cultivation in Ghana and have been
 209 widely applied in several previous studies on technical efficiency [9, 11, 41, 42, 43].

210 The technical efficiency of the i-th farmer is defined by

$$211 \quad TE_i = e^{-U_i} \quad (2)$$

212 Where U_i is the inefficiency effects component of the model.

213 The parameters of the stochastic frontier production function model, defined by equation (1)
 214 are estimated by the maximum-likelihood method using the program, FRONTIER 4.1 [16].

215 Tests of several null hypotheses for the parameters in the frontier production function are
 216 performed using the generalized likelihood-ratio test statistic defined by

$$217 \quad \lambda = -2\{\ln[L(H_0)/L(H_1)]\} \quad (3)$$

218 where $L(H_0)$ and $L(H_1)$ denote the values of the likelihood function under the null (H_0)
 219 and alternative (H_1) hypotheses, respectively. If the null hypothesis is true, the test statistic
 220 has approximately a chi-squared or a mixed chi-squared distribution with degrees of freedom
 221 equal to the difference between the numbers of the parameters involved in the alternative
 222 and null hypotheses. If the inefficiency effects are absent from the model, as specified by the
 223 null hypothesis, $H_0 : \delta_0 = \delta_{01} = \delta_{02} = \delta_1 = \dots = \delta_6 = \gamma = 0$, where $\gamma = \sigma^2 / \sigma_S^2$ and
 224 $\sigma_S^2 = \sigma_v^2 + \sigma^2$, then λ is approximately distributed according to a mixed chi-squared
 225 distribution with at least 10 degrees of freedom. In this case, critical values for the
 226 generalized likelihood ratio test are obtained from Table 1 of Kodde and Palm [32].
 227

228 **2.3.2 Estimating the impact and determinants of technical efficiency**

229 The determinants of technical efficiency were estimated by regressing the technical
 230 efficiency scores on NERICA adoption together with other socio economic covariates such
 231 as age, gender, education, household size, non-farm income, farm level covariates such as
 232 fertilizer and herbicide use as well as other institutional covariates like access to roads,
 233 distance to market, access to agricultural development projects, access to FBOs, access to

234 NGOs, and access to extension services using ordinary least squares regression (OLS)
235 procedure.

236 The OLS regression model is explicitly expressed as:

$$237 \quad TE_{Si} = \alpha_0 + \alpha_a A + \sum_{k=1}^5 \alpha_{Hk} H_{ki} + \sum_{k=1}^2 \alpha_{Gk} G_{ki} + \sum_{k=1}^6 \alpha_{Ek} E_{ki} + e_i \quad (4)$$

238 where $\alpha_a, \alpha_{Hk}, \alpha_{Gk}$ and α_{Ek} are parameters of the A, H, G and E variables, respectively;

239 A denote NERICA adoption, H_1 denotes the age of the household head; H_2 denotes the
240 gender of the household head; H_3 denotes the number of years of formal education of the
241 household head; H_4 denotes the size of the household and H_5 denotes the non-farm
242 income of the household head; G_1 represents the use of fertilizer in rice production and G_2
243 is the use of herbicide in rice production; E_1 is represents access to roads; E_2 is the
244 distance to market; E_3 denotes access to extension services; E_4 denotes access to
245 agricultural development projects; E_5 denotes access to FBOs; E_6 denotes access to
246 NGOs; and e_i is the random error term in the model.

247 In estimating the impact of NERICA adoption on technical efficiency, we expect the adoption
248 of NERICA varieties to result in two potential outcomes for any farmer selected at random.
249 Assuming that the potential outcome for adopting NERICA varieties is y_1 and that for not
250 adopting is y_0 , then the average treatment effect which represents the expected population
251 impact of adoption can be derived as follows:

$$252 \quad TE_i = y_{i,1} - y_{i,0} \quad (5)$$

$$253 \quad ATE = E(y_1 - y_0) \quad (6)$$

254 where TE_i denotes 'treatment effect' and represents the effect of adoption on farmer i , $y_{i,1}$
255 the potential impact for adopters, and $y_{i,0}$ as the potential impact for non-adopters of
256 NERICA varieties.
257

258 In reality, an outcome and its counterfactual cannot be observed and so $y_1 - y_0$ is undefined
259 for farmer i . Since adoption is a necessary condition for impact, then $y_0 = 0$ for a randomly
260 sampled farmer. This implies that the impact on farmer i is $y_{i,1}$ and the average adoption
261 impact $ATE = E(y_i)$. This in reality underestimates the true population impact because y_1
262 is observed only for adopting, a situation that may result in the problem of selection bias. If
263 $N_A = 1$ denotes adoption and $N_A = 0$, denotes non-adoption, the average impact on the
264 adopting sub-population, ATT, was more relevant for this study. This was derived as:
265

$$ATT = E(Y_1 | N_A = 1) \quad (7)$$

267

268 Where Y_1 = the outcome variable (technical efficiency)

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270 Two broad approaches have been used in the quest to deal with selection bias associated
 271 with the noncompliance or endogenous treatment variable [29]. One of the approaches is
 272 based on the assumption of conditional independence [21], which postulates the existence
 273 of a set of observed covariates k , which, when controlled for, renders the treatment status
 274 independent of the two potential outcomes. This approach also referred to as Propensity
 275 score matching was used in this study. Different matching procedures were explored and the
 276 best results were selected for the discussion.

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278

279 3. RESULTS AND DISCUSSION

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281 This section describes the results of the estimation of the stochastic frontier production for
 282 rice. Furthermore, the determinants of technical efficiency as well as the population impact
 283 parameters estimated for using OLS and PSM methods are presented and discussed.

284

285 3.1 Descriptive statistics and household characteristics

286 Table 1 presents descriptive statistics of the sample households. Overall, 68 per cent of the
 287 farmers have adopted and cultivating the NERICA rice varieties. The average age of the
 288 heads of sample was 51 years old with males accounting for about 81 per cent. On the
 289 average, more than half of the sampled rice producers had formal education. With an almost
 290 equal gender distribution, the typical household includes an average of about 7 members.

291 The data on institutional variables suggest that about 67 per cent of the rice producers have
 292 access to extension services. Access to Non-governmental organizations (NGOs) and
 293 farmer based organizations (FBOs) accounted for about 15 per cent and 6 per cent,
 294 respectively (Table 1). Averagely, the rice producers travelled a distance of 3.87 km to
 295 participate in markets (Table 1).

296

297 Farm level characteristics reveal that, rice producers planted an average of about 173.74
 298 kilograms of seeds per hectare. For every hectare of rice cultivated, an average of 366.57
 299 kilograms of fertilizer and 44 litres of herbicide were applied per household. The average
 300 production of rice was approximately 2934.53 kg per household. The average labour use
 301 was approximately 197.25 man-days per hectare. Although rice was the dominant source of
 302 household income as well as income from agriculture in general, income from non-farm
 303 activities was approximately US\$107 accounting for almost 12 per cent of the total
 304 household income (Table 1).

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317 **Table 1.** Descriptive statistics of the variables in the stochastic frontier production model

Characteristics	Mean	Standard Dev.
Adoption	0.68	
Average Technical efficiency	0.69 ^a	0.14
Household covariates		
Household size (N)	6.75	3.44
Male producers (%)	80.61	
Female producers (%)	19.39	
Age of producer (years)	50.88	12.61
Educated producers (%)	60.62	
Institutional covariates (%)		
Extension	67.01	
NGOs	14.52	
FBOs	5.63	
Infrastructural covariates		
Existence of market (%)	29.9	
Av. distance to market (km)	3.87	4.14
Farm level covariates		
Output (kg)	2934.53	4600.79
Area (ha)	0.86	1.01
Labour (man-days/ha)	197.25	213.73
Seed (kg/ha)	173.74	183.38
Fertilizer (kg/ha)	366.57	1006.55
Herbicides (lit/ha)	44.88	454.26
Agric income (USD)	825.90	2004.75
Nonfarm income (USD)	107.40	305.65

^asignificant at the 1 per cent level

3.2 Empirical results on technical efficiency

The maximum likelihood estimates of the parameters of the Cobb-Douglas stochastic frontier production function are presented in Table 2. The values of the explanatory variables in the Cobb-Douglas stochastic frontier model were mean-corrected by subtracting the means of the variables so that their averages were zero. This approach indicates that the first-order parameters are estimates of output elasticities for the individual inputs at the mean values.

All estimated first-order coefficients in the production function fall between zero and one, except that for fertilizer. The negative estimate contradicts the monotonicity condition that all marginal products are positive at the mean input levels. The results indicate that seed, land, labour, fertilizer and herbicides are essential factors for rice production and the impacts of these variables on the mean rice outputs are significant. However, all these factors had a negative effect on rice output. For the reason that the technical efficiency model was used as a step in the analyses, its estimation comprised of purely production input variables.

Table 2. Maximum-likelihood estimates for parameters of the Cobb-Douglas stochastic frontier production models for rice farmers in Ghana

Variable	Parameter	Coefficient	SE
Constant	β_0	0.419	0.047
Land	β_1	0.015 ^a	0.099
Labour	β_2	0.0095 ^a	0.070
Seeds	β_3	0.039 ^b	0.038
Herbicide	β_4	0.028 ^a	0.083
Fertilizer	β_5	-0.059 ^a	0.075
Gamma	γ	0.367 ^a	0.054
Variance parameters	σ^2	0.797	0.061
Log likelihood function		105.19	

^asignificant at the 1 per cent level, ^bsignificant at the 5 per cent level, per cent level

The results further suggest that except fertilizer, all the other variables had a positive significant effect on technical efficiency. This indicates that rice producers are operating below the maximum allowable level of production given the technology available to them. Consequently, increasing the levels of land labour and quantity of seed are likely to increase their level of rice output.

The γ -parameter associated with the variance of the technical inefficiency effects in the stochastic frontiers is estimated to be very high and was highly significant at 1 per cent. This indicates that the technical inefficiency effects are a significant component of the total variability of rice output.

This result is supported by the second hypothesis test in which the null hypothesis, $H_0: \gamma = 0$, where $\gamma = \sigma^2 / (\sigma_v^2 + \sigma^2)$ is the ratio of the variance associated with inefficiency effects and its sum with the variance of the random errors in the rice production. The results obtained indicate that the null hypothesis of no technical inefficiencies of rice production should be strongly rejected (Table 3). This suggests that the traditional production function is not an adequate representation of the data given the assumptions of the stochastic frontier model.

The first null hypothesis, $H_0: \beta_j = 0$ for all $i \leq j = 1, 2, \dots, 5$, states that the second-order coefficients in the translog production function have zero values and so, if this hypothesis is true, then the Cobb-Douglas production function applies. This null hypothesis is not rejected at 5 per cent level of significance (Table 3), implying that the Cobb-Douglas production function is an adequate representation of the data given the assumptions of the stochastic frontier model.

Table 3. Tests of null hypotheses for parameters in the stochastic frontier production function for rice producers in Ghana

Null hypothesis	λ	Critical Value ^a	Decision
$H_0: \beta_j = 0$ for all $i \leq j = 1, 2, \dots, 7$	15.92	32.1	Do not reject H_0
$H_0: \gamma = 0$	19.21	16.3	Reject H_0

^a Taken from table 1 of Kodde and Palm [32] using 5 per cent level of significance.

3.3 Elasticities and returns to scale

The estimates of the elasticities of output with respect to inputs of production are presented in Table 4. Because the variables of the Cobb-Douglas model were mean-corrected to zero, the first-order coefficients are the estimates of elasticities at the mean input levels. For the Cobb-Douglas model, the elasticities of mean rice output with respect to the different inputs depend on several parameters and values of the inputs. The elasticity of mean rice output with respect to the j -th input variable is defined by the following expression [9]:

$$\frac{\partial \ln E(Y_i)}{\partial \ln X_{ji}} = \{\beta_j + \sum_{k=1}^5 \beta_{jk} \ln X_{ki}\} - C_i \left(\frac{\partial \mu_i}{\partial \ln X_{ji}} \right)$$

(9)

$$\text{where } \mu_i \text{ is the inefficiency in the model; } C_i = 1 - \frac{1}{\sigma} \left\{ \frac{\phi\left(\frac{\mu_i}{\sigma} - \sigma\right)}{\Phi\left(\frac{\mu_i}{\sigma} - \sigma\right)} - \frac{\phi\left(\frac{\mu_i}{\sigma}\right)}{\Phi\left(\frac{\mu_i}{\sigma}\right)} \right\}; \phi \text{ and } \Phi$$

represent the density and distribution functions of the standard normal random variable, respectively.

The empirical results show that, from the estimates of the Cobb-Douglas production function model, the estimated elasticities of mean rice output with respect to land, labour, seeds, herbicides and fertilizer, at mean input values, were 0.015, 0.0095, 0.039, 0.028 and -0.059, respectively. This indicates that, if land under rice, with the required quantities of labour, seeds, herbicides and fertilizer were to be individually increased by 1 per cent, then the mean production of rice is estimated to increase by 0.015, 0.0095, 0.039 and 0.028 per cent, and decrease by 0.059 per cent respectively. This is because the estimated output elasticity with respect to land, labour seeds and herbicides were found to be positive while that for fertilizer was found to be negative and was all statistically significant.

The returns to scale estimates, evaluated at the mean input a value is 0.130 (Table 4). This value is significantly less than one, indicating that rice producers in Ghana are operating under increasing returns to scale.

Table 4. Elasticities of mean rice output with respect to inputs in the stochastic frontier production functions

Input	Estimated output elasticity
Land	0.015(0.099)*
Labour	0.0095(0.070)
Seeds	0.039(0.038)
Herbicide	0.028(0.083)
fertilizer	-0.059(0.075)
Returns to scale	0.130 (0.365)

*Standard errors are in parenthesis

3.4 Technical efficiency indexes

Table 5 shows the distribution of the predicted technical efficiencies of the sample rice producers. The mean technical efficiency was estimated to be 0.691, with the maximum of 0.937 and the minimum of 0.127. This implies that, on the average, the rice farmers were producing rice about 69 per cent of the potential (stochastic) frontier production levels, given the technology currently being used. Thus, in the short run, there is capacity for increasing

technical efficiency in rice production by 31 per cent without necessarily varying the existing input levels.

In the present study, in general, more than half of the producers had a mean technical efficiency in the range of 0.71–0.99. The remaining proportion of the rice producers had mean technical efficiency ranging from 0.51–0.70. This means that in general, most of the sample rice producers on the average are technically efficient in the allocation and use of inputs.

Table 5. Percentages of technical efficiencies of rice farmers in Ghana within decile ranges

Interval	Percentage
<0.5	7.2
0.51–0.60	13.9
0.61–0.70	24.2
0.71–0.80	35.1
0.81–0.90	19.1
0.91–1.00	0.5
N	194
Mean	0.691
SD	0.139
Maximum	0.937
Minimum	0.127

3.5 Determinants of technical efficiency

A summary of the empirical results of the coefficient estimates for the determinants of technical efficiency is provided in Table 6. The results suggests that significant factors influencing technical efficiency in rice production include NERICA Adoption, Gender, Education, Access to road, Household size, NGOs, Extension and the use of Herbicide. Except for household size which had a negative effect, all the other factors positively influenced technical efficiency.

The positive significant relationships between NERICA adoption and technical efficiency levels of rice producers suggest that producers who adopted and planted NERICA varieties tended to have smaller technical inefficiencies in rice production than non-adopters, other things being equal. The results further indicate that holding other factors constant under the assumption of homogeneous impact, adoption of the NERICA rice varieties is associated with a increase of about 11 per cent in technical efficiencies on smallholder rice farms in the Ghana.

The positive significant effect of the education variable, which implies educated farmers are more technically efficient in their rice production. It is therefore an important factor to be considered in improving rice production in the country. Education augments the capacity of farmers to obtain and optimize the use of information in relation to production inputs, consequently improving their use of inputs efficiently [40, 44]. In addition, improvement in resource use and hence productivity could result from enhanced human capital through increased access to educational training.

435 **Table 6.** Determinants of Technical efficiency of rice producing households in Ghana

Variable	Estimate	Std. error
NERICA Adoption	0.114 ^a	0.0169
Gender	0.042 ^b	0.0176
Age	-0.000527	0.000578
Education	0.00552 ^a	0.00169
Access to road	0.0351 ^b	0.0169
Distance to markets	-0.00151	0.00176
Nonfarm income	0.0000655 ^b	0.0000256
Household size	-0.00631 ^a	0.00209
Agric. Projects	-0.0138	0.0189
FBOs	0.00394	0.0195
NGOs	0.0338 ^c	0.0167
Fertilizer use	0.00821	0.0156
Herbicide use	0.0301 ^c	0.0155
Extension	0.043 ^b	0.0187
Constant	0.555 ^a	0.0414
F-stat.	19.17 ^a	
Adjusted R ²	0.6154	
N	194	

436 ^asignificant at the 1 per cent level, ^bsignificant at the 5 per cent level, ^csignificant at the 10
437 per cent level

438
439 In addition, non-farm income from off farm activities accruing to the household has a positive
440 significant relationship with technical efficiency. This result suggests that the more income
441 obtained by farmers from other non-farm activities, the more technically efficient they
442 become. Similar results were obtained by Villano and Fleming [43] who found that non-farm
443 income enhances farmers' ability to timely acquire the right amount of basic inputs
444 necessary for efficient rice production hence becoming more efficient in their farming
445 operations.

446 The negative effect of household size on technical efficiency suggests that farmers with
447 small family sizes tend to be more technically efficient than those with larger farm sizes. With
448 larger house sizes, there is the possibility of some of the household members snagging in
449 other non-farm activities hence reducing the attention directed into rice production, this may
450 result in lower technical efficiency. This corroborate by the positive effect of non-farm income
451 on technical efficiency (Table 6). Similar results were obtained by Oduol et al. [37] in the
452 Democratic Republic of Congo. The empirical result further depicts a positive effect of
453 gender on the technical efficiency. This suggests that male farmers were more likely to be
454 technically efficient in rice production than their female counterparts. The largely male
455 dominated rice producers in the country could account for this.

456
457 The use of herbicides was positively related with technical efficiency signifying that rice
458 production could be improved by increasing the use of herbicides. This could be as a result
459 of the fact that weeds control in rice production is very essential hence ability to manage and
460 keep them in very low intensity has a significant influence on production. Rice producers in
461 Ghana are generally financially constrained in the acquisition of inputs such as herbicides;

462 promoting access to such inputs therefore has the potential of improving efficient rice
463 production.

464
465 Our results also suggest that institutional variables such as the existence of roads used in
466 the transport of both inputs and produce and access to organisations that provide
467 agricultural extension and financial services such as NGOs and access to extension are
468 significant determinants of technical efficiency. The existence of such organisations
469 enhances farmers' access to vital extension, financial and market information which when
470 utilised effectively is likely to improve technical efficiency. This result is further sustained by
471 the high proportion of farmers with access to extension (Table 1). It also signifies the
472 significant role played by NGOs in agriculture in the country since regardless of the low
473 proportion of farmers having access to NGOs, yet its influence on technical efficiency is
474 significant. Positive effects have been found between such institutions and technical
475 efficiency [14, 41, 42]. Development interventions aim at enhancing technical efficiency in
476 the country could establish and strengthen linkages with these institutions and also between
477 these institutions and farmers.

478

479 3.6 Impact of NERICA adoption of on technical efficiency

480 The estimated population impact parameters for the PSM are presented in Table 7. The
481 table shows results from three matching methods namely kernel matching, nearest neighbor
482 matching, and stratified matching. Comparing the standard errors of the methods, the
483 nearest neighbor matching methods were more efficient and were therefore discussed in the
484 study.

485

486 The results suggests that adoption of NERICA varieties has had a positive and
487 significant impact on technical efficiency of smallholder rice producers in Ghana. The
488 estimated average impact of adoption NERICA varieties on technical efficiency of sample
489 farmers was denoted by ATT. Consequently, the impact parameter suggests that adoption
490 of NERICA rice varieties is likely to increase technical efficiency by 2.1 per cent for the semi-
491 parametric estimates and 3.6 percent for the pure parametric estimates. This however
492 coincides with the expectations of all stakeholders in the rice sector including development
493 partners. Similar findings have been reported by Chaovanapoonphol et al., [14] where
494 impact of impact of agricultural loans was found to significantly increase technical efficiency
495 of rice farmers in the Upper North of Thailand. In addition, Mouelhi [34] also found a positive
496 significant impact of adoption of impact of on technical efficiency in the Tunisian
497 manufacturing sector.

498

499 **Table 7.** Estimated population impact parameters

	Treated	contr.	ATT	Std. Err.	t-test
<u>Kernel</u>					
Semi parametric	112	82	0.031	.	.
Parametric	112	82	0.035	.	.
<u>Nearest neighbor</u>					
Semi parametric	112	82	0.031 ^a	0.021	1.520
Parametric	112	67	0.053 ^b	0.036	1.492
<u>Stratification</u>					
Semi parametric	112	97	0.031 ^b	0.021	1.520
Parametric	112	97	0.031 ^b	0.021	1.520

500 ^asignificant at the 1 per cent level, ^bsignificant at the 5 per cent level.

501

502

On the contrary, conflicting findings have been reported by Oduol et al [37] where the impact of adoption of soil and water conservation technologies were found to significantly reduce technical efficiency of small holder farmers in sub-Saharan Africa. Holden et al. [27] and Kassie [31] also found significantly lower returns on plots with improved technologies. For this study, the inability of the treatment variable (adoption) to capture cost of adoption as well as other corresponding packages that comes with it could account for the minimal impact of NERICA on technical efficiency. Consequently, Future projects that seek to ensure access to seeds and other critical inputs should also include strategies to ensure that the cost of adoption of the varieties and that of other corresponding packages that comes with it is well thought-out.

4. CONCLUSION

The aim of this paper was to examine whether the adoption of NERICA rice varieties introduced and disseminated among rice farmers has had an impact on technical efficiency of smallholder rice producers in Ghana. In addition, the paper focused on estimating the technical efficiency and examining its determinants among smallholder rice producers. It also explored the effectiveness of institutional linkages among farmers to improve technical efficiency of smallholder farmers.

We first estimated a Cobb-Douglas stochastic production frontier and used it to generate the technical efficiency scores. The estimated technical efficiency scores were regressed on NERICA adoption besides other socio-economic, institutional and farm level covariates, which are hypothesized to affect technical efficiency and finally to estimate the impact of adoption of NERICA varieties on technical efficiency, propensity score matching and ordinary least squares regression procedure to consistently estimate the average treatment effect.

Our analyses revealed a high adoption rate of 68 per cent among sample farmers. We further found the estimated technical efficiency to range from 12.7 per cent to 93.7 per cent with an average of 69.1 per cent suggesting that rice farmers in Ghana could increase technical efficiency in rice production by 31 per cent without necessarily varying the existing input levels. Our findings further revealed that, adoption of NERICA rice varieties has been found to have a positive and significant impact on technical efficiency of rice producing households in the country, suggesting that the benefits of adoption of the NERICA varieties have been translated into improved technical efficiency. This suggests that access to improved varieties is an essential factor to target among others in the promoting interventions aimed at improving technical efficiency.

The result highlights institutions such as NGOs and extension services to have a positive influence on technical efficiency. This implies that continuous provision of training through the establishing and strengthening linkages between farmers and these institutions is recommended to enhance the smooth transformation of adoption efforts into efficient rice production among smallholder rice farmers in the country.

In this study, the impact of adoption on technical efficiency was examined using cross sectional dataset. A panel dataset could be obtained by conducting a complementary survey that presents the adoption and impact variables over time could allow for a more thorough analysis of the impact of the NERICA on technical efficiency over time. In addition, Future research that seeks to examine the costs associated with adoption and that of other corresponding packages that come with it is essential.

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COMPETING INTERESTS

We declare that no competing interests exists

REFERENCES

1. Adeoti, A I. Factors Influencing Irrigation Technology Adoption and its Impact on Household Poverty in Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 2009; 109(1):51–63.
2. Africa Rice Center. NERICA on the move, a bulleting on NERICA rice in Africa. 2003:1-2.
3. Akudugu MA, Guo E, Dadzie SK. Adoption of Modern Agricultural Production Technologies by Farm Households in Ghana: What Factors Influence their Decisions? *Journal of Biology, Agriculture and Healthcare*. 2012; 2(3)
4. Aneani F, Anchirinah VM, Owusu-Ansah F, Asamoah M.. Adoption of Some Cocoa Production Technologies by Cocoa Farmers in Ghana. *Sustainable Agricultural Research*. 2012;1(1)
5. Angrist DJ, Imbens GW. Sources of identifying information in evaluation models” Technical Working Paper No. 117. 1991 (NBER, Cambridge, MA).
6. Asuming-Brempong S, Osei-Asare YB. Has imported rice crowded-out domestic rice production in Ghana? What has been the role of policy? *African Association of Agricultural Economists (AAAE) Conference proceedings*, 2007: P 91-97.
7. Asuming-Brempong S, Gyasi KO, Marfo KA, Diagne A, Wiredu AN, Asuming-Boakye A, Haleegoah J, Frimpong BN. The exposure and adoption of New Rice for Africa (NERICAs) among Ghanaian rice farmers: What is the evidence? *African Journal of Agricultural Research*. 2011; 6(27): 5911-5917.
8. Battese GE. Frontier production functions and technical efficiency: A survey of empirical applications in agricultural economics. *Agricultural Economics*. 1992;7: 185-208.
9. Battese GE, Broca SS. Functional forms of stochastic frontier production functions and models for technical inefficiency effects: a comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis*. 1997; 8:395-414.

- 606 10. Battese GE, Coelli TJ. A Model for Technical Inefficiency Effect in Stochastic
607 Frontier Production for Panel Data. *Empirical Economics*. 1995 20: 325- 345.
- 608
- 609 11. Battese GE, Malik SJ, Gill MA. An investigation of technical inefficiencies of
610 production of wheat farmers in four districts of Pakistan. *Journal of Agricultural*
611 *Economics*. 1996; 47:3749
- 612
- 613 12. Becerril J Abdulai A. The Impact of Improved Maize Varieties on Poverty in Mexico:
614 A Propensity Score-Matching Approach, *World Development*. 2009; 38(7): 1024–
615 1035.
- 616
- 617 13. Bravo-UretaBE, Pinheiro AE. Efficiency analysis of developing country agriculture:
618 A review of the frontier function literature. *Agricultural and Resource Economics*
619 *Review*. 1993; 22: 88–101.
- 620
- 621 14. Chaovanapoonphol Y, Battese GE, Chang HS. The impact of agricultural loans on
622 the technical efficiency of rice farmers in the Upper North of Thailand. *Productivity,*
623 *Efficiency, and Economic Growth in the Asia-Pacific Region*. 2009, Berlin,
624 Heidelberg: Springer-Verlag. 279-295.
- 625
- 626 15. Christensen LR, Jorgenson DW, Lau LJ. Transcendental logarithmic production
627 frontiers. *Review of Economics and Statistics*. 1973; 55(1): 28-45.
- 628
- 629 16. Coelli TJ. A guide to FRONTIER version 4.1: A computer program for stochastic
630 frontier production and cost function estimation. Centre for Efficiency and
631 productivity Analysis. Working Paper No. 7/96. 1996, Department of Econometrics,
632 University of New England, Armidale.
- 633
- 634 17. Coelli T, Rao DSP, O'Donnell CJ, BatteseGE. *An Introduction to Efficiency and*
635 *Productivity Analysis*. 2005 New York, USA: Springer.
- 636
- 637 18. Dankyi AA, Andah K, Moris MM, Fosu Y. Farmer Characteristics, Ecological Zones
638 and Adoption Decisions: A Tobit Model Application for Maize Technology in Ghana.
639 *Agriculture and Food Science Journal of Ghana*. 2005.
- 640
- 641 19. Dehejia RH, Wahba S. Propensity Score-Matching Methods for Non-experimental
642 Causal Studies. *The Review of Economics and Statistics*. 2002; 84(1): 151-161.
- 643
- 644 20. Diagne A, Adekambi SA, Simtowe FP, Biaou G. Impact of agricultural technology
645 adoption on poverty: The case of NERICA rice varieties in Benin. Paper
646 presented at the 27th Conference of the International Association of Agricultural
647 Economists in Beijing in 2009.
- 648
- 649 21. Diagne A, Demont M. Taking a new look at empirical models of adoption: Average
650 treatment effect estimation of adoption rate and its determinants. *Agricultural*
651 *Economics*. 2007; 37: 201-210.
- 652
- 653 22. Dibba L, Diagne A, Fialor SC, Nimoh F. Diffusion and adoption of new rice varieties
654 for Africa (NERICA) in the Gambia. *African Crop Science Journal*. 2012; 20(1): 141-
655 153
- 656

- 657 23. Donkoh SA, Tiffin JR, SrinivasanCS.. Who adopts Green Revolution (GR)
658 technology in Ghana? *International Journal of Agricultural Science*. 2011; 1(1):23-
659 44.
- 660
- 661 24. Duffuor K. Budget Statement and Economic Policy of the Government of Ghana for
662 the 2010 Fiscal Year. 2009
- 663
- 664 25. Farrell MJ. The measurement of productive efficiency. *Journal of Royal Statistical*
665 *Society*. 1957; 3:253-290.
- 666
- 667 26. Heckman J, Vytlacil E. Structural equations, treatment effects, and econometric
668 policy evaluation. *Econometrica*. 2005; 73: 669–738.
- 669
- 670 27. Holden S, Shiferaw B, Pender J. Market imperfections and land productivity in
671 Ethiopian highlands. *Journal of Agricultural Economics*.2001; 52: 53-70.
- 672
- 673 28. Imbens G, Wooldridge JM. Recent developments in the econometrics of program
674 evaluation. *Journal of Economic Literature*. 2009; 47(1): 5–86.
- 675
- 676 29. Imbens G. Nonparametric estimation of average treatment effects under exogeneity:
677 A review. *Review of Economics and Statistics*. 2004; 86: 4–29.
- 678
- 679 30. Jayne TS, Mather D, Mghenyi E. Smallholder farming under increasingly difficult
680 circumstances: policy and public investment priorities for Africa, Food Security
681 International Development Policy Syntheses 54507. 2006, Michigan State
682 University, Department of Agricultural, Food, and Resource Economics,
683 www.aec.msu.edu/fs2/papers/idwp86.pdf (March 2013).
- 684
- 685 31. Kassie M. Technology adoption, land rental contracts and agricultural productivity,
686 PhD dissertation. 2005; Norwegian University of Life Sciences.
- 687
- 688 32. Kodde DA, Palm FC. Wald criteria for jointly testing equality and inequality
689 restrictions. *Econometrica*. 1986; 54:1243–6.
- 690
- 691 33. Kuwornu JKM, Owusu ES. Irrigation access and per capita consumption expenditure
692 in farm households: Evidence from Ghana. *Journal of Development and Agricultural*
693 *Economics*. 2012;4(3):78-92.
- 694
- 695 34. Mouelhi RBA. Impact of the adoption of information and communication
696 technologies on firm efficiency in the Tunisian manufacturing sector. *Economic*
697 *Modelling*. 2009, (26): 961–967
- 698
- 699 35. Ministry of Food and agriculture, Ghana. Medium Term Agriculture Sector
700 Investment Plan (METASIP). 2010: 3-144
- 701
- 702 36. Nimoh F, Addo K, Tham-Agyekum EK. Effect of formal credit on the performance of
703 the poultry industry: The case of urban and peri-urban Kumasi in the Ashanti
704 Region. *Journal of Development and Agricultural Economics*.2011; 3(6):236-240.
- 705
- 706 37. Oduol JBA, Binam AJN, Olarinde L, Diagne A, Adekunle A. Impact of adoption of
707 soil and water conservation technologies on technical efficiency: Insight from
708 smallholder farmers in Sub-Saharan Africa. *Journal of Development and Agricultural*
709 *Economics*. 2011; 3(14): 655-669 DOI: 10.5897/JDAE11.091.

- 710
711 38. Ojehomon VET, Adewumi MO, Omotesho OA, Ayinde K, Diagne A. Adoption and
712 Economics of New Rice for Africa (NERICA) Among Rice Farmers in Ekiti State,
713 Nigeria. *Journal of American Science*. 2012; 8(2)
714
715 39. Ray SC. *Data Envelopment Analysis: Theory and Techniques for Economics and*
716 *Operation Research*. 2004, Cambridge University Press, New York.
717
718 40. Solís D, Bravo-UretaBE, QuirogaR. Technical Efficiency among Peasant Farmers
719 Participating in Natural Resource Management Programmes in Central America. *J.*
720 *Agric. Econ.* 2009; 60: 202–219. doi: 10.1111/j.1477-9552.2008.00173.x
721
722 41. Sriboonchitta S, Wiboonpongse A. On estimation of stochastic production-frontiers
723 with self-selectivity: Jasmine and non-Jasmine rice in Thailand. *Asia-Pacific*
724 *Productivity Conference*. 2004a, University of Queensland, Brisbane, 14=16 July
725
726 42. Sriboonchitta S, Wiboonpongse A. The effect of production inputs, technical
727 efficiency and other factors on Jasmine and non-Jasmine rice yields in production
728 year 1999/2000 in Thailand. *Asia-Pacific Productivity Conference*. 2004b, University
729 of Queensland, Brisbane, 14-16 July
730
731 43. Villano RA, Fleming EM. Technical inefficiency and production risk in rice farming:
732 Evidence from Central Luzon, Philippines", *Asian Economic Journal*. 2006; 20(1):
733 29-46.
734 44. Weir S, Knight J. Education externalities in rural Ethiopia. evidence from average
735 and stochastic frontier production functions, Working paper CSAEWPS/2000- 4,
736 Centre for the Study of African Economies, University of Oxford
737
738 45. Wiredu AN, Mensah-Bonsu A, Andah, EK, Fosu KY. Hybrid cocoa and land
739 productivity of cocoa farmers in Ashanti region of Ghana. *World Journal of*
740 *Agricultural Sciences*. 2011;7(2):172-178.
741
742 46. Zhou Z, Robards K, Helliwell S, Blanchard C. Composition and functional properties
743 of rice. *International Journal of Food Science and Technology*. 2002.
744
745 47. Zhu J. Quantitative models for performance evaluation and benchmarking: data
746 envelopment analysis with spreadsheets and excel solver. 2003. Kluwer Academic
747 Publishers, Boston.