Research Article

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Do the determinants of food security differ in improved rice variety adoption? Evidence from Sierra Leone

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Abstract: The Sierra Leonean government has implemented the improved rice varieties directed at enhancing more rice production to reduce food insecurity. This paper evaluates the food security effect of improved rice variety adoption using cross-sectional data collected in 2017 from a randomly selected sample of 624 rice farmers in Sierra Leone. The analysis uses the endogenous switching regression and propensity score matching (PSM) approach. The results revealed that the adoption of improved rice varieties has a significant positive effect on food security. That confirms the crucial role of improved rice variety adoption in increasing food production and food security. Therefore, the study recommended the intensification of policies that promote improved rice variety adoption, if more food production and food security are to be realized. Further, the government should continue the lead in rice variety promotion and dissemination and in enhancing an enabling environment for the effective adoption of farmers. Given the preponderant evidence of the different factors of food security, appropriate policies that seek to promote formal education, more income generation for farmers, and easy and credible access to farmland for landless farmers would enhance food security.

Keywords: improved rice variety, food security, food availability, rice farmers

1 Introduction

The food production system remains one of the biggest challenges for sustainable development that must be solved to eradicate food insecurity and extreme poverty. Notwithstanding the efforts to produce enough food to feed the global population, there remain more people who face uncertainties about their ability to obtain food (Jacques 2004). Studies show that more than one in seven people, which constitute 14.3% of the global population, access less than enough food (Godfray et al. 2010). The vast majority of whom are in countries of Sub-Saharan Africa (SSA), where an estimated 30 percent of the population suffers from hunger and undernourishment (Luan et al. 2013). In most of these food-insecure countries of SSA, agriculture remains a backbone contributing a substantial proportion to the economic growth and development. However, the countries continue to experience low food production and food insecurity. Meanwhile, SSA is the only region in the world where insufficient food production is the primary cause of food insecurity. In other parts of the world, aggregate food production has increased through higher yields, and food insecurity is a result of poor distribution and limited income by the consumers (Coulibaly et al. 2017).

Sierra Leone, like most other SSA countries, has difficulties in its agricultural sector and in achieving its food security needs. Studies estimate that the country has over 70% of the populations below the national poverty line, 52% living on less than US\$1 per day, and 26% are not able to afford the minimum daily calorific requirements (Conteh et al. 2012). Also, there is evidence of limited access to capital, inadequate investment in the agriculture sector, weak natural resource management, and constraints in promoting technological changes among the economically marginalized rural farmers (Louhichi and Y-Paloma 2014). The production growth of Sierra Leonean staple rice remains unimproved and insignificant in the food security efforts. The farming system allows about 4% of the farmers to

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produce adequate rice to meet their annual food needs. The culminating effect has been the increasing reliance on food aid and commercial food imports for a significant portion of Sierra Leone's domestic staple rice food requirements.

In solving the problems of low food production and food insecurity, the existing literature offers a number of solutions. It perceived food aid and importations of food as imperative in addressing the low food production problem and food insecurity in developing countries. That includes the ability to create financial resources required to import food (Trueblood and Shapouri 2001; Kidane et al. 2006; Clapp 2017). There is, however, doubt about the effectiveness of the approach and uncertainties about the food-insecure population benefiting from the generated income. Equally, Barrett (2006) alludes that food aid is seen to be comparatively economical and easy to get during humanitarian emergencies. That is because developed countries are more likely to allocate resources to emergency food aid than to agriculture and long-term development (Barrett 2006). Then, it is uncertain if food aid is prudent in contributing to food security sustainably as it makes developing countries entirely dependent on foreign handouts. This study, therefore, maintains that without a robust agricultural food production chain, policymakers cannot solve the challenges of low food production and food insecurity. The practice of agricultural land expansion and the implementation of yield-enhancing technologies could be the possible ways of achieving growth in food production in Africa (Kaliba et al. 2018). However, the implication of the practice of expanding agricultural land area goes far beyond achieving agriculture growth to improve sustainable food security for smallholder farmers.

In the face of high priority by many governments in SSA for more food production, rice offers an opportunity in reversing the rising trend of food insecurity. In part, that is because rice has a rapid growth rate and is the fastest emerging staple cereal and second major source of energy for a large population of more than 750 million people in Africa (Seck et al. 2012; Arouna et al. 2017). In Sierra Leone, for instance, the distinctiveness of the dietary habits of especially those in rural communities is the overdependence on rice. That is where food is quite synonymous with rice and a day's meal is never complete without at least a spoonful of rice (Johnny and Mansaray 2019). Hence, sustainable increases in rice production and food security could be contingent on the development and adoption of yield-enhancing technologies such as improved rice varieties. Such improvements must be achieved without significantly expanding the agricultural land area, thereby destroying soil fertility or degrading the environment.

To harness the robust potential of improved rice varieties, the main rice research institution in Sierra Leone (Rice Research Station, Rokupr), in collaboration with key international rice research institutions, has developed and released several improved rice varieties. Currently, there are over 27 registered improved rice varieties in Sierra Leone. These include the pure-line selections from the native varieties of Asian origin, the *Oryza sativa*—often called the ROK varieties, as well as the new rice for Africa (NERICA) varieties that reveal attributes of local rice varieties (*Oryza glaberrima*) and the Asian rice varieties (*Oryza sativa*) (Chakanda et al. 2013; Conteh et al. 2014). These have received comparatively more attention in other SSA countries for their peculiar qualities of high yield and desirable agronomic and market traits (Wopereis et al. 2008; Saito et al. 2014). The thrust of releasing these improved rice varieties in Sierra Leone was to provide farmers with additional opportunities for rice self-sufficiency and food security through significant growth in rice production.

Drawing from the existing literature, the adoption of improved rice varieties can boost productivity growth. In addition, it can reduce the probability of crop failures, safeguard more production for household food consumption, and improve farmers' income and food security in SSA countries (Arouna et al. 2017). A study conducted in Madagascar revealed that farming communities with higher improved rice technology adoption rates had more yields and lesser levels of food insecurity (Minten and Barrett 2008). Likewise, implementing a meta-analysis of the impacts of new technologies (fertilizers, new crops, and more nutritious crops) on farmers' food security, a recent study established that the interventions of new rice technologies had the potential to directly improve farm households' food security levels (Stewart et al. 2015). In Asia, the extensive adoption of improved varieties of wheat and rice steered up increases in yields and food security (Evenson and Gollin 2003). At the same time, a study reveals how improved rice varieties contributed tremendously in enhancing more rice production in India and China, accounting for 14–23% of total production value over a two-decade period (Fan et al. 2005). That greatly reduced large numbers of rural poor and food insecurity. Islam (2018) also provides evidence on how the adoption of improved rice varieties can induce food security through directly influencing output levels, food availability, and incomes of farm households and indirectly by raising employment, and wage rates of functionally landless laborers in Bangladesh (Islam 2018).

So far, most of the empirical studies emphasize exclusively the food security effects of adopters in the Africa context, but failing to identify what would happen

to the adopters if they have not adopted the technology. That complicates the importance of agricultural technology as a food security instrument. It also limits the existing literature on improved rice variety adoption to adequately direct policy decisions in achieving rural farm household food security. Conceptualization of the food security effects of agricultural technology adoption needs to permit comparability between adopters and nonadopters (Mendola 2007; Nabasiye et al. 2012) because of the possible food security outcome effects of both cases. Besides, studies (Yengoh and Armah 2015; Johnny and Mansaray 2019) that examined issues of food security in Sierra Leone primarily ignored farmers' improved rice variety adoption and are less rigorous in offering crucial and comprehensive policy implications.

Hence, the objectives of this study are (a) to identify the determinants of improved rice varieties; (b) to analyze the factors that influence food security status of adopters and nonadopters of improved rice varieties, and (c) to estimate the effect of adoption on food security status among the farmers. From an econometric perspective, the shared food security and improved rice variety adoption relationship could result in the problem of endogeneity. Also, the variations in the food security outcomes between adopters and nonadopters of improved rice varieties could be a result of unobserved heterogeneity. Studies show that ignoring the problem of endogeneity and unobserved heterogeneity could lead to biased and inconsistent estimation of the impact of technology adoption (Asfaw et al. 2012; Etea et al. 2019). This study, therefore, employed two impact evaluation techniques (endogenous switching regression and PSM methods) to quantify the impact of improved rice variety adoption on food security and to account for the endogeneity of the adoption decision due to unobserved farmers' socioeconomic characteristics. Overall, the findings from this study provided information crucial for the policymakers to make resourceful reforms to the existing policies that ensure more rice production and food security. To the best of the author's knowledge, this study represents one of the first empirical evidences of food security at the farm level from the perspective of improved rice variety adoption in Sierra Leone.

2 Methodology

2.1 Conceptual and theoretical framework

This study provides a conceptual framework that explains how improved rice variety adoption is likely to impact the

food security status of farmers. It is expected that improved rice variety adoption can enhance high yields and subsequently more food for the farm household. Besides, improved rice variety adoption probably increases farmers' incomes from the sale of surplus rice. That could be translated into increased food expenditure on other foods of required diets and, finally, improvement in the farmer's food security status. Alternatively, the adoption of improved rice varieties provides more food that is expected to directly contribute to the farmer's food intake, which will translate into the farmer's food security. Consequently, this study acknowledges the food security effect of improved rice variety adoption through the aforementioned pathways. That is, through indirect income and direct rice food intake. According to Conteh et al. (2012) and Louhichi and Y-Paloma (2014), rice accounts for more than 75% of the income and livelihood of the active population and more than 50% of Sierra Leone dietary needs. Thus, in addition to the income accrued from the sale of rice product, the adoption of improved rice varieties functions as a proxy for rice food availability, providing the required calories and energy for farmers. Food security is a complex process, which emphasizes the ability to make sure people have continuous access to sufficient, safe, and nutritious food. Coupled with that, the food preferences and dietary needs for active and healthy life (Pinstup-Andersen 2009). The most prominent issue, however, is the capacity to make available the required food. That is dependent on two factors, including production and consumption (Luan et al. 2013). In that context, emphasis is laid on the food security effect of available rice mainly from the domestic production, ignoring the market-purchased rice and transfers through other means, such as borrowing, remittances, and food aid.

This study follows the utility maximization model to conceptualize farmer's adoption decision about improved rice varieties (Rahm and Huffman 1984; Shiferaw et al. 2014). According to the model, farmer's adoption decision is based on whether the expected net utility derived from adopting the new technology is greater than from abandoning or rejecting it. For an improved rice variety, a farmer decides between whether to adopt to maximize their utility or not. Given U_i^a as the benefit in the adoption (a) and U_i^d as the benefit in the nonadoption (d), the farmer decides to transit from the state of nonadoption to the state of adoption of an improved rice variety on farm if $U_i^a - U_i^d > 0$ and decides to abandon if $U_i^d - U_i^a > 0$. Hence, a model characterized by a set of binary-dependent variables determines this adoption/nonadoption decision (Y_i) such that:

$$Y_i^* = X_i\beta + \varepsilon_i \quad (1)$$

where Y_i^* is the probability of the farmers' adoption decision, " $i = 1, \dots, m$ " denotes selection of the improved rice variety adoption, $X_i\beta$ is the index function with X_i representing a vector of observed farmer i and farm f characteristics for adoption/nonadoption of improved rice variety, and β is the vector of unknown parameters to be estimated.

Because the net benefit of adoption and nonadoption of an improved rice variety is unobservable, equation (1) is mapped to an observable binary variable. It takes "1" if the farmer adopts and "0" otherwise:

$$Y_i^* = \begin{cases} 1 & \text{if } U_i^a > U_i^d \\ 0 & \text{if } U_i^d \leq U_i^a \end{cases} \quad (2)$$

In the first situation ($Y_i = 1$), the utility from the improved rice variety is higher, whereas in the second scenario ($Y_i = 0$), the utility is smaller than or equal to the local rice variety. The probability that the farmer will adopt the improved rice variety ($Y_i = 1$) is determined by a set of explanatory variables.

$$\begin{aligned} P_i &= P(Y_i = 1) = P(U_i^a > U_i^d) \\ &= P[\alpha_i^a F_i(L_i M_i) + \varepsilon_i^a > [\alpha_i^d F_i(L_i M_i) + \varepsilon_i^d] \\ &= P[\varepsilon_i^a - \varepsilon_i^d > F_i(L_i M_i)(\alpha_i^a - \alpha_i^d)] \\ &= P[\mu_i > F_i(L_i M_i) \cdot \beta] = F_i(X_i \beta) \end{aligned} \quad (3)$$

where $F_i(X_i \beta)$ is the cumulative distribution index or function with X_i representing $n \times k$ matrix of the explanatory variables and β is a $k \times 1$ vector of parameters that is estimated. $P_i(\cdot)$ represents the probability function and μ_i is the composite random error term. The probability that an individual farmer will adopt an improved rice variety is a function of the vector of explanatory variables (socio-economic or demographic characteristics) and the unknown parameters and error term.

2.2 Empirical strategy

This study considers food security (the variable of interest) as a linear function of observed variables along with a dummy variable for the adoption of improved rice varieties. That could be indicated as a linear estimation model as follows:

$$A_i = \alpha_j + \beta y_i + \varepsilon_i \quad (4)$$

where A_i is the outcome variables (food security), y_i is an indicator variable for adoption of improved rice varieties, j_i is the observable variable, β is the vector of parameters

to be estimated, and ε_i is the error term. The influence of improved rice variety adoption on food security is measured by the estimates of the parameter β . The linear regression approach, however, might generate biased estimates because it assumes that the adoption of improved rice varieties is exogenously determined, although it is possibly endogenous.

The decision of whether to adopt or not is not intentional and may be contingent on several factors of individual self-selection. Farmers who adopted may exhibit distinct characteristics from the farmers who did not adopt, and their decision to adopt may be built on expected benefits that are derived for improved rice varieties. Farmers' and farms' unobservable characteristics may influence both the decision to adopt improved rice varieties as well as food security, ensuring inconsistent estimates of the influence of improved rice variety adoption on food security.

This study explicitly addresses such a problem of endogeneity using simultaneous equation models. If improved rice varieties were randomly assigned to farm households, as may be the case of experimental research, the causal effect of improved rice variety adoption on food security could be evaluated as the difference in food security status between adopters and nonadopters of improved rice varieties. The primary objective of the random assignment is that it guarantees the treatment status to be uncorrelated with any other variables, whether observable or unobservable. Consequently, the possible outcomes will be self-determining or independent of the treatment status. That means the random assignment ensures equal distribution of all the household characteristics between untreated and treated groups (Asfaw et al. 2012). However, the improved rice variety in this study is not randomly distributed between the two groups of farmers (adopters and nonadopters), but rather the farmers choose whether to adopt or not, based on the expected benefits (food security) as well as other factors influencing their decision.

Also, even if the problem of endogeneity is accounted for, it may be unsuitable to employ a binary regression model of adopters and nonadopters to evaluate the effect of improved rice variety adoption on food security outcome. The problem is whether the adoption of improved rice varieties could ensure an average effect over the whole sample of farmers through an intercept shift or could ensure food security by way of slope shifts in the welfare of farmers (Alene and Manyong 2007). Binary regression suggests that the set of explanatory variables has the same influence on

adopters and nonadopters. That is, they both have common slope coefficients. That also means that improved rice variety adoption has the same intercept shift effect irrespective of the coefficients of the other explanatory variables influencing food security. If it is assumed that factors influencing the adoption of improved rice varieties have differential effects on food security, the food security outcome functions for adopters and nonadopters need to be specified, while at the same time accounting for endogeneity. The econometric problem will thus involve both sample selection (Heckman 1979) and endogeneity (Hausman 1978). Concerning the aforementioned challenge, a PSM approach could be a means for assessing the improved rice variety adoption in situations where self-selection bias is a problem (Tefamariam et al. 2018). The PSM approach stabilizes the observed distributions of covariates across the adopters and nonadopters of improved rice varieties. It does not, however, account for sample selection, which results from unobservable covariates. That justifies the use of endogenous switching regression model that addresses the weakness of the PSM approach (Alene and Manyong 2007; Asfaw et al. 2012; Tefamariam et al. 2018).

2.2.1 Endogenous switching regression model

Considering the preceding discussions, this study describes the food security outcome of farmers using two estimation models and a criterion function y_i that determines which condition the farmer faces.

$$y_i^* = \beta X_i + \mu_i \quad (5)$$

$$\text{Condition 1 : } A_{1i} = \alpha_1 j_{1i} + \varepsilon_{1i} \quad \text{if } y_i = 1 \quad (6)$$

$$\text{Condition 2 : } A_{2i} = \alpha_2 j_{2i} + \varepsilon_{2i} \quad \text{if } y_i = 0 \quad (7)$$

where y_i^* represents the unobservable or latent variable for improved rice variety adoption, y_i is its observable component, X_i is the nonstochastic vector of observed farmers' socioeconomic factors of adoption, A_i is the farmer food security outcome in conditions 1 (adopters) and 2 (nonadopters), j_i denotes a vector of exogenous variables assumed to influence food security, and μ_i and ε_i are the respective random disturbance terms associated with the adoption of improved rice varieties and food security outcome variable. The food security outcome function includes explanatory variables such as farm household characteristics (age, gender, family size, education).

Yet, it must be underscored that variables in nonstochastic vectors j_i in equations (5)–(7) may overlap and that suitable identification suggests that at least one variable in X is not in j . In such situations, the decisions of farmers of adoption and nonadoption categories of improved rice varieties may result in nonzero covariance between the error terms of the improved rice variety adoption decision equation and the food security outcome equation. Therefore, the error terms μ_i , ε_{1i} , and ε_{2i} were assumed to have a trivariate normal distribution, with zero mean and the following nonsingular covariance matrix, which is expressed as:

$$\begin{pmatrix} \sigma_{\varepsilon_{1i}}^2 & \sigma_{\varepsilon_{1i}\varepsilon_{2i}} & \sigma_{\varepsilon_{1i}\mu_i} \\ \sigma_{\varepsilon_{1i}\varepsilon_{2i}} & \sigma_{\varepsilon_{2i}}^2 & \sigma_{\varepsilon_{2i}\mu_i} \\ \sigma_{\varepsilon_{1i}\mu_i} & \sigma_{\varepsilon_{2i}\mu_i} & \sigma_{\mu_i}^2 \end{pmatrix} \quad (8)$$

where $\text{var}(\varepsilon_{1i}) = \sigma_{\varepsilon_{1i}}^2$, $\text{var}(\varepsilon_{2i}) = \sigma_{\varepsilon_{2i}}^2$, $\text{var}(\mu_i) = \sigma_{\mu_i}^2$, $\text{cov}(\varepsilon_{1i}\varepsilon_{2i}) = \sigma_{\varepsilon_{1i}\varepsilon_{2i}}$, $\text{cov}(\varepsilon_{1i}\mu_i) = \sigma_{\varepsilon_{1i}\mu_i}$, and $\text{cov}(\varepsilon_{2i}\mu_i) = \sigma_{\varepsilon_{2i}\mu_i}$. As A_{1i} and A_{2i} are simultaneously not observable, the covariance between ε_{1i} and ε_{2i} is not defined (Maddala, 1986). That implies that because the error term of the adoption equation (5) μ_i is correlated with the error terms of the food security outcome functions (equation (6)) and (equation (7)), the expected values of ε_{1i} and ε_{2i} contingent on the sample selection are nonzero (and should be truncated):

$$\begin{aligned} E(\varepsilon_{2i}/A = 0) &= E(\varepsilon_{2i}/\mu_i \leq -j'\lambda) = \sigma_{\varepsilon_{2i}\mu_i} \frac{-\phi(j'\lambda/\theta)}{1 - \Phi(j'\lambda/\theta)} \\ &= \sigma_{\varepsilon_{2i}\mu_i} \gamma_{2i} \end{aligned} \quad (9)$$

$$\begin{aligned} E(\varepsilon_{1i}/A = 0) &= E(\varepsilon_{1i}/\mu_i > -j'\lambda) = \sigma_{\varepsilon_{1i}\mu_i} \frac{-\phi(j'\lambda/\theta)}{1 - \Phi(j'\lambda/\theta)} \\ &= \sigma_{\varepsilon_{1i}\mu_i} \gamma_{1i} \end{aligned} \quad (10)$$

where ϕ and Φ , respectively, depict the probability density and cumulative distribution functions; A_{1i} and A_{2i} are inverse Mills' ratios of ϕ and Φ evaluated at $j'\lambda$. Inverse Mills' ratios were added to equation (1) to account for the selection bias.

The endogenous switching models are regressed using full information maximum likelihood estimation (Asfaw et al. 2012; Tefamariam et al. 2018). The full information maximum likelihood approach simultaneously estimates the probit model or selection equation (adoption of improved rice varieties) and the regression equations (outcome of food security) to obtain consistent standard errors. Given the assumption of trivariate normal distribution for the error terms, the log likelihood

function for the system of equations (5)–(7) can be expressed as follows:

$$\ln L_i = \sum_{i=1}^N y_i \left[\ln \phi \left(\frac{e_{1i}}{\sigma_{e1}} \right) - \ln \sigma_{e1} + \ln \phi(\varphi_{2i}) \right] + (1 - y_i) \left[\ln \phi \left(\frac{e_{2i}}{\sigma_{e2}} \right) - \ln \sigma_{e2} + \ln \phi(\varphi_{2i}) \right] \quad (11)$$

where $\varphi_{ji} = \frac{\beta X_i + y_i e_{ji} / \sigma_j}{\sqrt{1 - y_j^2}}$, $j_i = 1, 2$, with y_j representing the coefficient between the error term μ_i of the selection equation (5) and the error term ε_{ij} of equations (6) and (7), respectively. The significance and signs of the correlation coefficients (ρ) obtained from the simultaneous estimations are very pertinent. If the estimated covariance $\sigma_{\varepsilon_{1i}\mu_i}$ and $\sigma_{\varepsilon_{2i}\mu_i}$ are statistically significant, then the improved rice variety adoption decision and the food security outcome variable are correlated. That means we can find proof of endogenous switching and reject the null hypothesis of absence of sample selectivity bias (Maddala 1986). Negative selection bias ($\rho > 0$) implies that farmers with the below-average food security statuses are more likely to adopt improved rice varieties. If there is positive selection bias ($\rho < 0$), then farmers with the above-average food security statuses are more likely to adopt improved rice varieties.

Also, for identification motives, the instance that X_i contains at least one element not in J_i was followed, imposing an exclusion restriction on equation (11). The hypothesis is that the probability of a farmer to adopt improved rice varieties is an increasing function of two selection instruments. That is, its prior exposure by access to information from extension services and off-farm activities during the last year. Following Asfaw et al. (2012) and Tesfamariam et al. (2018), this study accepted these instruments through a simple rejection test: if a variable is an appropriate selection instrument, the decision to adopt will be affected; otherwise, the food security outcome variable among nonadopters will not be affected. Results demonstrate that the two variables can be assumed as appropriate selection instruments for improved rice variety adoption in Sierra Leone.

By employing endogenous switching regression, it provides a comparative analysis of the expected food security status of adopters (a) and nonadopters of improved rice varieties, (b) examines food security in the counterfactual assumptions that adopters of improved rice varieties did not adopt, and (c) that nonadopters did adopt (d) as follows:

$$E(A_{1i}/y_i = 1) = \alpha_1 j_{1i} + \sigma_{\varepsilon_{1i}\mu_i} y_{1i} \quad (12)$$

$$E(A_{2i}/y_i = 0) = \alpha_2 j_{2i} + \sigma_{\varepsilon_{2i}\mu_i} y_{2i} \quad (13)$$

$$E(A_{1i}/y_i = 1) = \alpha_2 j_{2i} + \sigma_{\varepsilon_{2i}\mu_i} y_{2i} \quad (14)$$

$$E(A_{2i}/y_i = 0) = \alpha_1 j_{1i} + \sigma_{\varepsilon_{1i}\mu_i} y_{1i} \quad (15)$$

The average treatment effect on the treated (ATT) is given by the difference between equations (12) and (14) and the average treatment effect on the nonadoption of improved rice varieties by the difference between equations (13) and (15) (Tefamariam et al. 2018).

2.2.2 The PSM technique

The PSM approach was employed to complement the endogenous switching regression in comparing the food security outcome of adopters of improved rice varieties and their counterparts. In this study, the propensity score of those adopting improved rice varieties was first generated using a probit model. That was followed by the ATT estimation centered on the predicted propensity scores ($\Pr(j)$). The PSM was indicated as follows:

$$\Pr(j_1) = \Pr(y_1 = 1|X_1) = E(y_1|X_1) \quad (15)$$

where $y_1 = \{0, 1\}$ represents whether the farmer adopted improved rice varieties and X_1 denoted the characteristics of the adopters. The ATT, Ψ_{ATT}^{PSM} , is shown as follows:

$$\Psi_{ATT}^{PSM} = E[\Psi e_1|y = 1, \Pr(j)] - E[\Psi e_2|y = 0, \Pr(j)|y = 1] \quad (16)$$

Also, this study followed recent studies to estimate the ATT using the nearest neighbor matching (NNM), kernel-based matching (KBM), and radius methods (RM) of the PSM (Pan, 2014; Takam-Fongang et al., 2019; Tesfamariam et al., 2018).

2.3 Description of the study area and data

This study focuses on rice farmers in Sierra Leone. Sierra Leone is a relatively small country, which is situated on the West Africa coast bounded by the Republic of Guinea, Republic of Liberia, and the Atlantic Ocean. Sierra Leone consists of 71,620 km² of land and 200 km² water lying between latitude 7° and 10° North of the equator, and longitude 10.5° and 13° West (National Census 2015). It is presupposed that Sierra Leone has sizeable agricultural potential. That is due to the tropical climate of mild temperatures that range from 26 (mean minimum) to 36 (mean maximum). Coupled with that,

there are the issues of abundant rain, which spans from May to November, and a relatively short dry season from December to April each year. The topography characterized by the ecosystem of uplands, lowlands encompassing substantial farmland, and relatively high levels of fertile soils (Odell 1974; Chakanda 2009). That also suggests the suitability for crop production, particularly rice. Administratively, Sierra Leone is divided into 4 regions (i.e., North, South, East, and Western Area), which are further subdivided into 13 rural districts and 1 urban area (see Figure 1).

Hence, this study builds on a cross-sectional survey in 13 administrative rural districts of Sierra Leone, which represents a more significant part of the country's territory under rice cultivation as the most important agricultural activities. The selection of the sample was through a simple multistage sampling technique. The first stage involved a random selection of two chiefdoms from each district based on the agricultural potential and accessibility. At least four towns/villages were randomly selected from a chiefdom based on the rice production as the main agricultural activity. The final stage involved

the random selection of rice farming households consistent with the number of farmers in the towns or villages. At least eight farm household heads (the ultimate units of sampling) were interviewed. In total, 26 and 87 sample chiefdoms and towns/villages were randomly selected for an overall sample of 624 farmers. The survey data were collected between April 2017 and September 2017 using a structured questionnaire.

The survey was based on farmers' reported indicators of whether there were adequate or shortfalls of rice available from the domestic production during a year. In this case, farmers were asked to reveal their available food from the domestic rice production over a year in three categories: surplus food availability, at-level/par food availability, and deficit food availability concerning rice of domestic output. Surplus food availability assumes a situation where a farm household enjoys a period of more food consumption. Deficit food availability describes a situation where a farm household suffers from a period of decline in food consumption or a lack of access to sufficient food (Pinstrup-Andersen 2009). At-level/par food availability, on the other

Figure 1: Maps of Sierra Leone indicating data collection locations. Source: Authors' survey, 2017.

hand, relates to a situation where a farm household has neither food shortage nor a surplus. Food available for consumption (in kcal) from the total food crop outputs was also employed to assess the food security status among households. That was deduced by estimating the number of kcal (C_i) available in the staple rice at farm level by taking the difference between total calories available from production and consumption need as follows (Rahman and Chima 2018):

$$C_i^* = C_i - \delta_i \quad (17)$$

where C_i is the standard calorie availability per 100 g of rice. The consumption need δ_i is the per capita food needs of the respective farm household i —expressed as a ratio of farm household food allocation (i.e., grams of rice per farm household per day) to the farm household adult-equivalent. The information on the standard calorie availability per 100 g of rice, brown, long-grain raw (1,549 kcal) was obtained from SELFNutrition (<http://nutritiondata.self.com/>).

The farm household food allocation was presumed to be proportionate to the energy requirements of individuals, given age and sex. That was determined through the adult-equivalent reference scale by estimating the mean calorie requirements for male and female farmers from 19 to 50+ years of age. That resulted in a reference value of 2,550 kcal (Table 1), in accordance with the Food and Nutrition Board guidelines (Claro et al. 2010).

At the same time, the survey considered farmers' socioeconomic variables that indicate greater affluence and proxies for social status that influence food availability. The selection of the different variables was made in a way reflective of farm households' endowment of the different forms of farm capital. The variables such as the age of farmer, educational level of the farmer, farmer's gender, farm household size, and farming experience represent farm household human capital (Handa et al. 2004). Concerning financial capital, farm household income, the value of livestock, and availability to credit facilities, which are considered in the existing literature, were included as factors influencing food security (Aidoo et al. 2013). Also, there were variables to measure the farmer's access to vital farm resources such as farmland, farm size, inorganic fertilizer, market information, and government extension services. Arguably, these variables are exogenous to food security, and we based their inclusions on motivation by the existing technology innovation literature (Adesina and Zinnah 1993).

Table 1: Adult equivalent reference scale giving age and gender of farmers^a

Age (years)	Calories ^a (kcal)	Adult-equivalent conversion factor
Men		
11–14	2,500	0.98
15–18	3,000	1.18
19–24	2,900	1.14
25–50	2,900	1.14
51+	2,300	0.90
Women		
11–14	2,200	0.86
15–18	2,200	0.86
19–24	2,200	0.86
25–50	2,200	0.86
51+	1,900	0.75

^a According to recommended dietary allowance (Claro et al. 2010).

3 Results and discussion

3.1 Descriptive statistics of variables used in the analyses

The descriptive statistics of key socioeconomic characteristics of sample farmers by improved rice variety adoption status are shown in Table 2. The t -statistics show that some variables used in the empirical analysis have a significant difference between adopters and nonadopters. Specifically, the adopters were significantly older than the nonadopters, with mean ages of about 45 and 43 years, respectively. That relates to active farm labor and a distinct feature for food-secure farm households. That indicates how the youths generally perceive the farming activity as an unbuoyant and unsustainable occupation and pursued different interests. The results also show a significant difference between nonadopters and adopters of improved rice variety concerning gender, as male constitutes about 69% and 78% of adopters and nonadopters, respectively. Similarly, farmers who adopted improved rice varieties were better educated with an average of about 7 years of formal education compared with the nonadopters of about 3 years.

The results likewise show a positive correlation between income and the adoption of improved rice varieties where the mean annual income of adopters and nonadopters was significantly different at about Le 4.08 million and Le 1.84 million, respectively. At the same time, farmers who adopted improved rice varieties have significantly larger farm sizes of about 2.3 ha compared

Table 2: Descriptive statistics of variables employed in the analysis

Variables	Description	Nonadopters Mean (SD)	Adopters Mean (SD)	t-test p-value
FOOD_SEC	Farmer's food security outcome	0.609 (0.489)	0.545 (0.499)	0.083
AGE	Age of the farmer (years)	42.750 (12.199)	44.752 (10.882)	0.042
GEND	Sex of the farmer, binary, 1 = male	0.776 (0.418)	0.694 (0.461)	0.036
EDUC	Level of education, in year	3.490 (5.210)	4.632 (5.510)	0.015
LIVESTO	Value of livestock assets, in million Le	0.668 (2.161)	0.939 (2.800)	0.234
INCOME ^a	Previous year's income, in million Le	1.843 (2.898)	4.084 (8.767)	0.001
F_HH_SIZ	Household help on rice farm,	5.219 (3.012)	5.655 (3.171)	0.108
F_EXPE	General farming experience, in years	13.859 (10.769)	14.877 (9.885)	0.249
Land ownership				
OWNED_L	Land owned by farmer	0.688 (0.465)	0.613 (0.488)	0.076
RENT_L	Rented land	0.229 (0.421)	0.336 (0.473)	0.008
SHARE_CROP	Share cropping	0.083 (0.277)	0.051 (0.220)	0.119
F_SIZE	Total land for rice production, in acres	3.906 (2.759)	5.738 (6.807)	0.000
FERT	If a farmer adopt fertilizer, binary, 1 = yes	0.250 (0.434)	0.537 (0.499)	0.000
CRED	If a farmer access credit, binary, 1 = yes	0.276 (0.448)	0.333 (0.472)	0.156
MKT_INF	If a farmer access market, binary, 1 = yes	0.255 (0.437)	0.477 (0.500)	0.000
FBO	If joined farmers' organization, 1 = yes	0.844 (0.364)	0.884 (0.320)	0.163
EXT_SERV	If visit by extension agent, binary, 1 = yes	0.521 (0.501)	0.748 (0.434)	0.000
OFF_FARM	Off farm employment, binary, 1 = yes	0.047 (0.211)	0.083 (0.277)	0.105

^a Sierra Leonean currency, the Leone (Le); at the time of data collection Le7500 = US\$1. Source: Authors' computation.

with the nonadopters who cultivated about 1.6 ha. That is also consistent with Asfaw et al. (2012), who found farm size as a farm welfare indicator that has a direct relationship with the adoption of improved agricultural technologies. No significant difference was observed between adopters and nonadopters concerning the years of rice farming experience.

The cultivation of farmer's land was significantly different among most nonadopters compared with adopters of improved rice varieties. However, the use of rented lands was significantly higher among adopters compared with farmers who were nonadopters. That corroborates with previous studies that show a positive and significant impact of a robust land ownership structure such as land rental on the adoption of improved rice varieties (Mansaray et al. 2019). Most adopters belonged to farmers' organizations compared with nonadopters. The difference in the means indicates the significant role of improved rice variety adoption in enabling farmers' social capital (Tefamariam et al. 2018). Also, the adoption of chemical fertilizers was significantly higher for adopters, and they seem to have easy access to market information and more access to agricultural extension services. As expected, access to market information and agricultural extension services played a significant role in creating awareness about improved rice variety. That corroborates with Mwangi and Kariuki (2015), who suggest that more access to

market information and agricultural extension services played a significant role in creating awareness about improved rice variety. That influences whether a farmer adopts an improved rice variety.

To further understand the differences between the farmers who adopted improved rice variety and the nonadopters, this study categorized the sample into two food security groups using the index of food available for consumption (in kcal). In each category, farmers with positive index were termed as more food-secure, while those with negative values were termed as less food-secure, respectively. That is, if $C_i^* \geq 0$ implies more food-secure at the farm level, otherwise less food-secure (see equation (17)). Table 3 presents the distributions of the categories of farmers on whether they adopted improved rice varieties, based on the food security status at the farm level. As observed in the results, the more food-secure farmers who adopted improved rice varieties have a relatively higher educational level. They also have more livestock assets and easier access to credit facilities than less food-secure farmers. In contrast, the results show no significant differences for the educational level of farmers, the value of livestock had on food security status of farmers, and access to credit facilities concerning the nonadopters of improved rice varieties. The results also reveal significant differences between more food-secure and less food-secure of both adopters and nonadopters of an improved rice variety concerning farm household

income, farm size, the adoption of inorganic fertilizer, and easy access to market information.

There are also significant differences between more food-secure and less food-secure farmers who are non-adopters of improved rice variety, whereas there are no differences between more food-secure and less food-secure adopters of improved rice variety. There are, however, no significant differences between more food-secure and less food-secure farmers between adopters and nonadopters of improved rice variety in terms of gender, the three classifications of farmland ownership (owned, rental, and sharecropping), as well as access to extension services.

In the ensuing sections, a rigorous analytical model is estimated to show whether these differences in the significance mean of improved rice variety adoption remain unchanged after controlling all influencing factors. To estimate the influence of improved rice adoption on food security, it is essential to keep in mind that farmers who adopt improved rice varieties might have attained a better food security status even had they not adopted.

3.2 Determinants of improved rice variety adoption: Endogenous switching regression

The results of the two-stage endogenous switching regression model estimated for improved rice variety

adoption and its impact on food security at farm level are presented in Table 4. The results in the selection equation (column 1) indicates the first stage of providing the driving force behind farmers' decision to adopt improved rice varieties. That had been interpreted as normal probit coefficients. The results show the statistical significance of the coefficients of a relative number of variables. Gender was significantly different from zero and negative in the selection equation. That indicated that the availability of more female farmers increased the inclination to adopt improved rice varieties, suggesting that females are more likely to adopt improved rice varieties than their male counterparts. However, the result contradicts the findings of recent studies who reveal that farmers in female-headed households were less likely to adopt improved varieties as they often have limited resources to manage their resource-poor farm (Doss and Morris 2000). The income of farmers was positive and significantly different from zero. That suggests that all things being equal, as the incomes of farmers increased, their inclination to adopt improved rice varieties also increased. To a greater extent, however, farming in Sierra Leone is subsistent and the income-generating capacity of farmers is limited mainly due to their farming activities such as sales of farm output and contract labor (Johnny and Mansaray 2019). The positive and statistical significance of the coefficient of farm size implies that farmers who cultivate large farms are more likely to adopt improved rice varieties than farmers with small farms.

Table 3: Differences in farmers' characteristics by food security status

	Adopt (IRV)			Nonadopt (IRV)		
	More secure	Less secure	<i>t</i> -test <i>p</i> -value	More secure	Less secure	<i>t</i> -test <i>p</i> -value
AGE	44.251	45.328	0.305	40.205	46.720	0.000
GEND	0.727	0.657	0.113	0.795	0.747	0.437
EDUC	4.117	5.224	0.037	3.889	2.867	0.185
LIVESTO	0.550	1.385	0.002	0.469	0.979	0.111
INCOME	2.828	5.527	0.001	1.258	2.756	0.000
F_HH_SIZ	5.216	6.159	0.002	5.094	5.413	0.475
F_EXPE	15.558	14.095	0.125	12.761	15.573	0.077
LAND_OWNED	0.610	0.617	0.890	0.650	0.747	0.158
RENT_L	0.338	0.333	0.925	0.248	0.200	0.444
SHARE_CROP	0.052	0.050	0.918	0.103	0.053	0.231
F_SIZE	4.506	7.154	0.000	2.581	5.973	0.000
FERT	0.489	0.592	0.033	0.308	0.160	0.021
CRED	0.407	0.249	0.001	0.274	0.280	0.922
MKT_INF	0.515	0.433	0.088	0.308	0.173	0.037
EXT_SERV	0.740	0.756	0.704	0.487	0.573	0.246

Source: Authors' computation.

Table 4: Endogenous switching regression estimates for the determinants of improved rice variety adoption and food security

	Food security (FOOD_SEC)					
	Selection		Adoption		Nonadoption	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
AGE	−0.002	0.006	−0.124	0.157	−0.068	0.072
GEND	−0.291**	0.138	6.031*	3.287	3.908**	1.835
EDUC	0.013	0.012	−0.155	0.278	−0.441***	0.146
LIVESTO	−0.021	0.028	−0.556	0.686	−0.060	0.324
INCOME	0.038*	0.020	−0.346*	0.206	−0.220	0.268
F_HH_SIZ	0.000	0.020	0.155	0.478	0.229	0.239
F_EXPE	0.004	0.007	0.048	0.175	−0.048	0.084
RENT_L	−0.142	0.150	−2.722	3.482	−3.106*	1.864
SHARE_CROP	−0.267	0.246	1.351	6.776	0.128	2.618
F_SIZE	0.068***	0.020	−0.370	0.235	−2.379***	0.308
FERT	0.732***	0.145	−0.419	3.318	0.736	2.321
CRED	0.219*	0.132	2.657	3.123	−0.443	1.682
MKT_INF	0.525***	0.128	5.566*	3.026	2.575	1.901
FBO	0.428**	0.182	0.950	4.740	−0.298	2.182
EXT_SERV	0.290**	0.130				
OFF_FARM	0.222	0.260				
CONSTANT	−0.744**	0.336	−3.892	8.675	7.429	4.108
Wald χ^2	21.730					
Log likelihood	−3001.458					
LR test of indep. eqns.	18.240***					
$/\ln s_{1i}$			3.357***	0.035	2.224***	0.054
ρ			0.080	0.099	−0.073	0.275

*, **, *** denote significance at the 0.1, 0.05, and 0.01 level, respectively.

Source: Author's computation.

Similarly, this study shows consistently positive and statistically significant coefficient of fertilizer adoption. That highlights the role of the use of chemical fertilizer in facilitating the adoption of improved rice varieties among farmers, a result consistent with the recent study (Abdoulaye and Sanders 2005). The results were consistent with another study (Kassie et al. 2015) in terms of access to credit, indicating positive coefficient, which was significantly different from zero. That implies that farmers with less credit-access constraints are more likely to adopt improved rice varieties. At the same time, the coefficient of easy access to market was positive and significant. That demonstrates that more access to the market information significantly increases the likelihood of the farmer to adopt improved rice varieties.

Farmers who are members of farmers' organizations and can access agricultural extension services are more likely to adopt improved rice varieties. That is indicated by the significant and positive coefficient for the membership to farmers' organization. It supports the idea that farmers' social capital enhances information sharing, which tends to facilitate participation in sustainable farming practices and interventions (Bandiera and Rasul 2006). As one

would expect the access or visit by extension agents would increase the likelihood of receiving frequent technical advice and, therefore, a higher probability of adopting improved seed rice. Thus, better conditions in the agricultural extension services in Sierra Leone would give direct and corresponding effects on improved seed rice adoption.

3.3 Determinants of food security among improved rice variety adopters and nonadopters

The full information maximum likelihood estimates of the endogenous switching regression model for improved rice variety adoption (stage 2) are shown in Table 4. The results of the correlation coefficient (ρ) provide an indication of selection bias and the existence of observed and unobserved factors influencing farmers' decision to adopt improved rice varieties. The nonsignificance of covariance estimates for both adopters and nonadopters shows that in the absence of adoption of improved rice

varieties, there will be a difference in evidence in the food security outcome between adopters and a random farmer caused by observed factors as well as between nonadopters and a random farmer caused by unobserved factors. Also, the significant value of the Wald test for independence of the equations suggests interdependence between the selection equation and the outcome equations for adopters and nonadopters. That offers more proof of endogeneity. Test results established the validity of our instrument because it has a significant effect on the adoption decision of improved rice varieties but do not affect the food security outcome.

The estimation results of the endogenous switching regression show that gender has a common and positive food security effect of both adopters and nonadopters. That means, the occurrence of more male farmers can significantly increase the food security of both adopters and nonadopters. That corroborates with recent studies that show that male-headed farm households are more likely to have a higher average value of rice production and can invest better effort on their farms for better rice production than female-headed farm households, and (Coulibaly et al. 2017) contrariwise, females especially those who are widows or divorcees have limited resources to manage their resource-poor farms.

Other estimates including education, income, land ownership, farm size, and access to market information influence the food security outcome of adopters and nonadopters differently. The results show that the coefficient of income of adopters in column 2 shows a negative and significant association with food availability. While the result is disappointing, it is only disclosing the situation of farmers in Sierra Leone where the income-generating capacity of farmers is limited mainly to their farming activities such as sales of farm output and contract labor. To a greater extent, however, farming in Sierra Leone is subsistent. It had not been able to provide enough marketable surpluses that can earn farmers more income. Other income sources, such as credit, had been inadequately obtained. Formal banking and credit-lending institutions tend to be expensive and difficult to access by rural farmers. That restrains farmers from diversifying their income-generating capability that can contribute to ensuring more food production and food security. At the same time, the results demonstrate that more access to market information (a proxy for transaction costs) significantly increased the likelihood of the farmer being food-secure as an outcome of adopters of improved rice varieties. That is consistent with other studies who reveal that easy access to information on input and output markets can

reflect the cost of buying inputs as well as the cost of taking products to the market (Kassie et al. 2013). Hence, it will be laudable for farmers to have better access to market information to increase the likelihood of better-improved rice variety adoption that enhances more food production and food security.

On the other hand, the results of the nonadoption of improved rice variety in column 3 reveal significant and negative association with food security concerning education, farmers' access to land through rental, and the size of land that farmers cultivated. The results of the effect of the educational level of nonadopters on attaining food security are inconsistent with suggestions of recent studies show that household heads with a relatively high level of education or with more human capital suffer less from food insecurity (Etea et al. 2019). Education could empower farmers to seize different off-farm employment opportunities that are unavailable to less educated ones, which impacts their food access and consumption decisions positively. In Sierra Leone, however, the educational level among the rural farmers is very low with a 4-year average for the entire sample (Table 4). That could possibly restrain farmers from accepting new practices and technologies which may enhance more food production.

The finding that the nonadopters who have easy access to farmland through rental are less likely to be food-secure points to the need for a firm economic basis for effective access to farmland by all potential farmers. That result contradicts a recent study, which attributes the increasing access to land through effective land rental markets by those who are productive but own little or no land to positive effects on household income and food security (Muraoka et al. 2018). Hence, it is necessary to reassess the relevance of land ownership as a means of encouraging improved rice variety adoption.

The negative coefficient of farm size is suggesting that the nonadopters who cultivate small farmers are more food-secure than farmers who cultivate large farms. That seems counterintuitive at first sight. But then, it may imply that farmers with small farm size are more effective (or productive) than farmers with larger farms in terms of providing more food. According to a recent study, the world's poorest are generally landless (Leathers and Foster 2004). Hence, the relationship between food security and farming on given farmland is mainly appropriate for the farm households. A study posits that there is an inverse relationship between farm size and farm production (Altieri et al. 2015). That indicates that as the farmland size is smaller, the

household tends to be more productive. That is because the farm household invests more in land improvement. In Sierra Leone, farmers are only limited to growing on small pieces of land since they found it difficult to do large-scale farming. Also, they are not sure of the provision of incentives such as improved technologies that would enhance productivity growth on these small parcels of land. It is then expected to negatively affect the agricultural production of Sierra Leonean farmers, limiting their potential to achieve food security.

3.4 Impact of the improved rice variety adoption on food security: PSM estimation

As the results from the endogenous switching regression may be instrumentally sensitive, the PSM approach was also used to check the strength of the estimated effect of improved rice variety adoption on food security obtained from Table 4. Table 5 shows the probit estimation results from which the propensity scores have been derived in stage 3. The results corroborate with those from the endogenous switching regression estimate, which includes eight factors (gender, farmers' income, farm size, adoption of chemical fertilizer, access to credit facilities, easy access to market information, membership in farmers' organization, and access to agricultural extension services) that are significantly related to improved rice variety adoption. The statistical test was conducted to determine whether or not PSM balances the distribution of the relevant covariates in both the treatment and control groups (Takam-Fongang et al. 2019).

As observed in Table 6, the propensity score test shows a significant reduction in bias after matching, and most importantly, there is a relative number of significant differences of the covariates in matched adoption and nonadoption data. Figure 2 illustrates the standardized bias across covariates before and after matching. After matching, standardized bias across covariates is closer to zero. Also, a visual illustration of the density distributions of estimated propensity scores for the two groups of adopters and nonadopters (Figure 3) indicates that the common support assumption (CSA) that requires each adopter to have a corresponding nonadopter as a match was justified. There was an overlap in the propensity scores distribution of both adopter and nonadopter in which all the treated and untreated group scores satisfied the common

Table 5: Probit estimation results of improved rice variety adoption (PSM)

	Coef.	Std. err.
AGE	−0.002	0.006
GEND	−0.290**	0.138
EDUC	0.013	0.012
LIVESTO	−0.020	0.028
INCOME	0.038*	0.020
F_HH_SIZ	0.000	0.020
F_EXPE	0.004	0.007
RENT_L	−0.149	0.150
SHARE_CROP	−0.269	0.246
F_SIZE	0.067***	0.020
FERT	0.730***	0.145
CRED	0.221*	0.132
MKT_INF	0.524***	0.128
FBO	0.429**	0.182
EXT_SERV	0.287**	0.128
OFF_FARM	0.248	0.257
CONSTANT	−0.741**	0.335
Log likelihood	−314.226	
Prob > χ^2	0.000	
Pseudo R^2	0.160	
Obs.	607	

*, **, *** denote significance at the 0.1, 0.05, and 0.01 level, respectively.

Source: Authors' computation.

support condition. That implies that each farmer had a positive probability of being either food-secure or not.

However, to check the quality and robustness of the results, different matching algorithms in the PSM were employed in Table 7. The test results show a reduction in the mean standardized bias for NNM, RM, and KBM, respectively (see columns 7 and 8). That suggests no observable differences in the variables of adopters and nonadopters after matching. Hence, the nonadopter's farmer-group was assumed to be a good counterfactual. The pseudo- R^2 also specifies how well the covariates explain the probability of adoption of improved rice varieties. The results show low pseudo- R^2 values after matching, suggesting the absence of differences in the distribution of covariates between the adopters and nonadopters.

At the same time, the p -values had remained significant and total bias reduction values not reduced after matching for NNM, RM, and KBM, respectively. That suggests a credible counterfactual in which the matching process was capable of effectively ensuring treatment-control groups' distribution balance of the covariates. These results generally show a nonsystematic adoption and nonadoption distributional balance of the covariates concerning the food security outcome. Therefore, any difference in the food security outcome

Table 6: Tests for selection bias after matching

Variable	Matched sample mean		Bias		t-test	
	Treated	Control	% Bias	% Bias reduction	t-value	p > t
AGE	44.751	45.173	-3.700	76.100	-0.600	0.549
GEND	0.694	0.834	-31.800	-73.900	-4.850	0.000
EDUC	4.637	2.380	41.800	-118.100	6.310	0.000
LIVESTO	0.868	0.459	18.600	-109.200	3.390	0.001
INCOME	3.928	7.839	-66.200	-88.700	-6.330	0.000
F_HH_SIZ	5.703	6.425	-23.300	-62.300	-3.500	0.000
F_EXPE	14.986	19.228	-41.100	-276.900	-5.710	0.000
RENT_L	0.335	0.249	19.100	21.600	2.740	0.006
SHARE_CROP	0.050	0.040	3.800	73.700	0.660	0.507
F_SIZE	5.888	4.173	33.000	7.600	4.760	0.000
FERT	0.539	0.556	-3.600	94.300	-0.480	0.628
CRED	0.333	0.257	16.500	-43.500	2.420	0.016
MKT_INF	0.477	0.311	35.500	26.000	5.000	0.000
FBO	0.888	0.895	-2.100	81.700	-0.330	0.740
EXT_SERV	0.746	0.798	-11.100	76.100	-1.810	0.071
OFF_FARM	0.083	0.024	24.500	-48.000	3.860	0.000

Source: Authors' computation.

between the adopters and nonadopters, which might arise, would be due to the adoption of improved rice varieties.

With a successful matching process, the average treatment captured the effect of improved rice variety adoption on food security. That was also measured based on the different PSM algorithms including NNM, KBM, and RM estimator in Table 8 (Tefamariam et al. 2018). The causal effects from all three matching algorithms indicate

that the adoption of improved rice varieties positively and significantly increases the probability of food security. That implies that the food security status of adopters was greater than those of nonadopters.

These results are consistent with recent studies. For instance, Takam-Fongang et al. (2019) found that the adoption of improved maize varieties enhances maize yield in Cameroon. Consequently, farmers realized higher yields from maize production than their nonadopter counterparts.

Figure 2: Standardized bias across covariates before and after matching.

Figure 3: Propensity score distribution on the region of common support. Note: the upper and bottom halves of the graph show the distribution of propensity scores for the adopters and nonadopters of improved rice varieties, respectively. Source: Authors' computation.

Asfaw et al. (2012) also found that the adoption of improved agricultural technologies has a significant positive effect on consumption expenditure in Ethiopia and Tanzania. Pan (2014) found that participation in agricultural extension has a positive effect on food security-related rationalization of farmer nutrient management behaviour in China. In this study, improved rice varieties seem to be crucial to farmers in Sierra Leone as it led to significantly better food security status among adopters. It is, however, important to note that the estimation of the food security effect of improved rice varieties among farmers may not be representative of a broader scale of the Sierra Leonean food system. Besides the availability of rice at the farm level, this study did not take into consideration other elements of food security, such as accessibility, affordability, nutritional security, and the supply of different foods in Sierra Leone. Also, it was observed that the level of food availability changes with the pattern of agricultural seasons. That means, the degree of adopting other coping strategies, aside from domestic

food production, could be high during the agricultural production periods and very low during the harvest period. Extending this study to examine other food security indicators is a concern for future research.

3.5 Food security status of rice farmers

Further, this study tries to illustrate the food availability capacity of farmers and their efforts to smooth the consumption of rice over time. As observed in Figure 4, the domestic rice availability status at the farm level conforms to the rhythm of seasonal rice production activities in Sierra Leone. That is, when the beginning of rice harvests marks the end of the lean season, which reaches its peak in June and July. Rice is harvested between August and January in different rice farm locations in Sierra Leone. A study also specified that certain food crops are adequately available only through a certain period of the year (Rahman and Chima 2018).

Table 7: Summary statistics of the matching quality indicators

Method	Ps R^2		LR χ^2		$p > \chi^2$		Mean standardized bias		% bias reduction	
	Before	After	Before	After	Before	After	Before	After	Before	After
PSM	0.160	0.157	119.630	183.810	0.000	0.000	24.600	23.500	43.000	100.000
NNM	0.160	0.115	119.630	133.710	0.000	0.000	24.600	19.900	43.000	43.000
RM	0.160	0.151	119.630	88.900	0.000	0.000	24.600	24.600	43.000	43.000
KBM	0.160	0.102	119.630	119.080	0.000	0.000	24.600	18.900	43.000	57.000

Source: Authors' computation.

Table 8: Propensity score matching estimation

	Mean outcome		ATT	S.E	t-value
	Adoption	Nonadoption			
Nearest neighbor matching (NNM)					
Food security outcome	-4.137	-6.227	2.091***	3.424	0.610
Kernel-based matching (KBM)					
Food security outcome	-4.137	-6.194	2.057***	2.754	0.750
Radius caliper matching (RM)					
Food security outcome	-4.137	-3.155	-0.982***	1.459	0.670

*** denotes significance at the 0.01 level.

Source: Authors' computation.

Figure 4 reveals that most farmers in the sample experienced surplus food availability in October, November, December, January, and February (during peak harvest). December represented the most food-secure or surplus food availability period and was marked with excessive food consumption at harvest time. That behaviour is intended to compensate for weight loss during the hunger period, which is typical among rural Sierra Leonean rice farmers. A current stance in the seasonal food shortage in rural communities is the wasteful utilization of available food. Hence, it could be argued that the hunger season is to a greater extent a customarily induced occurrence as well as the

inability of the farming systems to produce sufficient food for rural communities.

The farmers have food availability at a level during March, April, and May. That precedes food deficit or unavailability in June, July, August, and September. The most severe food shortages are June and July, which mark the end of the planting period and the preharvest period of crops. This study describes experiences in the food hunger season when most of the people in Sierra Leone, especially in rural areas, go without food for several days at a time. During the hunger season, there is likelihood for fewer (and insufficient) meals to be served than at harvest time. The number of meals per day is

Figure 4: Food availability status at farm level (irrespective of IRV adoption). Source: Authors' survey, 2017.

mostly reduced from 3 to 1. Further inquiry (during this survey) also suggests that meals become more diversified during the hunger season as farmers tend to eat whatever is available. Many farm households consume other foodstuffs such as cassava, yam, sweet potato, and wild tubers.

4 Conclusion

This study investigates the effect of improved rice variety adoption on food security at the farm level in Sierra Leone. The study employed cross-sectional farm-level data collected in 2017 from a randomly selected sample of 624 rice farmers in Sierra Leone. The causal effect of improved rice variety adoption was estimated using an endogenous switching regression model. That helps to estimate the actual food security effect of improved rice variety adoption by controlling the challenges of selection problem on farmers' decisions to adoption. Two main conclusions can be drawn from the results of this study on the effect of improved rice variety adoption on food security. Foremost, the adopters of improved rice varieties have different characteristics than those farmers who did not adopt. Second, the switching regression results suggest that adopters of improved rice varieties in Sierra Leone have a significantly higher likelihood of food security than the nonadopters even after controlling all confounding factors. Thus, the results from this study largely confirm the positive role of the adoption of improved rice varieties on the food security of farm households.

Concerning the determinants of improved rice varieties, the results conclude that socioeconomic factors such as income, farm size, adoption of chemical fertilizer, access to credit facilities, easy access to market information, membership of farmers' organizations, and access to the agricultural extension are identified to enhance the adoption of improved rice varieties. That signifies the need for a strategy to support and influence agricultural extension services and other rural institutions such as output–input markets and credits to promote the adoption of the existing improved rice varieties. In terms of the determinant of food security among adopters and nonadopters, the results conclude that food-secure adopters and nonadopters were significantly induced by the following factors: gender, education, income, rental land, and farm size.

This study draws the following implications. Foremost, it is identified that food security and the influence of the adoption of improved rice variety induce

food production. Therefore, the study recommends intensification of policies that promote improved rice variety, if more food production and food security are to be realized. The government through its agricultural extension services should continue the lead in rice variety promotion and dissemination and in enhancing an enabling environment for the effective adoption of farmers. Better sensitization about the potential of improved rice varieties coupled with the availability of improved seeds at affordable prices provides the most promising policy mix to speed up adoption. Also, given the preponderance of the evidence that emerges from recent studies about the different factors of food availability and the importance of rice as a significant source of food in Sierra Leone, the effect of socio-economic issues on farm-level food security needs to be taken into account. Appropriate policies that seek to enhance effective and secure access to farmland, more formal education, and income generation for farmers would enhance household food security.

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