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The impact of improved rice (*Oryza sativa* L.) varieties adoption on household food security in North-Western Ethiopia

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ABSTRACT

Improving agricultural productivity through the adoption of improved crop varieties is a key strategy for enhancing household food security in developing countries. This study evaluated the impact of adopting improved rice varieties on household food security in Pawe District, north-western Ethiopia. A cross-sectional survey was conducted using data collected from 374 farm households, comprising 187 adopters and 187 non-adopters of improved rice varieties. An Endogenous Switching Regression model was employed to account for both observable and unobservable selection biases associated with farmers' adoption decisions. The results revealed that farmers' education level, access to extension services, participation in training, proximity to extension centers, and market accessibility significantly influenced the likelihood of adopting improved rice varieties. The ESRM estimates further demonstrated that adoption had a positive and statistically significant effect on household food security, measured by food consumption expenditure per adult equivalent. The estimated Average Treatment Effect on the Treated (ATT) indicated that adopters achieved approximately 13% higher food consumption expenditure compared with the counterfactual outcome of non-adoption. Similarly, the Average Treatment Effect on the Untreated (ATU) showed that non-adopters could increase their food consumption expenditure by about 65% if they adopted improved rice varieties. The findings highlight the importance of strengthening agricultural extension systems, expanding farmer training programs, improving market access, and promoting the wider dissemination of improved rice technologies. The study concludes that the adoption of improved rice varieties plays a significant role in improving household food security and enhancing rural livelihoods in north-western Ethiopia.

KEY WORDS: *Adoption*; *Food security*; *Impact*; *Rice varieties*; *Pawe*

1. Introduction

Agricultural technology adoption is a key pathway for improving productivity, enhancing rural livelihoods, and strengthening household food security, particularly among smallholder farmers (Brenya *et al.*, 2023). Improved agricultural technologies, including improved crop varieties, enable farmers to overcome production constraints, increase yields, enhance income, and improve welfare outcomes (Hailu *et al.*, 2021; Kassie *et al.*, 2015). However, the benefits of these technologies depend on farmers' adoption decisions, which are shaped by socioeconomic characteristics, institutional support, market

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access, and perceived economic returns (Abate *et al.*, 2021)

Rice **(***Oryza sativa* L**.)** is one of the world's most important staple crops and contributes substantially to food security, employment, and rural income generation (FAO, 2024). The crop is produced under diverse agroecological systems, including upland, rain-fed lowland, and irrigated environments (FAO, 2023). In Sub-Saharan Africa (SSA), increasing population growth, urbanization, and changing consumption patterns have accelerated rice demand, while domestic production remains insufficient, creating a need for productivity-enhancing technologies (Seck *et al.*, 2023; Shen *et al.*, 2024; USDA, 2026)

Ethiopia has considerable potential for rice production due to its favorable agroecological conditions and availability of suitable land resources (FAO, 2023; MoA, 2022). The country has an estimated 39.35 million hectares suitable for rice cultivation, and rice production has expanded into major producing regions, including Amhara, Benishangul Gumuz, Oromia, Gambella, and Somali (MoA, 2020).

Rice has become increasingly important as a source of food, income, employment, and livelihood improvement among smallholder farmers (EIAR, 2019). Recent evidence shows that rice area coverage increased from 48,418 hectares in 2017 to 85,289 hectares in 2021, accompanied by a rise in production from 1.36 million to 2.68 million quintals (CSA, 2021).

The expansion of rice production in Ethiopia has been supported by the development and dissemination of improved rice varieties by research institutions (MoA, 2022; Misganaw, 2023). Several improved varieties have been released to increase productivity and enhance farmers' livelihoods (Abebaw *et al.*, 2022; Assaye, 2023). However, adoption of improved rice varieties remains constrained in many rice-producing areas due to limited access to quality seed, financial constraints, weak extension services, and market challenges (Welay, 2025).

The northwestern lowlands of Ethiopia, particularly the Benishangul Gumuz Region, are among the major rice-producing areas due to their suitability for rain-fed rice cultivation (Andargie *et al.*, 2024). In Pawe district, rice production was introduced following the establishment of the Pawe Agricultural Research Center (PARC) and has become an important crop for household consumption and income generation (Kebebew *et al.*, 2011).

PARC and other research institutions have promoted improved upland rice varieties, including Pawe-1, NERICA-3, and NERICA-4, which have shown higher yield potential compared with local varieties (PARC, 2021).

Despite the increasing importance of rice production in Pawe district, empirical evidence on the food security impacts of improved rice variety adoption remains limited. Existing studies have largely focused on production performance, varietal development, and adoption determinants, with limited attention to whether adoption improves household food security outcomes.

Therefore, this study aimed to assess the impact of improved rice variety adoption on household food security, measured through food and total consumption expenditures in Northwestern Ethiopia.

2. Material and Methods

2.1 Description of the study area

The study was conducted in Pawe District, Metekel zone of the Benishangul Gumuz Regional State, North-Western Ethiopia. The district is located approximately 575 km northwest of Addis Ababa, at about 11°09′ N latitude and 36°03′ E longitude, with an average altitude of around 1,120 meters above sea level (CSA 2021; BGRDRM, 2022). The district is predominantly characterized by lowland (Kolla) agroecological zone, which provides favourable conditions for rice production due to relatively high temperatures and adequate rainfall. The area receives an average annual rainfall of about 1,582 mm, with a mean annual temperature of approximately 32.7 °C, creating suitable environmental conditions for crop production, particularly rice cultivation (PARC, 2021; BGRDRM, 2022).

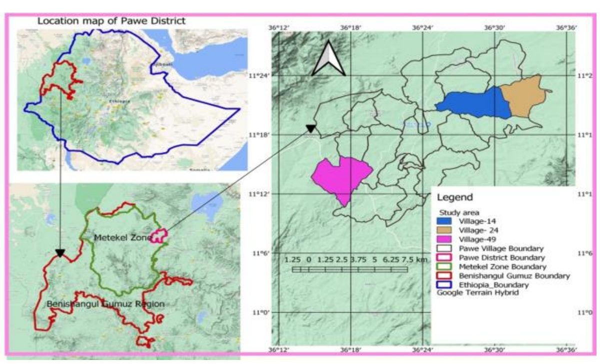

Fig. 1: Map of the study area

Topographically, Pawe District is characterized mainly by gentle slopes, and a substantial proportion of its land is suitable for cultivation. Approximately 60% of the land area is suitable for agricultural production, with about 50.4% classified as arable land (BoA, 2021). Administratively, the district consists of 20 rural kebeles, where crop production is the dominant livelihood activity and rice production is widely practiced (PDAO, 2022). The farming system is mainly a mixed farming system with crops serving as the primary source of household food and income. Major crops grown in the area include cereals such as maize, sorghum, finger millet, rice, and teff, as well as pulses and oilseeds including soybean, groundnut, and sesame, which are produced for both household consumption and market purposes (CSA, 2021; PDAO, 2022).

2.2 Sampling procedures

A multistage sampling procedure was employed to select sample households for the study (**Table 1**). In the first stage, Pawe district was purposively selected due to its potential for rice production and the widespread cultivation of both local and improved rice varieties. In the second stage, three rice-producing rural kebeles were selected using a simple random sampling technique. In the final stage, households were selected using a simple random sampling technique from the data of rice-producing households obtained from the respective kebele agricultural offices. The sampling frame included both adopters and non-adopters of improved rice varieties to ensure adequate representation of treatment and comparison groups. The sample size was determined using the Yamane (1967) formula with a 5% level of precision:

$$n=\frac{N}{1+N(e^{2})} \text{ --(1)}$$

Where: n = required sample size, N = total number of rice-producing households in the selected kebeles, and e = desired level of precision (0.05).

Table 1: Households and sample sizes in the study areas

Kebeles	Total HH	Sampling frame		Sample size		Total sample
		Non-adopter	Adopter	Non-adopter	Adopter	
Kebele 14	2005	1003	1002	65	65	130
Kebele 24	1856	930	926	60	60	120
Kebele 49	1944	974	970	62	62	124
Total	5804	4155	1644	187	187	374

Source: Kebele Agricultural Offices for the sampling frame

To ensure comparability between adopters and non-adopters of improved rice varieties, the sample households were further stratified into two groups: adopters and non-adopters. The sample size was equally distributed between the two groups, resulting in 187 adopters and 187 non-adopters. The distribution of sampled households across the selected kebeles is presented in **Table 1**. Thirdly, the total sample size was proportionally allocated among the selected kebeles using the Probability Proportional to Size (PPS) sampling technique based on the number of farm households in each kebele (Kish, 1965; Cochran, 1977).

$$\text{si} = \frac{Pi}{N} \times n \text{ --(2)}$$

Where: Si = Allocated sample for each stratum i (i = 1 … n), Pi = Population of stratum i (i = 1 … n) and N = Total population of the study area

2.3 Data collection methods

Both quantitative and qualitative data were collected from primary and secondary sources to generate comprehensive information for the study (**Table 2**). Primary data were gathered from sampled respondents through face-to-face interviews using a semi-structured questionnaire, while qualitative information was collected through key informant interviews guided by an open-ended checklist. Secondary data were obtained from relevant sources, including published journal articles, research proceedings, institutional reports, and documents from concerned stakeholders to complement and support the primary data.

2.4 Method of data analysis

The collected data were analyzed using various statistical techniques and an econometric model in STATA. Descriptive and inferential statistics, along with an Endogenous Switching Regression (ESR) model, were employed to analyze the data and estimate the impact of the adoption of improved rice varieties on household food security.

2.5 Descriptive and inferential analysis

Descriptive statistics, including mean, standard deviation, frequency, and percentage, were used to summarize the socioeconomic characteristics, institutional factors, and production-related attributes of sample households. Inferential statistical tests, including the independent-samples t-test and chi-square (χ^2) test, were employed to examine the statistical differences between adopters and non-adopters of improved rice varieties. The t-test was used to compare the mean values of continuous variables. At the same time, the chi-square test was applied to assess the

Table 2: Variables included in the model

Variable	Measurement	Expected sign
Age	Age of household head (years)	±
Sex	1 = Male, 0 = Female	+
Education	Years of schooling	+
Household size	Adult equivalent	+
Farm size	Hectares owned	+
Livestock holding	Tropical Livestock Unit (TLU)	+
Rice farming experience	Years	+
Credit access	1 = Yes, 0 = No	+
Extension access	1 = Yes, 0 = No	+
Training participation	1 = Yes, 0 = No	+
Distance to market	Kilometers	–
Distance to extension center	Kilometers	–
Food security	Food consumption expenditure/adult equivalent Total consumption expenditure	Dependent

association between categorical variables across the two groups.

2.6 Econometric model

Impact evaluation studies based on observational data often face challenges related to selection bias because treatment participation is not randomly assigned. Propensity Score Matching (PSM) and Endogenous Switching Regression (ESR) models are among the commonly used approaches for addressing selection bias when baseline data are unavailable (Adela *et al.*, 2018). The PSM method reduces observable selection bias by constructing a comparable counterfactual group based on the estimated probability of treatment participation (propensity score). However, PSM assumes that observed characteristics capture all relevant differences between adopter and non-adopter groups and does not account for bias arising from unobservable factors (Rosenbaum and Rubin, 1983).

In contrast, the Endogenous Switching Regression (ESR) model explicitly models the participation decision and accounts for both observable and unobservable sources of selection bias. It estimates separate outcome equations for adopter and non-adopter groups while allowing correlation between the selection equation and outcome equations (Lokshin and Sajaia, 2004). This makes ESR more appropriate when unobserved characteristics, such as managerial ability, motivation, risk preferences, farming skills, and attitudes, may influence both technology adoption decisions and household food security outcomes (Maddala, 1983).

The presence of observable selection bias implies that adopters and non-adopters may differ systematically in characteristics such as household demographics, farm size, access to extension services, institutional support, and resource endowments. These factors may independently affect the outcome variable, making simple comparisons between the two groups potentially misleading (Heckman *et al.*, 1998; Wooldridge, 2010). Similarly, unobservable factors may create endogeneity problems because they jointly influence both adoption decisions and outcome variables. Therefore, observed differences in outcomes between adopters and non-adopters cannot be attributed solely to the adoption of improved rice varieties (Imbens and Wooldridge, 2009).

Therefore, this study employed the Endogenous Switching Regression (ESR) model because it accounts for both observed and unobserved heterogeneity and provides consistent estimates of treatment effects under actual and counterfactual scenarios (Lokshin and Sajaia, 2004; Di Falco *et al.*, 2011). The ESR model involves two stages: the first stage estimates the adoption decision equation, while the second stage estimates separate outcome equations for adopters and non-adopters.

The adoption decision is based on the random utility maximization framework. A household adopts improved rice varieties if the expected utility from adoption exceeds the utility from non-adoption. The latent variable representing the difference in utility between adoption and non-adoption can be expressed as:

$$G_i^* = \beta X_i + u_i \; with \; G_i = \begin{cases} 1, & if \; G_i^* > 0 \\ 0, & if \; G_i^* \leq 0 \end{cases} \text{------(3)}$$

Where: G is the dichotomous variable that takes the value 1 if the farmer is an adopter and 0 otherwise; β is the vector of unknown parameters to be estimated, and X is the vector of explanatory variables; and u is the random error term with mean 0 and variance as σ^2. The maximum likelihood estimation is employed to estimate the vector of probit coefficients β.

Under the Endogenous Switching Regression (ESR) framework, the impact of adoption in improved rice varieties was estimated in two stages: the first stage concerns the decision to adopt improved rice varieties (equation 1), and the second stage consists in the estimation of two regimes outcomes equations: one for improved rice varieties adopters and another one for non-adopters (Maddala, 1983) represented as follows in equations 4 and 5:

$$Regime\ 1: Y_{1i} = \beta_1 X_i + \varepsilon_i \; if \; P_i = 1 \; (Adopters) \text{-------(4)}$$

$$Regime\ 2: Y_{2i} = \beta_2 X_i + \varepsilon_i \; if \; P_i = 0 \; (non\ adopters) \text{--(5)}$$

Where: Y_1 and Y_2 represent the outcome variables respectively for adopters (regime 4) and non-adopters (regime 5); X_i represents the vector of covariates of farmer i; β_1 and β_2 are parameters to be estimated; and ε_{1i} and ε_{2i} are errors associated with the outcome variables.

The error terms in the selection equation (3) and the outcome equations (4) and (5) are assumed to have a trivariate normal distribution with mean zero and covariance matrix (Ω) as follows:

$$\Omega = \begin{pmatrix} \sigma_{\varepsilon 1}^2 & \sigma_{\varepsilon 1 \varepsilon 0} & \sigma_{\varepsilon 1 u} \\ \sigma_{\varepsilon 1 \varepsilon 0} & \sigma_{\varepsilon 0}^2 & \sigma_{\varepsilon 0 u} \\ \sigma_{\varepsilon 1 u} & \sigma_{\varepsilon 0 u} & \sigma_u^2 \end{pmatrix} \text{-------------------(6)}$$

Where: $\sigma_u^2 = var\,(u_1)$, $\sigma_1^2 = var\,(\varepsilon_1)$, $\sigma_2^2 = var\,(\varepsilon_2)$, $\sigma_{1\mu}^2 = cov\,(u_i, \varepsilon_1)$, $\sigma_{2\mu}^2 = cov\,(u_i, \varepsilon_2)$

Furthermore, σ_u^2 is estimable up to a scale factor and can be assumed to be equal to 1 (Maddala, 1983) and $cov\,(u_i, \varepsilon_1)$ is not defined as Y_1 and Y_2 cannot be observed simultaneously. Moreover, the correlation between the error term of the selection equation and the outcome equation is not zero

($i.e., \ corr\ (u_i,\ \varepsilon_1) \neq 0\ and\ corr\ (u_i,\ \varepsilon_2) \neq 0$) which creates selection bias. ESR addresses this selection bias by estimating the inverse Mills ratios (λ_{1i} and λ_{2i}) the covariance terms ($\sigma_{1\mu}$ and $\sigma_{2\mu}$) and including them as auxiliary regressors in equations (4) and (5). If $\sigma_{1\mu}$ and $\sigma_{2\mu}$ are significant, we reject the absence of selection bias. In addition, $\sigma_{1\mu} < 0$ represents positive selection bias (i.e., households with above-average outcomes are more likely to choose to be in the treatment). The ESR model estimates can then be used to estimate ATT and ATU (Average treatment effect on untreated households) (Maddala, 1983; Wossen *et al.*, 2017) as follows:

$$E(Y_{1i}|T_i = 1)\gamma_1 X_{1i} + \lambda_{1i}\sigma_{1\mu} \quad \text{------------------(7)}$$

$$E(Y_{2i}|T_i = 0)\gamma_2 X_{2i} + \lambda_{2i}\sigma_{2\mu} \quad \text{-------------------(8)}$$

$$E(Y_{2i}|T_i = 1)\gamma_2 X_{1i} + \lambda_{1i}\sigma_{2\mu} \quad \text{-------------------(9)}$$

$$E(Y_{1i}|T_i = 0)\gamma_1 X_{2i} + \lambda_{2i}\sigma_{1\mu} \quad \text{-----------------(10)}$$

The ATT is then defined as the difference between equation (5) and equation (9)

$$\text{ATT} = E(Y_{2i}|T_i = 1) - E(Y_{2i}|T_i = 1) = X_{1i}(\gamma_1 - \gamma_2) + X_{1i}(\sigma_{1\mu} - \sigma_{2\mu}) \quad \text{----------------(11)}$$

2.7 Measurement of household food security

Household food security status was measured using annual food consumption expenditure per adult equivalent (FAE) and total consumption expenditure (TCE). These indicators are widely used in welfare and food security studies because they better reflect households' actual food access through consumption behavior and purchasing power, unlike production-based measures that may overlook market purchases and intra-household allocation (Deaton and Zaidi, 2002; World Bank Group, 2022; FAO, 2023). Food consumption expenditure was converted into adult equivalent units to adjust for differences in household size and demographic composition, ensuring comparability of welfare status across households (Deaton and Zaidi, 2002).

3. Results and Discussion

3.1 Descriptive characteristics of sample households

The table presents a chi-square test comparison of categorical characteristics between adopters and non-adopters of improved rice varieties. **Table 3** indicates that extension access and training participation show statistically significant differences. Households with access to extension services are significantly more likely to adopt improved rice varieties ($\chi^2 = 10.1$, $p < 0.01$), indicating that extension contact plays a crucial role in promoting technology adoption. Similarly, training participation is significantly associated with adoption status ($\chi^2 = 5.53$, $p < 0.05$), implying that capacity-building interventions enhance farmers' likelihood of adopting improved rice technologies.

The independent sample t-test results (**Table 3**) indicate both statistically significant and non-significant differences between adopters and non-adopters of improved rice varieties across selected continuous variables. The findings show that education level, proximity to extension services, household size, and market distance are the key variables that significantly differentiate adopters from non-adopters.

Specifically, adopters have significantly higher educational attainment than non-adopters ($t = -2.39$, $p < 0.05$), suggesting that more educated

Table 3: Distribution of sample households by categorical variables

Variable	Category	Adopters		Non-adopters		Total		χ^2
		Freq.	%	Freq.	%	Freq.	%	
Sex	Male	167	44.65	166	44.39	333	89.04	0.02
	Female	20	5.35)	21	5.61	41	10.96	
Off-farm participation	Yes	67	17.91	76	20.32	143	38.24	0.917
	No	120	32.09	111	29.68	231	61.76	
Credit access	Yes	68	18.18	68	18.18	136	36.36	0.00
	No	119	31.82	119	31.82	238	63.64	
Extension access	Yes	130	34.76	100	26.74	230	61.50	10.1***
	No	57	15.24	87	23.26	144	38.50	
Training	Yes	68	18.18	47	12.57	115	30.75	5.53**
	No	119	31.82	140	37.43	259	69.25	
Cooperative membership	Yes	91	24.33	83	22.19	174	46.52	0.68
	No	96	25.67	104	27.81	200	53.48	
Soil fertility	Fertile	106	28.34	94	25.13	200	53.48	1.54
	Infertile	81	21.66	93	24.8	174	46.52	

farmers are better able to access, interpret, and apply agricultural information, thereby increasing their likelihood of adopting improved rice varieties. Similarly, adopters are located significantly closer to extension services ($t = 4.203$, $p < 0.01$), highlighting the critical role of extension proximity in facilitating awareness, training, and adoption of improved technologies. Market distance is also significantly different between the two groups ($t = 2.82$, $p < 0.01$), indicating that households closer to markets are more likely to adopt improved rice varieties, likely due to better input access and stronger market incentives.

3.2 Impact of improved rice variety adoption on household food security

Selection equation (Improved rice variety adoption)

The ESR selection equation results presented in **Table 4** indicate that the decision to adopt improved rice varieties was significantly influenced by household, farm, and institutional factors. The significance of the selection equation confirms the presence of systematic differences between adopters and non-adopters, indicating non-random adoption decisions and justifying the application of the ESR model. Household size and access to extension services positively and significantly influenced improved rice variety adoption at the 1% significance level. Cooperative membership and soil fertility status also had positive effects on adoption decisions at the 10% significance level. In contrast, rice farming experience negatively influenced adoption at the 10% significance level.

Outcome equations: Food security among Adopters and Non-Adopters

The ESR model result in **Table 4** is statistically significant (Wald $\chi^2 = 59.40$, $p < 0.01$), indicating that the explanatory variables jointly explain

Table 4: Mean comparison of continuous variables

Variable	Adopters		Non-adopters		Total	t-value
	Mean	SD	Mean	SD		
Age	42.160	7.020	42.560	8.620	42.36	0.499
Education	1.600	1.650	1.190	1.670	1.40	-2.39**
Land size	2.727	0.689	2.720	0.703	2.723	-0.104
Livestock	4.310	0.130	4.580	0.127	4.45	1.477
Rice experience	5.210	3.028	5.220	2.234	5.22	0.038
Proximity to extension	1.710	0.738	2.410	2.180	2.06	4.203***
Household size	2.260	0.795	2.050	0.735	2.16	-2.57**
Proximity to the cooperative	1.380	1.038	1.530	0.923	1.46	1.46
Market distance	27.960	7.593	30.110	7.098	29.03	2.82***
Milling distance	1.700	1.270	1.920	1.890	1.81	1.33

variations in household food consumption expenditure per adult equivalent. The significant correlation coefficients ($\rho_1 = 0.972$ and $\rho_2 = 0.149$) confirm the presence of selection bias due to unobserved heterogeneity, validating the use of the ESR approach. Among adopters, education, cultivated land size, and household size significantly increased food consumption expenditure. Among non-adopters, household head age had a negative effect, while household size had a positive and significant influence on food consumption expenditure.

Correlation effects and ESR treatment effects

The significant rho parameters indicate that adoption decisions are influenced by unobserved characteristics that are also associated with food security outcomes. The positive and significant ρ_1 and ρ_2 values confirm the existence of selection effects, demonstrating that conventional regression approaches may produce biased estimates.

The treatment effect results **Table 4** show that improved rice variety adoption significantly increased household food consumption expenditure. The Average Treatment Effect on the Treated (ATT) was positive, indicating that adopters achieved higher food security compared with the counterfactual case of non-adoption. Similarly, the Average Treatment Effect on the Untreated (ATU) revealed that non-adopters could obtain substantial food security improvements if they adopted improved rice varieties.

Treatment effects of improved rice variety adoption on household consumption expenditure

The ESR-based treatment effect results (**Table 5**) indicate that improved rice variety adoption has a statistically significant positive effect on both food consumption expenditure (FCE) and total consumption expenditure (TCE). For FCE, the Average Treatment Effect on the Treated (ATT) shows that adopters achieved an expected value of 9.17 compared with 9.04 under the counterfactual non-adoption scenario, yielding a significant gain of 0.13. The Average Treatment Effect on the Untreated (ATU) further indicates that non-adopters would increase their FCE from 8.48 to 9.13 if they adopted improved rice varieties, with a gain of 0.65.

Table 4: ESRM estimates of adoption of improved rice varieties and rice yield outcomes

Variables	FCE			FCE		
	Selection equation	Adopters	Non-adaptors	Selection equation	Adopters	Non-adaptors
	(Coef., S.E.)	(Coef., S.E.)	(Coef., S.E.)	(Coef., S.E.)	(Coef., S.E.)	(Coef., S.E.)
Age	.001 (.009)	-.005(.004)	-.005**(.003)	.003(.009)	-.007*(.003)	-.006**(0.002)
Sex	.205(.211)	-.002(.087)	-.143*(.074)	.187(.210)	-.011(.081)	-0.134 *(.072)
Land size	-.093(.107)	.102**(.044)	.007(.037)	-.060(.113)	.089**(.042)	.013(.035)
Education	.044(.039)	.041**(.016)	-.012(.014)	.050(.0391)	.039**(.015)	-.016(.013)
Credit	-.008(.140)	-.089(.058)	-.016(.047)	-.026(.139)	-.069(.054)	.016(.045)
Off-farm	-.103(.136	-.006(.058)	.036(.049)	- .111(.138)	-.016(.056)	.042(.048)
Cooperative	.219*(.130)	.081(.054)	-.069(.047)	.159(.129)	.106**(.050)	-.075*(.044)
Market distance	-.029***(.009)	-.004(.003)	-.002(.004)	-.029 ***(.009)	-.005(.003)	-.000(.004)
Cooperative distance	-.104(.067)	-.006(.029)	-.008(.024)	-.119*(.067)	-.0124(.027)	-.010(.024)
Milling distance	-.53(.042)	-.002(.021)	.016(.013)	-.057(.042)	.008(.019)	-.015(.012)
Rice farming experience	-.030(.026)	-.020*(.010)	-.049***(.010)	-.026(.027)	-.016*(.009)	-.050***(.010)
Household size	.367***(.093)	.175***(.038)	.169 ***(.044)	.334***(.091)	.181***(.035)	.1595***(.044)
Livestock	-.022(.037)	.011(.015)	.003(.013)	-.031(.037)	.017(.014)	.001(.012)
Extension access	.376***(.098)			.362***(.097)		
Training	.127(.102)			.129(.129)		
Soil fertility	.159*(0.089)			.140(.114)		
Constant	-.159(0.737)	8.55 ***(.224)	9.42***(.240)	.101(.532)	8.89 ***(.209)	9.615***(.246)
rho_1 (ρ_1)	.972(0.021)			.969(.374)		
rho_2 (ρ_2)	.149*(0.445)			-.009 ***(.559)		
Observation			374			374
Wald chi^2(12)			59.40			68.6
Prob > chi^2			.0000			.0000

Note: Coef. = Coefficient; S.E. = standard error. *, **, *** denote significance at 10%, 5%, and 1%, respectively.

Table 5: Average treatment effects of improved rice variety adoption on household food and total consumption expenditure

Outcome variables	HH type	Decision stage			
		Adopters	Not-adopters	ATE (%)	Treatment effect
Food Consumption Expenditure (FCE)	(ATT)	9.170	9.040	0.130	0.130***
	(ATU)	9.130	8.480	0.650	0.650***
Total Consumption Expenditure (TCE)	(ATT)	9.430	9.310	0.120	0.120***
	(ATU)	9.330	8.780	0.550	0.550***
Heterogeneous effects	FCE	BH1=0.040	BH2=0.560	TH=0.780	
	TCE	BH1 =0.650	BH2 = -0.020	TH = 0.670	

Source: Own survey result (2021)

Similarly, for TCE, adopters recorded an expected value of 9.43 compared with 9.31 under non-adoption, resulting in a gain of 0.12 (ATT). Non-adopters could increase their TCE from 8.78 to 9.33 if they adopted, yielding a gain of 0.55 (ATU). The results also reveal heterogeneous effects, where the transitional heterogeneity (TH) is positive for both FCE (0.78) and TCE (0.67), indicating larger expected gains for non-adopters relative to adopters under potential adoption scenarios.

3.3 Robustness and Heterogeneity analysis

To examine the reliability and consistency of the estimated treatment effects, robustness checks were performed using alternative model specifications, including different sets of explanatory variables, alternative outcome specifications, and sensitivity analysis under varying assumptions. The results in **Table 6** remained qualitatively consistent across all specifications, with the estimated treatment effects maintaining their positive signs and statistical significance. The magnitude of ATT and ATU estimates varied only slightly, indicating that the observed welfare effects of improved rice variety adoption are stable and not driven by a particular model specification.

Table 6: Robustness and heterogeneity analysis result

Model Specification	ATT (%)	ATU (%)	Significance
Baseline ESR Model	13.2	65.4	***
Alternative Covariates	12.8	63.7	***
Log-transformed Outcome	14.1	66.2	***
Restricted Sample	12.5	61.8	**
Mean Effect	13.15	64.28	—

Note: **, *** indicated that 5% and 1% significance level respectively

The heterogeneity analysis further revealed positive transitional heterogeneity effects, suggesting that households that adopted improved rice varieties obtained greater welfare benefits under adoption than they would have experienced under the non-adoption scenario. This implies that adopters were able to effectively utilize the technology due to differences in access to resources, knowledge, extension services, and other household-specific characteristics. Overall, the robustness and heterogeneity results strengthen the evidence that improved rice variety adoption contributes significantly to enhancing household food consumption and overall welfare outcomes.

4. Conclusion

This study assessed the impact of improved rice variety adoption on household food security using the Endogenous Switching Regression (ESR) model. The findings confirm that adoption decisions are non-random and significantly influenced by household, institutional, and farm-level factors, justifying the use of the ESR approach to address selection bias.

Empirical results show that improved rice variety adoption has a significant and positive effect on both food consumption expenditure and total consumption expenditure per adult equivalent. Adopters consistently achieved higher welfare outcomes compared with their counterfactual non-adoption scenario, while non-adopters also exhibited substantial potential gains under adoption. The larger ATU values indicate considerable untapped welfare potential among non-adopting households. The estimated treatment effects showed that adopter households achieved approximately 13 percent higher food consumption expenditure than they would have attained without adoption. Similarly, non-adopting households could potentially increase their food consumption expenditure by approximately 65 percent if they adopted improved rice varieties. The results further reveal heterogeneous impacts of adoption, suggesting that the benefits of improved rice technologies vary depending on access to extension services, education, and resource endowments. Overall, the study concludes that improved rice variety adoption plays a crucial role in enhancing household food security and welfare in the study area.

In terms of policy implications, the results suggest that improving agricultural extension services, strengthening farmer training and education, ensuring timely access to quality seed and complementary inputs, enhancing rural market access, and supporting farmer cooperatives are essential strategies for increasing adoption and maximizing welfare gains from improved rice technologies.

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