REGULAR ARTICLE

FARM TECHNOLOGY ADOPTION BY SMALLHOLDER FARMERS IN GHANA

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ABSTRACT

Technology adoption by smallholder farmers is a key strategy to improve agricultural sustainability and productivity in developing countries. This study therefore investigated the factors influencing adoption of agricultural mechanisation and improved varieties by rice farmers in northern Ghana. A bivariate probit model was used to analyse the determinants of farmers' joint adoption decisions. The results indicated that the age and gender of the household head, the degree of specialisation in production, household size, and location of the farm were significantly associated with farmers' joint adoption decision. Furthermore, farm size, extension visits, herd ownership and the production system were significant factors in farm mechanisation adoption but not the adoption of improved rice varieties. The study concludes that several individual and household characteristics interplay to influence smallholders' joint adoption decisions. Hence, efforts to improve rice production in Ghana and other developing countries with similar characteristics should take into account these factors when disseminating innovations to smallholders.

Keywords: Joint-adoption, bivariate probit model, mechanisation, high-yielding varieties, northern Ghana
JEL Codes: C21, D24, Q12

INTRODUCTION

The modernisation of agriculture has been recognized as one of the ways to accelerate Ghana's medium-term economic development plan. Ghana's medium term economic plan is enshrined in the Growth and Poverty Reduction Strategy (GPRS II) which spells out the role of the agricultural sector in spearheading the country's economic growth and structural transformation (**GoG, 2006**; **GoG, 2010**). Consequently, the provision of adequate irrigation infrastructure, improving access to farm machinery as well as the dissemination of improved planting materials to farmers have been identified as key factors to enhance agricultural production, thereby accelerating economic development.

The Government of Ghana (GoG) in an effort to address the low productivity of agriculture and accelerate economic development has initiated steps to fund agricultural mechanisation under the Agricultural Sub Sector Improvement Programme (AgSSIP), and the Food and Agriculture Sector Development Programme (FASDEP) (**MoFA, 2010**). It is a key objective of Ghana's Medium-Term Agricultural Sector Investment Plan (METASIP) to increase rice farmers' access to farm machinery by assisting the private sector to establish Agricultural Mechanisation Services Enterprise Centres across the country. The drive to increase farm machinery use in Ghana is in line with numerous studies indicating that low level of mechanisation rather than technical inefficiency is the cause of low agricultural productivity in Sub-Saharan Africa (**Binswanger, 1978; Clarke, 2000; FAO-UNIDO, 2008; Sims and Kienzle, 2006**).

Agricultural mechanisation entails the use of draft power, tractor, or other forms of farm power to undertake agricultural production. The use of farm machinery can reduce labour drudgery, enhance timeliness in carrying out farm operations, and facilitate farm production and productivity (**Binswanger and Ruttan, 1978; Obi and Chisango, 2011**). A study by **Houssou and Chapoto (2015)** identified a positive correlation between farm mechanisation and cropland expansion among Ghanaian farmers. The authors however did not find any evidence of mechanisation increasing input use by the respondents. As noted by **Clark (2000)**, increased farm power can directly enhance production through increasing the area under cultivation, allowing farmers to cultivate more area than if they were to employ manual methods in production.

Indications are that policy reforms on mechanisation have not achieved the desired results because of fiscal burden of government-supported programs and weak demand from producers (**Diao et al., 2014; Food and Agriculture Organisation, 2000; Mrema et al., 2008; Obi and Chisango, 2011; Pingali et al., 1987; Sims and Kienzle, 2016**). Despite the aforementioned challenges, **Diao et al. (2014)** observed an increase in the demand for agricultural mechanisation in Ghana in recent times.

Productivity growth in agriculture is the result of several factors including the adoption of multiple technologies that complement each other. Consequently, there is considerable interest in irrigation technology, farm mechanisation, adoption of improved varieties and inorganic fertilizers by policy-makers and researchers in developing countries. This study does not examine all these productivity-enhancing technologies but focuses on only the adoption of farm mechanisation and improved varieties.

Adoption of improved crop varieties is regarded as a key strategy to enhance agricultural productivity and accelerate economic development in Ghana. Making improved planting materials available to farmers remains one of the key objectives of the Agricultural Sub-Sector Improvement Programme (AgSSIP), and the Food and Agriculture Sector Development Programme (FASDEP) (**MoFA, 2010**). Despite efforts by research institutions and scientists to develop and disseminate improved crop varieties to farmers, available evidence indicate low level of adoption by producers in many developing countries (**Afolami et al., 2015; Simtowe et al., 2006**). Reasons for the non-adoption of improved varieties vary: high cost of adoption, lack of access to improved varieties, conservatism, lack of knowledge of existing technologies, among other factors. The cost of adoption, however, remains an important factor especially among peasant farmers who are poor and risk-averse. Farmers are also sometimes conservative and often drag their feet when it comes to choosing a new variety which they are not accustomed to. A weak agricultural extension service, lack of information about existing improved varieties and high level of illiteracy among smallholder farmers are possible factors that may hinder adoption of improved crop varieties.

The agricultural and development economic literature contains numerous studies on adoption of improved (high-yielding) crop varieties (e.g. **Dontsop-Nguezet et al,. 2016; Huang et al., 2015; Khonje et al., 2015**) and farm mechanisation (e.g. **Houssou and Chapoto, 2015; Kuworni et al., 2017**). Majority of the previous studies focused on identifying the factors affecting technology adoption (e.g. **Abdoulaye et al., 2014; Adesina and Baidu-Forson, 1995; Houssou and Chapoto, 2015; Sodjinou et al., 2015**) while others examined the effect of adoption on efficiency and productivity (e.g. **Adofu et al., 2013; Asante et al., 2014; Hossain et al., 2006; Nandal and Rai, 1986**), food security (e.g. **Nata et al., 2014**) or household welfare (e.g. **Afolami et al., 2015; Amao and Awoyemi, 2008; Asfaw 2010; Awotide et al., 2012**). **Kijima et al. (2008)** and **Dontsop-Nguezet et al. (2011)** investigated the impact of NERICA adoption on income and poverty in Uganda and Nigeria, respectively. However, empirical study on the joint decision to adopt improved varieties and farm mechanisation is hard to find.

Most studies on farmers' joint adoption decisions have focused on the adoption of improved crop varieties and inorganic fertiliser (e.g. **Kabila et al., 2000; Shakya and Flinn 1985; Ogada et al., 2014; Ouma et al., 2002**). This is because the adoption of improved varieties and inorganic fertiliser is seen as a joint decision based on the complementary roles of the two. In this study, a similar assumption is made: adoption of improved varieties and farm mechanisation are complementary activities that enable smallholder farmers to increase their farm productivity. The study makes the assumption that farmers can increase their yields or enhance the productivity of seed by the application of mechanized equipment in production that saves time and ensures higher efficient of farm operation. **Nandal and Rai (1986)** hypothesized that higher mechanisation intensity index positively correlates with output and productivity of paddy rice. Mechanisation of farm operations also reduces drudgery and enables more work to be done in a shorter time resulting in greater farm efficiency.

A clear understanding of the factors that affect the joint decision to adopt improved varieties and agricultural mechanisation is therefore important to help increase the yield of smallholder farmers. This paper therefore seeks to empirically investigate the factors that influence the choice of Ghanaian smallholder rice producers to jointly adopt agricultural mechanisation and modern varieties. The rest of the paper is structured as follows: section 2 covers the materials and methods, including the specification of the bivariate probit model, sampling and data description. Section 3 covers the results and discussion of the main findings while section 4 covers the conclusion and policy recommendations.

METHODS AND DATA

Model specification: The bivariate probit model

Farmers face myriad of choices with regard to production, many of which are interrelated. For example, a farmer may be faced with the choice of whether to adopt improved varieties and whether to use farm mechanisation in production. The two choices represent a decision to adopt improved production practices which are expected to enhance farm output.

The bivariate model is often used to estimate choices or decisions that are interrelated as opposed to choices that are independent. For rural farm households, the choice to simultaneously adopt HYV and farm mechanisation is considered to be interrelated, hence the application of a bivariate probit model to analyse the joint decision. The bivariate probit model can be regarded as a model for estimating joint binary outcomes. The binary outcomes may be correlated, having a correlation of ρ. When the correlation between the two outcomes is significant, it justifies the use of a bivariate probit (or logit) model to estimate jointly the two decisions. In other words, an insignificant correlation coefficient for the two binary choices is indication that the two probit models can be estimated separately. The bivariate probit model is a simultaneous equations model that controls for the endogeneity of two related choices (**Ashford and Snowden, 1970**).

The bivariate probit model may be expressed as a continuous latent variable measuring propensity, utility or preferences. For example, let Y_1^* represent farmers' preference for improved or traditional rice varieties, and Y_2^* represent farmers' preference for mechanisation or non-mechanisation (the use of manual labour). For both choices, what is observed is the individual's varietal choice, given by Y_1 and mechanisation adoption status Y_2. The unobserved latent variables may be represented as in Eq. 1 and Eq. 2.

$$Y_1^* = x_1\beta + e_1 \qquad (1)$$

$$Y_2^* = x_2\beta + e_2 \qquad (2)$$

The latent variables Y_1^* and Y_2^* are related to the

observed choices (or varietal choice and mechanisation dummies) Y_1 and Y_2 as shown in Equations (3) and (4)

$$Y_1 = \begin{cases} 1 & if \ Y_1^* > 0 \\ 0 & otherwise \end{cases} \qquad (3)$$

$$Y_2 = \begin{cases} 1 & if \ Y_2^* > 0 \\ 0 & otherwise \end{cases} \qquad (4)$$

The model is just identified when we have the same vector of covariates in each equation (**Greene, 1995:458**). The error terms, e_1 and e_2 are dependent and normally distributed such that Eq. 5.

$$E[e_1] = E[e_2] = 0, \ var[e_1] = var[e_2] = 1 \ and \ cov[e_1, e_2] = \rho \qquad (5)$$

There is no endogeneity bias if a Wald test proves that ρ is not significant. In this case, the two models can be estimated separately. However, the significance of ρ indicates that the two models are interrelated and that the two equations can be jointly estimated to yield unbiased estimates. The log-likelihood for the bivariate probit model is given by Eq. 6.

$$L = \prod_{y_1=0} \Phi(-x_{y_1}\beta_{y_1=1,y_2=1})\Phi_2(x_{y_1}\beta_{y_1}, x_{y_2}\beta_{y_2}, \rho)$$
$$\prod_{y_1=1,y_2=0} \Phi_2(x_{y_1}\beta_{y_1}, -x_{y_2}\beta_{y_2}, -\rho) \qquad (6)$$

Where: Φ is the standard univariate normal cumulative distribution and Φ_2 is the standard bivariate normal cumulative distribution with correlation ρ. Equations (1) and (2) are simultaneously estimated using maximum likelihood yielding unbiased parameter estimates for β and ρ.

The empirical model is presented as Eq/7).

$$Adoption = \beta_0 + \beta_1 age + \beta_2 sex + \beta_3 educ + \beta_4 householdsize + \beta_5 specialization + \beta_6 farmsize + \beta_7 extension + \beta_8 region + \beta_9 herd + \beta_{10} irrigation + u_i \qquad (7)$$

The variables and their descriptive statistics are presented in Table 1.

Sampling and data description

The study relied on data from a cross-section of 300 rice farmers sampled across northern Ghana using multistage stratified random sampling. Northern Ghana comprises Northern, Upper East and Upper West regions. Rice farmers were selected from Bolgatanga district and Bongo district, both in the two districts in the Upper East Region, and Tolon-Kumbungu district in the Northern region. The Upper West Region was excluded because not many farmers there engage in rice production. Information on rice production, access to production inputs, adoption decisions, input and output quantities and prices and socioeconomic and demographic characteristics of the households were collected. Stata version 14 was used in the data analysis.

RESULTS AND DISCUSSION

Descriptive characteristics of the respondents

Table 1 presents the descriptive characteristics of the respondents in the study.

The respondents had an average age of 41 years and 4 years of formal education. This shows that the respondents have low educational attainment. Average household size in the sample is 10 and farmers had on average 3 extensions contacts during the cropping season. Sixty-five (65) percent of the respondents used mechanisation in farming compared to 67% who planted improved rice varieties. Adoption of farm mechanisation was measured as use of mechanized (tractor) services in land preparation during the production process. High-yielding varieties included improved rice varieties introduced to farmers by research institutions such as the Crops Research Institute (CRI) and Savanna Agricultural Research Institute (SARI). The improved varieties include Jasmine 85, Togo Marshal and Rita 9, while the local varieties include Local red and Local white. The improved varieties are high yielding, early maturing and disease resistant. Majority (78%) of the respondents were males which is an indication that rice production is a male-dominated activity among the respondents. Average farm size was 0.86 hectares which indicates that the respondents are small-scale rice farmers. On average, 52% of total household land was allocated to rice production. This figure provides a measure of the degree of specialisation in rice production. About 34% of the respondents owned cattle while majority (67%) come from the Upper East Region. The distribution of irrigators and rain-fed rice farmers was equal for the sample.

Descriptive statistics of bivariate probit analysis variables

The summary statistics of the respondents according to their adoption status are presented in Table 2. The two groups are quite similar in some of their characteristics such as age, gender, household size, degree of specialisation in rice production, and number of extension contacts, but differ in other characteristics.

The mean farm size of adopters of mechanisation was higher than that of adopters of improved rice varieties while the proportion of adopters of HYV who had cattle was higher than their mechanisation counterparts. The result is quite consistent with a priori expectation because households with cattle are more likely to use animal power in farming in lieu of tractor services. Furthermore, households with larger farm lands are expected to use tractor services due to the enormous amount of work required to till large areas of land for cultivation. In the absence of adequate household labour, tractor services may become a more likely option for cultivating larger plots of land. Furthermore, 54% of HYV adopters used irrigation in farming compared to 51% for adopters of mechanisation. In terms of the regional distribution of the respondents, 44% of households who adopted mechanisation were located in the Northern Region while 38% of households who adopted improved rice varieties were found in the Northern Region. Adopters of HYV had

an average of 4 years of formal education compared to 3.6 years for users of mechanisation.

Determinants of agricultural mechanisation and modern variety adoption decisions

The bivariate probit regression estimates of smallholders' joint adoption decisions are presented in Table 3. The estimation of a bivariate probit model requires that the two adoption equations are correlated. The validity of the estimation was verified by testing the hypothesis that the two adoption equations are correlated. This was done by testing the statistical significance of the ancillary parameter rho which measures the correlation of the residuals from the two adoption models. The likelihood ratio test of rho (ρ) for the two models indicated statistical significance at the 5 percent level. The significance of rho (ρ) indicates that the two equations are strongly correlated. The result therefore validates the use of the bivariate probit model to estimate the joint adoption model.

Table 1: Definition of variables and summary statistics of respondents

Variables	Definition	Mean	Min.	Max.
Mechanisation	Dummy: 1 for adopters; 0 otherwise	0.65	0	1
High-yielding variety	Dummy: 1 for adopters; 0 otherwise	0.67	0	1
Age	Age of the household head in years	41.2	19	75
Sex	Dummy: 1 for male; 0 for otherwise	0.78	0	1
Education	Years of formal education	3.93	0	20
Household size	Number of household members	9.65	1	71
Degree of specialisation	Proportion of land allocated to rice	52.1	5.7	200
Extension contacts	Number of extension contacts	3.31	0	30
Regional dummy	Dummy: 1 for Northern; 0 otherwise	0.33	0	1
Herd ownership	Dummy: 1 if herd owner; 0 otherwise	0.34	0	1
Farm size	Farm size in hectares	0.86	0.08	4.86
Access to irrigation	Dummy: 1 for irrigation; 0 otherwise	0.50	0	1

Table 2: Descriptive statistics of bivariate probit analysis variables

Variable	Adoption of improved variety				Adoption of mechanisation			
	Adopters		Non-Adopters		Adopters		Non-Adopters	
Age	42.3	(12.7)	39.0	(11.2)	42.4	(11.9)	38.9	(12.8)
Sex	0.83	(0.38)	0.69	(0.46)	0.84	(0.37)	0.69	(0.47)
Education	3.97	(5.36)	3.86	(5.35)	3.57	(5.20)	4.61	(5.58)
Household size	9.35	(6.75)	10.3	(8.03)	9.66	(7.89)	9.63	(5.75)
Degree of specialisation	55.1	(34.9)	46.2	(31.9)	55.5	(36.0)	45.8	(29.6)
Farm size	0.88	(0.66)	0.81	(0.73)	0.95	(0.74)	0.69	(0.51)
Extension contacts	3.58	(5.95)	2.76	(3.20)	3.59	(5.91)	2.77	(3.51)
Regional dummy	0.38	(0.49)	0.24	(0.43)	0.44	(0.50)	0.14	(0.35)
Herd ownership	0.34	(0.47)	0.33	(0.47)	0.28	(0.45)	0.44	(0.50)
Access to irrigation	0.54	(0.50)	0.43	(0.50)	0.51	(0.50)	0.49	(0.50)

Standard deviations are given in parentheses.

Table 3: Determinants of agricultural mechanisation and modern variety adoption decisions

Variables	Improved variety adoption			Mechanisation adoption			Joint adoption	
	Coeff.	S. E.	Marg. Eff.	Coeff.	S. E.	Marg. Eff.	Marg. Eff.	S. E.
Age	0.019***	0.007	0.007	0.021***	0.007	0.007	0.009***	0.002
Sex	0.439**	0.205	0.162	0.558**	0.220	0.214	0.223***	0.069
Educational level	0.010	0.016	0.003	-0.024	0.017	-0.009	-0.003	0.006
Household size	-0.034**	0.014	-0.012	-0.042***	0.014	-0.015	-0.017***	0.005
Specialisation	0.008***	0.003	0.003	0.012***	0.003	0.004	0.005***	0.001
Farm size	0.018	0.143	0.006	0.362**	0.167	0.131	0.086	0.053
Extension contact	0.025	0.019	0.009	0.063***	0.023	0.022	0.020***	0.007
Regional dummy	0.794***	0.224	0.263	1.282***	0.240	0.390	0.431***	0.065
Herd ownership	0.137	0.176	0.046	-0.391**	0.185	-0.144	-0.063	0.063
Access to irrigation	0.017	0.180	0.007	-0.436**	0.197	-0.157	-0.094	0.065
Intercept	-1.162***	0.384		-1.533***	0.402			
Arthro	0.273**	0.114						
LR test of rho=0	5.835**							

***signifies statistical significance at 1 percent level; **indicates statistical significance at 5 percent level.

The age of the household head was positively related to the joint decision to adopt HYV and farm mechanisation and significant at the 1% level. Older farmers therefore had more likelihood to jointly adopt HYV and farm mechanisation compared to younger farmers. The results indicate that a unit increase in the age of the farmer increases the probability of jointly adopting HYV and farm mechanisation by 0.009. The direction of effect of age on the individual adoption decisions was similar to that of the joint adoption decision: older farmers were more likely to mechanize their farm operations and more likely to adopt improved rice varieties. The result of the study agrees with other studies that found age to be positively associated with the adoption of agricultural technologies (**Asante et al., 2014; Saka et al., 2005**). Older farmers, by virtue of experience, are more likely to be knowledgeable about productivity-enhancing technologies and therefore more likely to be adopters.

The result also indicates that male farmers are more likely to jointly adopt the two technologies relative to female farmers. The probability of joint adoption by male farmers was found to be 0.223 higher than female farmers. Most studies have reported higher adoption rates among men relative to women (e.g. **Dontsop-Nguezet et al., 2016; Huang et al., 2015**). The higher adoption rate of men relative to women have been attributed to men's control over production resources and being the main decision maker in the household. The direction of effect of the gender variable was similar for the individual adoption decisions as in the case of the joint adoption decisions. Male farmers were more likely to adopt farm mechanisation and improved varieties relative to female farmers. The result agrees with **Kuwornu et al. (2017)** who found that being a male farmer increased access to farm mechanisation in southern Ghana.

Farmers who allocated a greater proportion of household land to rice cultivation were more likely to jointly adopt HYV and farm mechanisation. Hence, the likelihood to jointly adopt the two production technologies is positively and significantly related to the degree of specialisation in production. The study showed that a unit increase in the proportion of land allocated to rice production increases the probability of jointly adopting HYV and farm mechanisation by 0.005. Specialisation in production is associated with higher efficiency hence farmers with greater specialisation may be expected to adopt productivity-enhancing technologies like HYV and farm mechanisation. The degree of specialisation was also positively significant in its effect on the adoption of both farm mechanisation and improved rice varieties at 1% level of significance. Farmers with a greater degree of specialisation in rice production are therefore more likely to adopt improved production technologies, which is consistent with economic theory. As stipulated by economic theory, specialisation leads to efficiency of production, hence rational producers seeking to improve efficiency are likely to specialize more as well as adopt productivity-enhancing technologies.

Household size was negatively related to the joint adoption decision of farmers. Hence, households with fewer members were more likely to jointly adopt the two technologies. A unit increase in household size however decreases the probability of joint adoption by 0.017. Farming in rural communities relies mostly on family labour with labour constrained households more likely to seek labour-saving technologies especially farm mechanization. **Khonje et al. (2015)** found adoption of improved maize varieties to be negatively related to household size in Eastern Zambia. **Sodjinou et al. (2015)** however observed a positive association between household size and organic cotton adoption in Benin. The effect of household size on the individual adoption decisions of households was similar to the joint adoption decision: smaller households were more likely to adopt both farm mechanisation and improved varieties as separate technologies. Family size is therefore an important factor in adoption decisions of smallholder households in the study area.

The study also revealed a higher propensity among households in the Northern Region to jointly adopt HYV and farm mechanisation compared to producers in the Upper East Region. The probability of jointly adopting HYV and farm mechanisation by farmers in the Northern Region was 0.431 higher than those in the Upper East Region. Location and geographical factors affect adoption decisions because of their influence on access to innovations, the price of inputs, production practices, soil characteristics, etc. The regional variable also had a similar effect on the adoption of farm mechanisation as well as the choice to plant improved varieties at the 1% significance level.

Contact with extension agents was positively related to joint adoption decisions of farmers and significant at the 1% level. A unit increase in the number of extension visits increased the probability of joint adoption by 0.02. Extension contact had a positive and statistically significant relationship with adoption of farm mechanisation at the 1% level but had no effect on the adoption of improved varieties.

The study also revealed that farm size, number of extension contacts, herd ownership and the production system were significantly related to adoption of farm mechanisation but had no effect on the adoption of improved rice varieties. Farm size and extension contact were positively related to adoption of agricultural mechanisation, implying that households with larger farms and more contact with extension agents were more likely to adopt agricultural mechanisation. The result is consistent with **Kuwornu et al. (2017)** who found size of land to be positively related to access to farm mechanisation in southern Ghana. Herd ownership and production system on the other hand, were negatively related to adoption of farm mechanisation, implying that households without cattle and rain-fed farmers were more likely to adopt agricultural mechanisation. The result indicates that cattle owners were likely to rely on animal traction, hence their low dependence on tractors.

CONCLUSION

The study investigated the factors influencing joint adoption of farm mechanisation and improved rice varieties by smallholder farmers in northern Ghana, using cross-sectional data from 300 farm households. A bivariate probit model was specified to derive estimates of

the joint adoption decision. The results of the study indicate that the decision to jointly adopt high-yielding varieties and farm mechanisation was influenced by the age and gender of the household head, the degree of specialisation in production, household size, and the location of the farm.

The study concludes that individual and household characteristics seem to play important role in smallholders' joint adoption decisions. Hence efforts to improve rice production should take into account these factors when disseminating innovations to smallholders. In particular, age, gender, household size and the degree of specialisation in rice production are factors that influence farmers' decision to jointly adopt improved varieties and farm mechanisation, and should therefore be taken into account when disseminating technologies to farmers.

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