2015-04-01

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http://hdl.handle.net/10026.1/4493

10.5836/ijam/2015-03-100
International Journal of Agricultural Management

Revised version incorporating all comments of the referees and the editor

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January 2015

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ABSTRACT

Farmers generally produce multiple crops while selectively adopting modern technologies in them to meet various needs. The present study jointly determines the factors influencing decisions to adopt modern technologies (i.e., HYV seeds and/or fertilizers) in multiple food crops (i.e., rice, yam and cassava) using a survey data of 400 farmers from Nigeria by applying a multivariate probit model. Model diagnostic reveals that the decisions to adopt modern technologies are significantly correlated, implying that univariate analysis of such decisions are biased, thereby, justifying use of multivariate approach. Results reveal that 68% of the farmers grew at least two food crops. Output price is an important determinant of HYV adoption. Farming experience is positively associated with HYV adoption whereas remoteness of extension services is negatively associated. HYV technology adoption is relatively higher for small farms whereas large farms use more fertilizers. Access to credit positively influences modern technology adoption. High profit is the main motive for adopting modern technologies. Policy recommendations include investments in extension infrastructure and credit services as well as measures to stabilise and/or improve output price efficiency, e.g., government procurement of outputs during harvest, grading and standardisation of food crops, reducing transaction costs of marketing and trade policies.

Key words: Socio-economic determinants, multivariate probit analysis, multiple crop production, modern technology adoption decisions, Nigeria.

JEL Classification: Q12, Q16, C21

1. Introduction

The right to food is one of the most consistently mentioned policy goals in international human rights documents, but it is the one that is most frequently violated (Clover, 2003). The

New Partnership for African Development (NEPAD) report states that it will require an investment of $18 billion a year in rural infrastructures to achieve MDG-1 of halving hunger from its 1990 level by 2015 in Africa (Boon, 2007). Long before the recent financial crisis, Africa was already in food crisis, as one in three adults and children are under-nourished and half of all Africans live on less than one dollar a day (Nambiro *et al*., 2008). The recent food, energy and financial crisis have turned an already serious problem into a catastrophe. Price increases to the tune of 60% or more for food and other products (Binswanger and McCalla, 2008) has driven an additional 100 million Africans further into poverty (Adesina, 2009). The situation in Nigeria is not any different from the rest of its neighbours.

Agriculture remains an important sector in the Nigerian economy, and is a major source of raw materials, food and foreign exchange and employs over 70 percent of the labour force and has the potential to diversify its economy (Liverpool-Tasie *et al*., 2011). Of the 178.5 million people (World Population Review, 2015), more than 70 million lives in rural areas engaged in small scale semi-subsistence agriculture (Liverpool-Tasie *et al*., 2011). Nigerian agricultural sector has a high potential for growth, but this potential is not being realised and productivity is low and basically stagnant (Aigbokhan, 2002). Ehui and Tsgas (2009) also observed that the farming system is mostly small scale characterised by low level of modern technology adoption and is largely dependent on the vagaries of the weather.

Cassava, yam and rice are the three main staple food crops in Nigeria where the former two have a wide range of industrial and commercial uses as well. Nigeria is one of the leading producers of cassava in the world (Ayoade and Adeola, 2009; Knipscheer *et al*., 2007; Nweke, 2004). Nigeria also accounts for 68% of global yam production and yam ranks highest as an important source of dietary calories for its people (Asiedu and Maroya, 2012). On the other hand, although the demand for rice as staple was low during the 1960s, it has started to rise since the 1990s, growing at an annual rate of 14% by mainly substituting other coarse grains, roots and tubers use for consumption (Erhabor and Ogojho, 2011). Awerije and Rahman (2014) noted that cassava has strong potential to support agricultural growth in Nigeria but currently is constrained by low level of productivity and efficiency, lack of processing and poor marketing infrastructure. Similarly, potential of yam also has not been realized mainly due to constraints in unavailability and affordability of high quality seed yams, on-farm postharvest losses, low soil fertility, and unexploited potential of yam markets by smallholder farmers (Asedu and Maroya, 2012). Nkonya *et al*. (2010) noted that the current yield of rice, cassava and yam is only 1.9, 12.3 and 12.3 mt/ha whereas the potential yields are 7.0, 28.04 and 18.0 mt/ha, respectively. Liverpool-Tasie *et al*. (2011), examining trends in production of selected crops (millet, yam, maize, cassava, and rice) for the period (1994-2006), noted that the output produced for most crops was stagnant or declining, with the exception of cassava, which saw modest increases in output. They also concluded that food crop production in Nigeria is far below its potential and the demand is far greater than locally produced supply (Liverpool-Tasie *et al.*, 2011).

Therefore, given such poor productivity performance of these major crops, it is important to identify: (a) the type of food crops grown at the farm level, (b) the extent of multiple cropping undertaken at the farm level; and (c) identify factors influencing adoption of modern technologies in them, so that the total production of food crops can be improved at the farm level, provided that the farms are managed properly, which in turn will contribute to support Nigeria's agricultural growth.

Farmers generally produce multiple crops while they selectively adopt modern technology in some or all of the crops in order to meet their consumption and various other needs depending on their socio-economic circumstances. In fact, farms are businesses where decisions are made and implemented by the farmer alone under relatively more external pressures than any other businesses (Groenwald, 1987 and Errington, 1991 cited in Willock *et al*., 1999). Therefore, such a complex decision making process cannot be realistically accommodated by examining factors influencing adoption of modern technology of each crop separately. Literature abounds with examination of factors influencing adoption of modern technology in crop production at the farm level largely focusing on single crop only (e.g., Mariano *et al*., 2012; Uaiene *et al*., 2009; Shiyani *et al*., 2002; Ransom *et al.*, 2003; Baidu-Forson, 1999), although in reality farmers produce multiple crops (e.g., Rahman, 2008, Benin *et al*., 2004; Floyd *et al*., 2003). To our knowledge, there is no single study that has jointly determined the factors influencing adoption of modern agricultural technology in multiple crops. Furthermore, farmers may not even adopt modern technology as a complete package (e.g., HYV seeds, fertilizers, irrigation and/or pesticides together), but selectively choose any component(s) of the package, e.g., only fertilizers but not irrigation or HYV seeds, which is more common, particularly in Africa.

Therefore, in order to realistically identify the host of factors influencing such a complex decision making process, i.e., adoption of modern technology selectively or totally as a package in any one or all of the multiple crops, we utilise a multivariate probit model which is capable of jointly estimating all the relevant parameters of the model and also provides evidence of jointness in the decision making process. This is the main contribution of our research to the technology adoption literature. In other words, the specific objective is to jointly determine the factors influencing adoption of modern technology components (i.e., HYV seeds and/or fertilizers) in any or all of the three major food crops (i.e., rice, yam and cassava). We do so by using farm-level cross-sectional data of 400 farmers from Ebonyi and Anambra states of Nigeria collected in 2012. This is because a more complete understanding of farmers' decision making process is of interest to policy makers and academics (Willock *et al*., 1999).

The paper is structured as follows. Section 2 presents the analytical framework, study area and the data. Section 3 presents the results. Section 4 concludes and draws policy implications.

2. METHODOLOGY

2.1 Conceptual model: the multivariate probit model

Several studies have analysed determinants of adoption of modern technologies. These are largely univariate probit, tobit or logit regressions of technology adoption of a single crop on variables representing socio-economic circumstances of farmers (e.g., Mariano *et al*., 2012; Uaiene *et al*., 2009; Shiyani *et al*., 2002; Ransom *et al*., 2003; Baidu-Forson, 1999). The implicit theoretical underpinning of such modelling is the assumption of utility maximization by rational farmers, which is described below.

We begin by postulating that the farmer produces a single crop, say rice. We also define modern technology in a broader sense in terms of specific elements or components, e.g., use of HYV seeds and fertilizers. We denote the adoption of HYV seed technology in rice as "*y*", where *y*=1 for adoption and *y*=0 for non-adoption. The underlying utility function which ranks the preference of the *i*th farmer is assumed to be a function of farmer as well as farm specific characteristics, "**x**" (e.g., education, farm size, family size, tenancy, extension services, etc.) and an error term with zero mean. The model is written as (Greene, 2012):

$$y^* = \mathbf{x}'\boldsymbol{\beta} + \varepsilon \qquad (1)$$

$y = 1,\ if\ y^* > 0$ (if HYV seed technology is adopted)

$y = 0, if\ y^* \leq 0$ (otherwise)

Since the utility derived is random, the *i*th farmer will adopt HYV seed technology if and only if the utility derived from adoption is higher than non-adoption. Thus, the probability of adoption of the *i*th farmer is given by (Greene, 2012):

$$\text{Prob}(\text{Y} = 1|\mathbf{x}) = F(\mathbf{x}, \boldsymbol{\beta})$$

$$\text{Prob}(\text{Y} = 0|\mathbf{x}) = \mathbf{1} - F(\mathbf{x}, \boldsymbol{\beta}) \tag{2}$$

where $F(\mathbf{x}, \boldsymbol{\beta}) = \mathbf{x}'\boldsymbol{\beta}$**.**

The functional form of Eq (1) depends on the assumption made for the error term *ε*, which is assumed to be normally distributed in a probit model. Thus for the *i*th farmer, the probability of the adoption of HYV seed technology is given by:

$$\text{Prob}(Y = 1|\mathbf{x}) = \int_{-\infty}^{x'\beta} \phi\,(t)dt = \Phi(\mathbf{x}'\boldsymbol{\beta}) \tag{3}$$

where $\Phi(t)$ is the cumulative distribution function of the standard Normal. This is the single equation probit model for adoption of a HYV seed in rice crop only.

Since we are interested in accommodating multiple crops that farmers generally grow and selectively adopt components of modern technologies in them, we adopt the multivariate probit model with M number of equations that is based on the same principle. The resultant equation system is given by (Greene, 2012):

$$y_m^* = \mathbf{x}'_m\beta_m + \varepsilon_m, y_m = 1\ if\ y_m^* > 0, 0\ otherwise, m = 1, \dots \dots M$$

$$E[\varepsilon_m|\mathbf{x}_1, \dots \dots, \mathbf{x}_M] = 0$$

$$\text{Var}[\varepsilon_m|\mathbf{x}_1, \dots \dots, \mathbf{x}_M] = 1$$

$$\text{Cov}\left[\varepsilon_j, \varepsilon_m\middle|\mathbf{x}_1, \dots \dots, \mathbf{x}_M\right] = \rho_{jm},$$

$$(\varepsilon_1, \dots \dots \varepsilon_M) \sim \text{N}_M[\mathbf{0}, \mathbf{R}] \tag{4}$$

The joint probabilities of the observed events $[y_{i1}, y_{i2}, \dots \dots y_{iM}|\mathbf{x}_{i1}, \mathbf{x}_{i2}, \dots \dots \mathbf{x}_{iM}]$, $i = 1, \dots$, *n,* that forms the basis for the likelihood function are the M-variate normal probabilities (Greene, 2012):

$$L_i = \Phi_M(q_{i1}\mathbf{x}'_{i1}\beta_1, \dots \dots \dots, q_{iM}\mathbf{x}'_{iM}\beta_M, \mathbf{R}^*), \tag{5}$$

where,

$$q_{iM} = 2y_{iM} - 1,$$

$$\mathbf{R}^*_{jM} = q_{ij}q_{iM}\rho_{jm}.$$

where ρ_{jm} is the correlation between ε_j and ε_m. The distributions are independent if and only if $\rho_{jm} = 0$. A user written full maximum likelihood estimation procedure is applied using STATA V10 software program (STATA Corp, 2010).

2.2. Study area and the data

Data used for the study were drawn from the two states: Ebonyi and Anambra states of Nigeria. Based on the cell structure developed by the Agricultural Development Programme, three local government areas (LGAs) from each state were selected randomly. Then 10 communities/villages from each LGA were chosen randomly. Next, farmers were chosen from these communities using a simple random sampling procedure. The total number of farm households in each village formed the sample frame. Then the sample size (*n*) of household units in the study area is determined by applying the following formula (Arkin and Colton, 1963):

$$n = \frac{Nz^2p(1-p)}{Nd^2+z^2p(1-p)} \quad (6)$$

where n = sample size; N = total number of farm households; z = confidence level (at 95% level z = 1.96); p = estimated population proportion (0.5, this maximizes the sample size); d = error limit of 5% (0.05).

Application of the above sampling formula with the values specified, which in fact maximizes the sample size, yielded a total required sample of 450. However, a total of 600 questionnaires were distributed (300 in each state with 30 in each community). Although 290 questionnaires from Ebonyi and 190 from Anambra states were returned, complete information was available in only 249 and 141 questionnaires from these states, respectively. Therefore, the final sample size stands at 400 households. Details on input and output data on three major food crops (i.e., cassava, yam and rice) were recorded in addition to key demographic and socio-economic information from each of the farm households. The co-author and two trained research assistants who are agricultural graduates were used for collecting primary data.

2.3 The empirical model

A multivariate probit model is developed to empirically investigate the socio-economic factors underlying the decision to grow multiple crops and use HYV seed technology and/or fertilizers in any or all of the food crops. The dependent variables are whether the farmer adopts HYV seed technology and/or fertilizers in each of the major staple food crops (i.e., rice, yam and cassava). For each case of adoption, the variable takes the value 1 and 0 otherwise. Furthermore, for each crop (e.g., rice) with two types of technologies (i.e., HYV seeds and fertilizers), there are four possibilities: (a) no modern technologies (*rice* = 0, *rfert* = 0); (b) only HYV seeds (*rice* = 1, *rfert* = 0); (c) only fertilizers (*rice* = 0, *rfert* = 1); and (d) both (*rice* = 1, *rfert* = 1).

Therefore, a total of six types of technology adoption functions are postulated, i.e., three crops with two types of technology adoption decisions in each. The following set of six equations provides possible combinations of $2^m - 1 = 2^6 - 1 = 63$ (Young *et al.*, 2009).

$y_1^* = \mathbf{x}'\beta_1 + \varepsilon_1, y_1 = 1\ if\ y_1^* > 0, 0\ otherwise$ (HYV rice seed adoption, *rice*)

$y_2^* = \mathbf{x}'\beta_2 + \varepsilon_2, y_2 = 1\ if\ y_2^* > 0, 0\ otherwise$ (HYV yam seed adoption, *yam*)

$y_3^* = \mathbf{x}'\beta_3 + \varepsilon_3, y_3 = 1\ if\ y_3^* > 0, 0\ otherwise$ (HYV cassava seed adoption, *cas*)

$y_4^* = \mathbf{x}'\beta_4 + \varepsilon_4, y_4 = 1\ if\ y_4^* > 0, 0\ otherwise$ (Fertilizer adoption in rice, *rfert*)

$y_5^* = \mathbf{x}'\beta_5 + \varepsilon_5, y_5 = 1\ if\ y_5^* > 0, 0\ otherwise$ (Fertilizer adoption in yam, *yfert*)

$y_6^* = \mathbf{x}'\beta_6 + \varepsilon_6, y_6 = 1\ if\ y_6^* > 0, 0\ otherwise$ (Fertilizer adoption in cassava, c*fert*) (7)

where $\mathbf{x} = (1, x_1, x_2, \ldots\ldots x_n)'$ is a vector of *n* covariates which do not differ between adopter categories (the deterministic component) and $\beta_m = (\beta_{m0}, \beta_{m1}, \beta_{m2}, \ldots\ldots\ldots \beta_{mn})'$ is a corresponding vector of parameters, including an intercept which we want to estimate. The stochastic component, ε_m, is thought of as those unobservable factors which explain the marginal probability of making a decision to adopt technology m (m = 1, 2, ….., 6). Each ε_m is drawn from a M-variate normal distribution with zero conditional mean and variance normalized to unity, where $\varepsilon_m \sim N(\mathbf{0}, \mathbf{\Sigma})$, and the covariance matrix $\mathbf{\Sigma}$ is given by (Young *et al.*, 2009):

$$\mathbf{\Sigma} = \begin{bmatrix} 1 & \rho_{12} & \cdots & \rho_{1m} \\ \rho_{21} & 1 & \cdots & \rho_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{m1} & \rho_{m2} & \cdots & 1 \end{bmatrix} \qquad (8)$$

The particular interest is the off-diagonal elements of the covariance matrix, ρ_{jm}, which represents the unobserved correlation between the stochastic component of the j^{th} and m^{th} type of technology adoption decisions (Young *et al.*, 2009). Because of symmetry in covariances, we have $\rho_{jm} = \rho_{mj}$. The joint estimation of Eq (7) is not only efficient but also allows us to estimate the joint probabilities of the technology adoption decisions. The marginal probability of observing m^{th} type of technology adoption can be expressed as (Young *et al.*, 2009):

$$\text{Prob}(y_m = 1) = \Phi(\mathbf{x}'\boldsymbol{\beta}_m) \quad for\ all\ m = 1, \ldots, 6 \qquad (9)$$

where $\Phi(.)$ Denotes the cumulative distribution function of the standard Normal. Furthermore, the joint probability of observing all possible types of technology adoption decision comes from the M-variate standard Normal distribution (Young *et al.*, 2009):

$$\text{Prob}(y_1 = 1, \ldots \ldots, y_m = 1) = \Phi_m(\mathbf{x}'\boldsymbol{\beta}_1, \ \ldots\ldots \mathbf{x}'\boldsymbol{\beta}_m; \ \mathbf{\Sigma}) \qquad (10)$$

where $\mathbf{\Sigma}$ is the covariance matrix.

The socio-economic variables selected to explain modern technology adoption decisions are: output price, subsistence pressure, farming experience, education of the farmer, farm size, tenurial status, extension infrastructure, main occupation of the farmer, and the amount of agricultural credit received. The choice of these explanatory variables is based on the literature with similar justification (e.g., Mariano *et al.*, 2012; Uaiene *et al.*, 2009;

Rahman 2008, Benin *et al.*, 2004; Shiyani *et al.*, 2002; Ransom *et al.*, 2003). In addition, farmers were also asked about the motivation for adopting modern technology in these crops and to rank each of the motives ((e.g., high yield, high profit, etc.) on a five-point Likert scale (i.e., 1 for least important motive and 5 for most important motive). This is because farmers' decision making process is also influenced by attitudes, objectives, behaviours and personality traits in addition to socio-economic factors (e.g., Willock *et al.*, 1999; Beedell and Rehman, 2000; Kobrich *et al.*, 2003; Bergevoet *et al.*, 2004). For example, Willock *et al.* (1999) and Beedell and Rehman (2000) applied the Theory of Planned Behaviour (TPB) to understand the conservation behaviour of the farmer in the UK. Similarly, Bergevoet et al (2004) applied the TPB model to understand the entrepreneurial behaviour of dairy farmers in the Netherlands. Although use of social-psychology model provides a more complete understanding of farmers' decision making process, there are a number of limitations for this approach. These are: requirement of a multidisciplinary team of researchers (Willock et al, 2009); very time consuming (Beedell and Rehman, 2000; Beedell and Rehman, 1999); responses require great deal of concentration from the respondents on obtuse/complex questions (Beedell and Rehman, 1999); require large range of valid variables (Willock *et al.*, 1999) and obviously is highly resource intensive and costly. Furthermore, implementation of this approach will be even more challenging in rural Africa. Therefore, while recognising the importance of social-psychology theory in explaining farmers' decision making, we picked up a simple set of questions from this domain, i.e., revealed motives behind the adoption of modern technology, as applied by Rahman and Sriboonchitta (1995). Table 1 presents definitions of the variables used in the multivariate probit model.

3. Results

Table 1 also presents the summary statistics of the sampled farmers. According to Table 1, adoption of modern technologies in crops is variable and generally very low, which perhaps explains low level of productivity of these major crops in Nigeria. Only 35% of the sampled farmers adopted HYV technology in cassava which is highest in the sample while the figure is only 18% for yam and 12% for rice producers. The use of fertilizers is similarly low (under 30%) for all crops.

Among the socio-economic factors, we see that the output price of yam is very high as compared with rice and/or cassava price, the average farm size is small (1.27 ha), average farming experience is about 20 years, education attainment is above primary level (7.8 years of completed schooling), low extent of tenancy (only 17% of operated area is rented in), farming is the main source of occupation for 52% of the sample, distance to extension office is 3.6 km and the average level of credit received is Naira 2.6 thousand per households.

3.1 Extent of multiple cropping and technology adoption

Table 2 presents the extent of multiple cropping and the level of HYV seed and/or fertilizer technology adoption amongst the sampled farmers. It is clear form Table 2 that farmers grow multiple crops instead of a single food crop. A total of seven combinations of cropping system were observed. Only 18% of the farmers produced a single crop of cassava with lowest average operation size of 0.53 ha whereas 'only rice' or 'only yam' produces are a third of that with slightly higher operation sizes. On the other hand a substantial 41% of the farmers grew a combination of yam and cassava with an average operation size of 0.99 ha followed by 24.8% of farmers growing all three major food crops with highest average operation size of 2.54 ha. The implication is that small farms with their small farm size tend to grow at least two crops whereas large farms tend to grow all three crops due to command over a much larger cultivated area.

However, when use of modern technologies was examined, the picture is rather mixed. Overall, 47% of the farmers adopted HYV seeds in any or all of their crops. The use of HYV technology is highest at 90% for farmers growing combination of rice and yam, followed by combination of rice and cassava (66.7%). Also, 47% of farmers applied fertilizers with an average application rate of 52.8 kg/ha in any or all three crops.

Seventy six percent of 'only yam' producers (who are only 5.3% of total farmers) have applied fertilizers with an average application rate of 125.1 kg/ha followed by 70% of 'rice and yam' producers (who are only 2.5% of total farmers) applying a highest rate of 162.2 kg/ha. The 'only rice' producers applied (who are only 6.25% of total farmers) applied fertilizer @ 87.36 kg/ha. Only 27.8% of 'only cassava' producers applied least amount of fertilizers of only 18.1 kg/ha, which perhaps explains low productivity of cassava in Nigeria. It seems that fertilizer application rate is highest in yam production followed by rice. The main reason of such high rate of fertilizer application in yam is because it is mainly destined for market and about 30% of the output is retained as seed yam for replanting. Akanbi *et al*. (2007) noted that application of fertilizer improved growth performance and tuber yield of white yam in South Western Nigeria. Based on the research in experimental plots, they recommended 450 kg/ha of NPK as optimum in their experimental plots which is far higher than the fertilizer use rate observed in yam in this study. Liverpool-Tasie *et al*. (2014) noted that farmers in Nigeria do apply fertilizer but at variable rates depending on the regions but the use rate is below the economic optimum level. For example, the application rate of nitrogen fertilizer in rice varies from 43 kg/ha in high potential rice state and 51.75 kg/ha in non-high potential rice state (Liverpool-Tasie *et al*. 2014). In comparison, farmers in the study areas already applied substantially higher amount of fertilizers in their rice crop.

3.2 Determinants of modern technology adoption in multiple crops: a multivariate probit analysis

Results of the full information maximum likelihood estimation of the multivariate probit model are presented in Table 3. The key hypothesis that the 'correlation of the disturbance terms across six technology adoption functions' are jointly zero is strongly rejected at the 1% level of significance, implying correlated binary responses between technology adoption decisions. This further establishes that the use of a multivariate model to determine crop choice decisions among farmers is justified. The lower panel of Table 3 shows that six of the 15 pairs of correlation amongst disturbance terms are significantly different from zero at the 10% level at least, which further establishes jointness of the decision making process. All of the significant correlations coefficients are positive. For example, the correlation coefficient between the disturbance terms of HYV yam and HYV rice seed adoption functions, $\hat{\rho}_{(yam,\ rice)}$, is positive implying that the unobservable factors which increase the probability of adopting HYV yam also increase the probability of adopting HYV rice. Similarly, the unobservable factors which increase the probability of applying fertilizers in yam also increase the probability of applying fertilizers in cassava, $\hat{\rho}_{(cfert,yfert)}$.

Globally, 30 of the 63 coefficients have a significant relationship with the adoption of modern technologies in multiple crops. Output price is a significant determinant of adopting HYV seed technology in rice and yam. The coefficient estimate on output price is the marginal effect of output price on the log of the ratio of probabilities; therefore, it is possible to produce a probability of a given outcome relative to the omitted category by exponentiating the index function (Young *et al.*, 2009). For example, a one Naira increase in rice price per kg is associated with an increase in the probability of adopting HYV rice seed technology by approximately 9.75% ($(e^{0.093} - 1) * 100\%$) relative to the probability of not adopting any technology in any food crops, i.e., the omitted category. Wiboonpongse *et al.*

(2012) noted that price of potato is an important determinant in choosing early season potato in Northern Thailand. Similarly, Rahman (2011) noted that gross return (i.e. output price x quantity) is an important determinant of HYV seed technology adoption decision in rice production in Bangladesh which is consistent with the findings of this study.

Subsistence pressure (i.e., family size) is negatively associated with HYV rice seed adoption. The reason may be due to the fact that cassava is a staple crop although rice consumption has grown substantially in Nigeria. Therefore, large families tend not to adopt HYV seed technology in rice production.

Farming experience is another significant determinant of adopting both HYV seed and fertilizer technologies. For example, a one year increase in farming experience is associated with an increase in the probability of adopting HYV yam seed technology by approximately 5.97% ($(e^{0.058} - 1) * 100\%$) and fertilizer use by approximately 2.63% ($(e^{0.026} - 1) * 100\%$) relative to the probability of not adopting any technology in any food crops. Wiboonpongse *et al*. (2012); Rahman (2008) and Shiyani *et al.* (2002) also noted positive impact of farming experience in modern technology adoption.

Farmers' education variable does not have any significant influence except that it is negatively associated with fertilizer use in cassava, which contrasts with the findings of Mariano *et al*. (2012) and Rahman (2008). The implication is that educated farmers are more likely to move away from agriculture and, therefore, are not likely to use fertilizers to increase yield of cassava. Role of education on technology adoption is generally mixed in the literature. In most cases it shows no significant effect, but when it does, the effect is generally positive.

Small farms are more likely to adopt HYV technology relative to large farms, except rice where the effect is opposite, i.e., large farms are more likely to adopt HYV technology in rice. This is also indicated in Table 2 where it is shown that average farm size of farms with rice crop in the system is systematically larger than other categories. Shiyani *et al.* (2002) also noted that small farmers in comparison to large farmers replace local varieties with new varieties at a faster rate if additional gains are substantial in India, which agrees with the findings of this study. With respect to fertilizer adoption, again large farms are more likely to apply fertilizers in rice crop relative to small farms. The costs of fertilizers may be more expensive relative to the cost of HYV seeds, and hence large farms are more likely to apply fertilizers relative to small farms, because they are presumably less financially constrained. Rahman and Parkinson (2007) noted that the use of fertilizer is positively related to farm size in HYV rice production in Bangladesh. Tenancy has a positive effect on fertilizer adoption, implying that farmers who rented land tend to use fertilizers in rice production to maximize yield and are probably more market-oriented.

Distance to extension office is significantly negatively associated with modern technology adoption. This clearly indicates the importance of extension services in disseminating modern agricultural technologies. Longer distance implies remoteness of the extension services which exerts detrimental effect on modern technology adoption by the farmers. For example, farms located every one km further away from the extension office are associated with a decrease in the probability of adopting HYV yam seed technology by approximately 11.07% $((e^{0.107}-1)*100\%)$ and fertilizer use in yam by approximately 9.31% $((e^{0.089}-1)*100\%)$ relative to the probability of not adopting any technology in any food crops. Apart from its nutritional value, yam plays an important role in social and religious festivals. In many areas in West Africa, it is an integral part of the cultural heritage of the people and occupies an important place in many traditional marriages and religious festivals (Eyitayo *et al*, 2010). Ayoola (2012) noted that the number of extension contacts significantly increase adoption of yam minisett technology in Middle Belt region of Nigeria. Similarly, the role of extension in influencing modern technology adoption was also noted by

Mariano et al (2012), Uaiene *et al.* (2009), Ransom *et al*. (2003) and Baidu-Forson (1999). Therefore, the observation of detrimental effect of the remoteness of extension services on modern technology adoption is not surprising.

Farming as main occupation is negatively associated with HYV technology adoption in yam and cassava whereas it is positively associated with fertilizer use in rice, which is quite puzzling. The implication is that the full time farmers tend not to adopt HYV seed technology but adopt fertilizers, although positive association is expected for all technology choices. A possible explanation may be unavailability of good quality HYV seed of crops which the full time farmers could easily identify. Constraints associated with the availability of farm inputs (i.e., HYV seeds and fertlizers) were highlighted during the interviews with Agricultural Development Program (ADP) managers, country representatives of IFDC and UNDP in Nigeria (Chima, 2015). Availability of good quality seed for yam has also been identified as a main constraint in in adopting modern technology in Nigeria (Ayoola, 2012).

Access to credit is another important determinant of modern technology adoption, as expected. For example, an increase of credit access of 1000 Naira is associated with an increase in the probability of adopting HYV rice seed technology by approximately 2.02% $((e^{0.020}-1)*100\%)$ and fertilizer use by approximately 1.51% $((e^{0.015}-1)*100\%)$ relative to the probability of not adopting any technology in any food crops. Mariano et al. (2012) and Uaiene *et al*. (2009) also noted significant influence of access to credit on adoption of modern technology in rice in the Philippines and maize in Mozambique, respectively.

Among the revealed motives for adoption of HYV technologies, high profit is significantly positively associated with modern technology adoption, whereas high yield is significantly positively associated with cassava production only. Profit motive influencing adoption of modern technology was noted by Mariano *et al* (2012), Baidu-Forson (1999) and

Rahman and Sriboonchitta (1995). The negative influence of 'high yield' motive but positive effect of 'high profit' motive on yam production signifies the point that farmers grow yam not for maximizing yield but to maximize profit. This is possible because market price of yam is higher than rice and cassava. Moreover, yam (particularly fresh ware yam) is still regarded as a luxury good and large tubers can particularly attract high prices often purchased for celebrations such as weddings (Kleih *et al*., 2012). Since most farmers in the study areas produced yam for sale, significant influence of high profit motive is not a surprise. Also yam farming occupies a prestigious cultural significance in the study area (among the Igbo's in Nigeria). There is a prestige associated with its farming with traditional honours (known as Eze ji – King of yam) for the best yam famers in the communities (Coursey and Coursey, 1971; Kleih *et al*. 2012; Ikejiani, 2014)

4. Conclusions and policy implications

The aim of this study was to jointly identify the determinants of modern technology adoption in multiple crops by farmers in Nigeria using a multivariate probit model. Specifically, the probability of adopting HYV seed and/or fertilizer technologies in three principal food crops (i.e., rice, yam and cassava) was investigated. The model diagnostic revealed jointness in the decision making process which cannot be discerned from the univariate approach that is commonly used in the literature. This is because the decisions to adopt modern technologies in food crops are significantly positively correlated. In other words, the probability of adopting modern technology in one crop increases the probability of adoption of modern technology in another crop. The implication is that there is significant synergy in decision to adopt modern technologies in multiple crops.

Results reveal that farmers grow multiple crops instead of any single crop as 68% of the surveyed farmers grew at least two food crops. The level of modern technology adoption is low and mixed and farmers selectively adopt components of technologies as expected.

Among the host of socio-economic factors, output price is an important determinant of HYV technology adoption. Remoteness of extension services significantly reduces probability of modern technology adoption and is the strongest determinant of all. Another important determinant of modern technology adoption is farming experience. Small farms are likely to adopt HYV seed technologies relatively more/faster than the large farms. On the other hand, large farms are more likely to adopt fertilizer technology relative to small farms. Access to credit is significantly positively associated with modern technology adoption. Among the revealed motives for adoption of modern technologies, high profit motive is a significant determinant.

The following policy implications can be derived from the results of this study. First, targeted investment in extension infrastructure and services will significantly increase modern technology adoption and deserves particular attention as the detrimental influence of the remoteness of extension office is the strongest in the index functions. Aye and Mungatana (2011) concluded that the extension services in Nigeria in general have not been effective, especially after the withdrawal of the World Bank funding from the Agricultural Development Project, which is the main agency responsible for extension services. Awerije and Rahman (2014) also suggested investment in extension infrastructure as well as building capacity of the extension workers on new and improved technologies including dissemination strategies to improve cassava productivity.

Second, provision of credit services will significantly promote modern technology adoption. This can be achieved through effective disbursement of credit through formal banking institutions and/or facilitating non-governmental development organizations (NGOs) targeted at the farming population.

Finally, measures are needed to stabilise output prices and/or improve price efficiency because high prices, although seem favourable to producers, are detrimental to food security and the poor in the long run (Gouel and Jean, 2012). Price stability can be achieved by a range of measures, such as, by government procurement of crops during harvest season when price falls substantially (i.e., storage policy), grading and standardisation of products, reducing transaction costs of marketing, and trade policy (i.e., involving taxes and subsidies). For example, Gouel and Jean (2012) noted that an optimal combination of storage and trade policies in poor developing countries exert a powerful stabilising effects for domestic food prices. Similarly, Kleih *et al*. (2012) noted that the price of yam changes substantially during the harvest season and marketing inefficiencies for yam include fragmented value chains, lack of capital and liquidity constraints and very high transportation cost. They recommended locally regulated grading and standardisation to improve price efficiency of yam, a suggestion with which we also concur based on our findings.

Although these policy options are challenging, effective implementation of these measures will significantly increase adoption of modern agricultural technologies in major food crops and subsequently raise crop production and support agricultural growth in Nigeria.

The present study examined the determinants of modern technology adoption based on socio-economic factors and farmers' revealed motives at a point/cross-section of time which provides a snap shot of the present scenario. However, for a complete understanding of the dynamics involved in the decision making process of the farmers, information from a cohort of selected farmers over a period of time using a wider range of variables from the socio-economic as well as social-psychology models is highly desirable.

ACKNOWLEDGMENTS

The paper was extracted from the second author's PhD thesis submitted at the School of Geography, Earth and Environmental Sciences, University of Plymouth, UK in 2015. The data required for this project was generously funded by the Seale-Hayne Educational Trust, UK. The authors gratefully acknowledge the comments of two anonymous reviewers and the editor for constructive and critical comments that have substantially improved this paper. All caveats remain with the authors.

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Tables of the manuscript: **Determinants of modern technology adoption in multiple food crops in Nigeria: a multivariate probit approach**

Table 1. Definition, measurement and summary statistics of the variables.

Variables	**Definition**	**Mean**	**Standard deviation**
Dependent variables			
High yield variety of rice (*rice*)	Proportion of total farmers growing	0.12	--
High yield variety of yam (*yam*)	Proportion of total farmers growing	0.18	--
High yield variety of cassava (*cas*)	Proportion of total farmers growing	0.35	--
Fertilizer in rice (*rfert*)	Proportion of total farmers applying	0.21	--
Fertilizer in yam (*yfert*)	Proportion of total farmers applying	0.27	--
Fertilizer in cassava (*cfert*)	Proportion of total farmers applying	0.25	--
Independent variables			
Output price			
Rice	Naira per kg	18.40	24.96
Yam	Naira per kg	36.25	23.01
Cassava	Naira per kg	8.78	9.27
Socio-economic factors			
Family size	Number of persons per household	3.88	1.91
Farming experience	Years	19.78	13.62
Education of farmer	Complete years of schooling	7.84	4.73
Farm size	Hectare	1.27	1.11
Share of rented in land	Proportion of operated area rented in	0.17	0.34
Distance to extension office	Km	3.64	3.56
Main occupation of farmers	Dummy (1 if farmer, 0 otherwise)	0.52	--
Agricultural credit	Thousand Naira	2.31	8.29
Motives for choosing technology			
High yield	Number	0.85	0.27
High profit	Number	0.53	0.41
Number of observations		400	

Note: Exchange Rate: GBP1.00 = Naira 200.00.

Table 2. Extent of modern technology adoption in multiple food crops amongst sampled farmers.

Producer categories	Percent of total farmers (%)	Farm operation size (ha)	Percent of farmers within each crop category		
			Adopting high yielding varieties (%)	Adopting fertilizers (%)	Amount of fertilizers applied (kg/ha)
Only rice producer (*rice* = 1; *yam* = 0; *cassava* = 0)	6.25	0.79	40.00	68.00	87.36
Only yam producer (*rice* = 0; *yam* = 1; *cassava* = 0)	5.25	0.68	57.14	76.19	125.14
Only cassava producer (*rice* = 0; *yam* = 0; *cassava* = 1)	18.00	0.53	52.78	27.78	18.10
Rice and yam producer (*rice* = 1; *yam* = 1; *cassava* = 0)	2.50	1.20	90.00	70.00	162.21
Rice and cassava producer (*rice* = 1; *yam* = 0; *cassava* = 1)	2.25	1.24	66.67	66.67	55.44
Yam and cassava producer (*rice* = 0; *yam* = 1; *cassava* = 1)	41.00	0.99	47.56	37.20	51.93
Rice, yam and cassava producer (*rice* = 1; *yam* = 1; *cassava* = 1)	24.75	2.54	36.36	61.62	44.00
Overall	100.00	1.27	47.25	47.00	52.77
Number of observations (farm households)	400				

Table 3: Joint determination of factors influencing modern technology adoption decisions in multiple food crops: a multivariate probit model

Variables	HYV rice seed technology	HYV yam seed technology	HYV cassava seed technology	Fertilizer in rice	Fertilizer in yam	Fertilizer in cassava
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
Constant	-6.637***	-4.982***	-1.087***	-1.362***	-0.554	-1.073***
Prices						
Output price	0.093***	0.081***	0.012	--	--	--
Socio-economic characteristics						
Family size	-0.025	-0.003	-0.005	0.076	-0.064	-0.077*
Farming experience	0.014	0.058***	0.018**	0.009	0.026***	0.012
Education of farmer	0.028	-0.028	-0.003	-0.002	-0.027	-0.032*
Farm size	0.174**	-0.768***	-0.436***	0.361***	0.009	-0.128*
Share of rented in land	0.091	-0.349	-0.121	0.643***	-0.027	-0.181
Distance to extension office	0.040	-0.105***	-0.056**	-0.038	-0.089***	-0.043*
Main occupation of farmers[§]	0.277	-0.704**	-0.482**	0.520***	-0.208	-0.101
Agricultural credit	0.020**	0.019*	-0.001	0.015*	0.017**	-0.002
Motives for choosing technology						
High yield	-0.899***	-0.208	0.993***	-1.192***	-0.257	0.445
High profit	0.456*	0.555**	0.643***	0.283	0.721***	1.201***
Model diagnostics						
Log likelihood	-863.635					
Wald $\chi^2_{(63\ df)}$	340.43***					
Correlation between the error terms						
$\rho_{(yam,\ rice)}$	0.367***					
$\rho_{(cas,\ rice)}$	0.004					
$\rho_{(rfert,\ rice)}$	0.205*					
$\rho_{(yfert,\ rice)}$	0.123					
$\rho_{(cfert,rice)}$	0.147					
$\rho_{(cas,yam)}$	0.009					
$\rho_{(rfert,yam)}$	-0.179					

Variables	HYV rice seed technology	HYV yam seed technology	HYV cassava seed technology	Fertilizer in rice	Fertilizer in yam	Fertilizer in cassava
	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient	Coefficient
$\rho_{(yfert, yam)}$	0.694***					
$\rho_{(cfert,yam)}$	0.334***					
$\rho_{(rfert,cas)}$	-0.125					
$\rho_{(yfert,cas)}$	-0.010					
$\rho_{(cfert,cas)}$	0.336***					
$\rho_{(yfert,rfert)}$	0.025					
$\rho_{(cfert,rfert)}$	0.151					
$\rho_{(cfert,yfert)}$	0.657***					
Wald $\chi^2_{(15\ df)}$ (H_0: Correlation between pairs of disturbance terms are jointly 0)	157.506***					
Predicted marginal probability	0.117	0.178	0.355	0.210	0.277	0.257
Number of observations	400					

Note: *** = significant at 1 percent level (p<0.01)
** = significant at 5 percent level (p<0.05)
* = significant at 10 percent level (p<0.10)
§ = dummy variable.
Source: Computed from Field Survey, 2012.