Ownership of mobile phone and farmer's participation in maize markets along the supply chain in Tanzania: The effect of common covariates

Angela Burton Mboma[1*]
Fredy T. M. Kilima[2]
Alban D. Mchopa[3]
Joachim schäfer[4]

[1*]anje.burton@gmail.com

[1] http://orcid.org/0009-0006-8474-3486
[2] http://orcid.org/0000-0002-0342-1228
[3] http://orcid.org/0000-0001-8547-6267
[4] http://orcid.org/0009-0003-2876-9030

[1] Mzumbe University, [2,3] Moshi Co-operative University, [1,2,3] Tanzania. [4] Baden Württemberg Cooperative State University - Lörrach, Germany.

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ABSTRACT

Mobile phone ownership has the potential to improve smallholder farmers' access to market information and commercial opportunities, yet its relationship with agricultural market participation remains inconclusive. Guided by Random Utility Theory, this study examined the socioeconomic and institutional factors associated with mobile phone ownership and maize market participation among smallholder farmers in Tanzania and assessed whether the two outcomes exhibit residual statistical dependence. The study employed a quantitative cross-sectional design using secondary household survey data comprising 1,578 analytical observations. A non-recursive bivariate probit model was estimated with household-clustered robust standard errors. The results indicated that being male, involvement in non-farm enterprises, and primary and secondary education were positively associated with mobile phone ownership. Maize market participation was positively associated with plot ownership, loan amount, maize unit price, and primary and secondary education, while age and casual employment exhibited negative associations. Educational attainment emerged as a significant common determinant of both outcomes. However, the estimated residual correlation was not statistically significant at the 5% level, indicating insufficient evidence of residual dependence after controlling for observed covariates. The findings highlight the importance of strengthening farmers' human capital alongside targeted interventions addressing digital inclusion, productive resources, agricultural finance, and market access. Policies should address the distinct constraints associated with technology ownership and maize market participation rather than treating mobile phone ownership as sufficient for agricultural market integration.

Keywords: Bivariate Probit; Covariates; Maize Market Participation; Mobile Phone Ownership; Smallholder Farmers; Tanzania

I. INTRODUCTION

Smallholder farmers play a central role in agricultural production systems across Sub-Saharan Africa and are expected to remain important contributors to agricultural development (Burke et al., 2020). Their activities support household livelihoods, generate employment opportunities along agricultural value chains and contribute to food security (Changalima & Ismail, 2022; Siwandeti et al., 2023). Improved access to agricultural markets can enhance these contributions by enabling farmers to convert surplus production into income, finance agricultural inputs and invest in productivity-enhancing technologies. Maize, which serves as both a staple food and a source of income in many African economies, provides an important context for examining smallholder farmers' market participation (Erenstein et al., 2022; Fan & Rue, 2020).

Despite the economic importance of maize, smallholder farmers continue to experience constraints in accessing agricultural markets. In Kenya, maize marketing is characterised by substantial reliance on farm-gate transactions and intermediary buyers (Kirimi et al., 2011). Comparable challenges have been documented in Ethiopia and Tanzania, where market participation is influenced by socioeconomic characteristics, productive resources and institutional conditions (Tafesse et al., 2023; Wilson & Lewis, 2015). Efforts to improve market access have included investments in physical infrastructure, agricultural market information systems and institutional arrangements intended to reduce transaction costs (Poole, 2017). Nevertheless, limited access to timely market information and reliable marketing opportunities continues to constrain smallholder farmers' participation in agricultural markets.

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Mobile phones have attracted increasing attention as potentially accessible technologies for improving agricultural communication and market information exchange. They may facilitate contact between farmers and buyers, reduce information-search costs and improve access to financial services (Aker & Mbiti, 2010; Mzomwe et al., 2021; Yao et al., 2022). Evidence from Uganda suggests that improvements in mobile phone coverage can support participation in markets for perishable agricultural commodities (Muto & Yamano, 2011). Furthermore, mobile money services may contribute to household welfare by facilitating financial transactions and transfers (Kikulwe et al., 2014). These potential benefits suggest that communication technologies can play a supportive role in agricultural market development.

However, the relationship between mobile phone ownership and agricultural market participation is not necessarily straightforward. Ownership does not automatically imply that farmers use mobile phones to obtain agricultural information, identify buyers or conduct market transactions. Evidence from different agricultural settings indicates that the economic benefits associated with mobile technologies depend on the nature of their use and the socioeconomic and institutional conditions under which farmers operate (Chikuni & Kilima, 2019; Nwafor et al., 2020; Tadesse & Bahiigwa, 2015). Consequently, the factors associated with acquiring a mobile phone may differ from those associated with participating in agricultural markets.

Several contextual conditions may contribute to these differences. Smallholder farmers who primarily produce for household consumption may sell agricultural products only when surpluses arise or immediate financial needs require them to do so (Fafchamps & Minten, 2012; Mpombo et al., 2022). Farmers may also rely on established informal communication networks and trusted trading relationships rather than mobile phone-based information services (Duncombe, 2016; Tadesse & Bahiigwa, 2015). Furthermore, limited digital literacy, language barriers, communication costs and unreliable infrastructure may constrain the effective use of mobile technologies for agricultural purposes (Anadozie et al., 2022; Mensah, 2021). These considerations highlight the importance of distinguishing access to mobile phones from their actual use in agricultural marketing.

Existing studies have contributed valuable evidence on mobile technologies, agricultural information access and market participation. Nevertheless, much of this literature examines technology access or agricultural marketing as separate outcomes, or focuses on the relationship between technology use and particular marketing activities. Less attention has been given to identifying the socioeconomic and institutional characteristics that are associated with both mobile phone ownership and maize market participation within a joint empirical framework. In particular, it remains important to establish whether the two outcomes share observable determinants and whether their unobserved components exhibit residual statistical dependence after accounting for those determinants.

This study addresses this gap by employing a non-recursive bivariate probit model to examine mobile phone ownership and maize market participation among smallholder farmers in Tanzania. The approach allows the two binary outcomes to be estimated jointly while permitting correlation between their unobserved components. Unlike specifications that treat mobile phone ownership as a direct explanatory variable for market participation, the present study does not impose a causal ordering between the two decisions. Instead, it identifies their common and outcome-specific correlates and assesses whether residual statistical dependence remains after controlling for observed characteristics.

The study contributes to the literature by distinguishing between common observable determinants and residual dependence in the context of smallholder maize marketing. This distinction provides evidence relevant to the design of digital inclusion and agricultural market interventions, particularly where technology access and market participation may be associated with different socioeconomic and institutional constraints.

1.1 Research Objectives

i. Identify the socioeconomic and institutional factors associated with mobile phone ownership among smallholder maize farmers in Tanzania.
ii. Examine the socioeconomic, institutional and market-related factors associated with smallholder farmers' participation in maize markets.
iii. Assess the extent to which mobile phone ownership and maize market participation share observable determinants and exhibit residual statistical dependence.

II. LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 Random Utility Theory (RUT)

This study is grounded in Random Utility Theory (RUT), which provides a framework for understanding individual choices among alternative courses of action. The theory assumes that individuals select alternatives based on their expected utility, subject to their preferences, resources and constraints. Because not all factors influencing

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individual decisions are observable, utility is represented by systematic and stochastic components (McFadden, 1974). In smallholder agriculture, decisions concerning mobile phone ownership and maize market participation may be understood as distinct choices influenced by expected benefits and associated costs. Mobile phone ownership may provide benefits through communication, access to information and financial transactions, while also involving handset acquisition, communication and learning costs (Aker & Mbiti, 2010; Kabbiri et al., 2018). Farmers are therefore expected to evaluate these benefits and costs within their available economic and social resources.

Similarly, maize market participation involves comparing the expected benefits of selling agricultural produce with those associated with retaining production for household consumption or other purposes. Market prices, productive resources, access to finance, transaction costs and household characteristics may influence this decision (Chikuni & Kilima, 2019; Mkuna & Wale, 2022). Although mobile phone ownership and maize market participation represent different choices, their determinants may overlap. For example, education may improve farmers' ability to acquire and use communication technologies while also strengthening their capacity to identify and evaluate marketing opportunities. Financial resources may influence both the affordability of mobile phones and the capacity to produce and market agricultural output. Accordingly, RUT provides a theoretical basis for specifying separate binary choice equations with a common set of explanatory variables. The unobserved components of these decisions may also be correlated, although the existence and magnitude of such correlation remain empirical questions.

2.2 Empirical Review

2.2.1 Socioeconomic and Institutional Determinants of Mobile Phone Ownership

The expansion of mobile communication technologies has created opportunities for improving information exchange and economic coordination in rural areas. Evidence from Sub-Saharan Africa suggests that mobile phones can reduce communication constraints and support access to information and financial services (Aker & Mbiti, 2010). In Tanzania, mobile-cellular subscriptions increased substantially between 2000 and 2022, reflecting the growing reach of mobile communication services. As illustrated in Figure 1, subscriptions increased from 0.32 per 100 inhabitants in 2000 to 91.9 in 2022 (Tylor, 2023). Nevertheless, subscription density should not be interpreted as the proportion of individuals owning mobile phones, since individuals may hold multiple subscriptions.

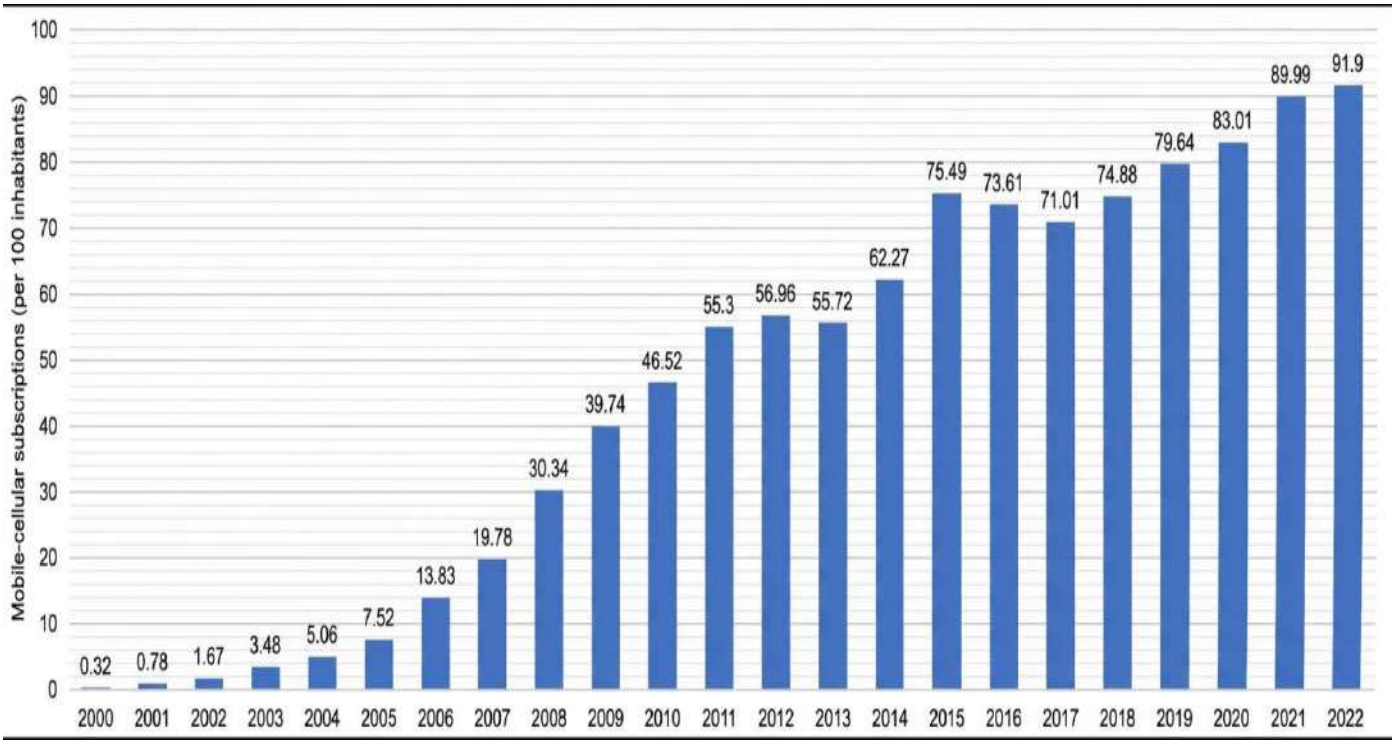


Figure 1
Mobile-cellular subscriptions per 100 inhabitants in Tanzania, 2000–2022.
Source: Tylor (2023).

Although Figure 1 demonstrates substantial growth in mobile-cellular subscriptions, the expansion of telecommunications services does not necessarily imply that smallholder farmers use mobile phones for agricultural marketing. Mobile phone ownership and effective use are distinct concepts, and the benefits associated with mobile technologies depend on farmers' socioeconomic characteristics, digital capabilities and access to relevant services

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(Aker & Mbiti, 2010; Kabbiri et al., 2018). Consequently, the increasing availability of mobile communication services raises an important empirical question concerning whether the factors associated with mobile phone ownership also influence farmers' participation in agricultural markets.

Kabbiri et al. (2018) examined mobile phone adoption in the agri-food sector and highlighted the importance of understanding the conditions influencing farmers' access to communication technologies. Similarly, Mwantimwa (2019) investigated mobile phone use among agro-pastoralist communities in Tanzania, demonstrating the relevance of local socioeconomic circumstances to technology engagement. The study has also highlighted the distinction between mobile phone ownership and the effective use of mobile services. James (2019) examined the welfare implications of mobile phones in Africa, while Malm and Toyama (2021) considered the socioeconomic benefits and burdens associated with mobile phone ownership in Tanzania. These studies indicate that access to technology should not automatically be equated with economic benefits.

In agricultural settings, digital skills, financial resources, communication costs and access to supporting infrastructure may influence farmers' ability to acquire and use mobile phones (Anadozie et al., 2022; Kabbiri et al., 2018). Studies of agricultural mobile services also emphasise the importance of users' capabilities and local conditions in shaping technology adoption (Muromba et al., 2025; Mwaseba et al., 2024). In General, the literature suggests that mobile phone ownership is associated with a combination of individual, household and institutional characteristics. This provides the basis for the first research objective, which examines the socioeconomic and institutional factors associated with mobile phone ownership among smallholder maize farmers in Tanzania.

2.2.2 Determinants of Smallholder Farmers' Maize Market Participation

Agricultural market participation is an important dimension of smallholder commercialisation because it enables farmers to exchange agricultural output for income. However, participation is influenced by production capacity, household needs, market opportunities and institutional conditions. Chikuni and Kilima (2019) examined smallholder market participation and mobile phone-based market information services in Malawi, highlighting the relevance of information access in agricultural marketing. In Tanzania, studies have investigated the role of agricultural supply chain conditions and socioeconomic characteristics in farmers' market participation decisions (Changalima & Ismail, 2022; Siwandeti et al., 2023).

Evidence from other African countries similarly identifies the importance of demographic, socioeconomic and institutional factors. Tafesse et al. (2023) examined determinants of maize farmers' market participation in southern Ethiopia, while Mkuna and Wale (2022) investigated the relationship between market orientation, participation and farmers' income in South Africa. The reviewed studies suggest that market participation is associated with both farmers' productive capacity and their ability to overcome transaction costs. Access to productive resources may facilitate the generation of marketable surpluses, while financial resources can support production and marketing activities. Market prices may also influence the expected benefits of selling agricultural produce. However, household characteristics such as age, education and participation in non-farm employment may have different associations with market engagement depending on farmers' livelihood strategies and resource constraints. These considerations support examining the selected socioeconomic, institutional and market-related variables within a common empirical specification.

Productive resources and financial capacity may enable farmers to produce marketable surpluses, meet transaction costs and respond to market opportunities. Educational attainment may also influence farmers' ability to access and interpret market information. Nevertheless, the relationships between these factors and market participation can vary according to household circumstances and the prevailing market environment. The literature therefore supports examining plot ownership, age, sex, educational attainment, livelihood activities, loan amount, maize unit price and credit-group membership as potential correlates of maize market participation. These considerations inform the second research objective.

2.2.3 Common Determinants of Mobile Phone Ownership and Market Participation

Previous studies have examined different aspects of mobile technology access, agricultural information services and market participation. For example, Urassa and Mvena (2016) investigated the use of mobile phones to access cattle market information in Tanzania, while Mbedule and Mungwabi (2023) examined smallholder orange farmers' access to market information. Yao and Shanoyan (2018) explored mobile money applications and smallholder market participation in Côte d'Ivoire and Tanzania. These studies provide useful evidence concerning digital technologies and agricultural marketing. However, technology ownership, technology use and market participation represent analytically distinct outcomes. The socioeconomic conditions associated with owning a mobile phone may not be identical to those associated with selling agricultural produce.

Moreover, shared observed determinants should be distinguished from dependence between unobserved factors. For example, education may be positively associated with both outcomes even when their residual correlation is not statistically significant. Conversely, correlated unobserved characteristics may exist even where individual

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explanatory variables have different associations across equations. A joint modelling approach can examine these issues by estimating separate binary equations while allowing correlation between their disturbances. The non-recursive bivariate probit model is suitable for this purpose because it permits an empirical test of residual correlation without specifying one observed outcome as a causal determinant of the other.

This distinction addresses the third research objective, which examines the common observable determinants of mobile phone ownership and maize market participation and tests whether residual statistical dependence remains after controlling for the included characteristics. The resulting evidence may help identify whether interventions targeting digital inclusion and agricultural marketing should address shared socioeconomic constraints, outcome-specific constraints or both.

III. METHODOLOGY

3.1 Research Design

This study employed a cross-sectional research design to analyse data collected between 2020 and 2021. The cross-sectional approach facilitates the examination of relationships among variables at a specific point in time, enabling an efficient assessment of the factors influencing mobile phone ownership and maize market participation (Saunders et al.,2012).The primary data source was the National Panel Survey Wave 5 (NPS Wave 5), conducted by the Tanzania National Bureau of Statistics and administered by the World Bank (NBS, 2022).

3.2 Study Area

The study covered Tanzania Mainland and Zanzibar, drawing on the geographical strata used in the survey: Dar es Salaam, other urban areas of Mainland Tanzania, rural Mainland Tanzania and Zanzibar. These strata capture differences in settlement patterns, infrastructure and socioeconomic conditions relevant to agricultural production and access to communication technologies.

3.3 Target Population and Sampling

The target population comprised smallholder maize farmers across the identified regions: Urban Mainland, Rural Mainland, Dar es Salaam, and Zanzibar. This population segment is central to the study's focus on agricultural market participation and technology adoption within Tanzania's maize supply chain.

The study utilised secondary data drawn from Tanzania's National Panel Survey. The original survey employed a stratified, multistage sampling design. For the present analysis, observations were selected based on the availability of information on maize production, mobile phone ownership, market participation and the explanatory variables and the final estimation sample comprised 1,578 analytical observations.

3.4 Data collection instruments and Procedures

The study relied on secondary data obtained from the Tanzania National Panel Survey, which collected information using structured household and agricultural questionnaires administered by trained enumerators. The survey covered household socioeconomic characteristics, agricultural production, asset ownership and related economic activities. For the present study, relevant variables were extracted from the available survey files, harmonised and prepared for econometric analysis. No primary interviews or questionnaires were administered by the authors.

3.5 Data analysis

The study employed quantitative data analysis to examine the socioeconomic, institutional and market-related factors associated with mobile phone ownership and maize market participation among smallholder maize farmers in Tanzania .The analysis focused on the variables presented in Table 1,with their theoretical and empirical justification provided in Section 3.5.3.The two dependent variables were specified as binary outcomes, indicating whether a farmer owned a mobile phone and whether the farmer participated in the maize market. Descriptive statistics were used to summarise the characteristics of the analytical sample. Frequencies and percentages were employed for categorical variables, while appropriate measures of central tendency and dispersion were used for continuous variables. A non-recursive bivariate probit model was subsequently employed to estimate the associations between the explanatory variables and the two binary outcomes simultaneously. This approach allows the equations to have common explanatory variables while accounting for potential correlation between their unobserved components.

The analysis was limited to the variables specified in Table 1.The reasons for including these variables are explained in section 3.5.One crucial variable, the unit price of maize, was computed by dividing the total value of maize sold by the quantity sold, following a common method used in comparable studies (Kweka,2023; Lowder et al.,2016).The variables are used to examine two principal outcomes using binary variables: whether farmers owned a mobile phone and whether they participated in the maize market. In addition to evaluating the correlation strength between the two outcomes, the authors also computed the probability of observing both market participation (Yi1) and

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mobile phone ownership (Yi2) to identify factors that affect both outcomes simultaneously. Mathematically, the expression for the joint probability is given as:

"p" ("y" _"i1" "=1," "y" _"i2" "=1|" "X" _"1" "," "X" _"2")"=φ" (〖〖"β'" 〗_"2" "X" 〗_"2" "," 〖〖 "β'" 〗_"1" "X" 〗_"1" ",ρ")…… (7)

where "φ" is the cumulative distribution function of the bivariate standard normal distribution, β denotes the parameters of the bivariate model to be estimated using the maximum likelihood method whereas X' is a vector of the covariates. The bivariate probit model was estimated in the STATA software (StataNow 19.5) with robust standard errors to account for heteroscedasticity and other potential specification errors, considering the cross-sectional nature of the study (Yao & Shanoyan,2018).Additionally, we assessed the correlation among the explanatory variables using the Variance Inflation Factor (VIF) and found that all VIF values were below 10, implying no significant multicollinearity (Gujarati, 2004).

The estimated coefficients illustrate how various factors impact the two primary outcomes. A positive and statistically significant coefficient for a specific variable indicates that as its value rises, the probability of both owning a mobile phone and participating in the market also increases. The correlation coefficient (ρ) quantifies the strength and direction of the linear relationship between the two latent variables. In this instance, a positive correlation indicates that individuals who are more inclined to own a mobile phone are also more likely to participate in the market, and vice versa.

3.5.1 Analytical Model

Since, "U" _"i1" " " and "U" _"io" are unobservable, empirical analysis requires treating these variables as a function of observable characteristics ("Z" _"i") of the ith decision maker. In a latent variable framework, the joint probability of 1 and 0 outcomes, are given as:

"U" _"i1" ("Z")"=" "β" _"1" "Z" _"i" "+" "ε" _"i1" for 1 outcome, and (2)

"U" _"i0" ("Z")"=" "β" _"0" "Z" _"i" "+" "ε" _"i0" for 0 outcome (3)

According to the proposed model, U_{i1} is an indicator of mobile phone ownership and participation in the commodity market, otherwise the indicator is U_{i0}; β *is* a vector of parameters to be estimated; ε_{i1} *and* ε_{i0} are the error terms assumed to be independently and identically distributed with a mean of zero and known variances (σ_{i1}^2 *and* σ_{i0}^2). The joint probability of a farmer owning a mobile phone and participating in the commodity market is presented as:

$$
\begin{aligned}
&p(1)=p(U_{i1}>U_{i0}) \\
&p(1)=p(\beta_1 Z_i+\varepsilon_{i1}>\beta_0 Z_i+\varepsilon_{i0}) \\
&p(1)=p(\varepsilon_{i0}-\varepsilon_{i1}<\beta_1 Z_i-\beta_0 Z_i) \\
&p(1)=p(\varepsilon<\beta Z_i) \\
&P(1)=\varphi(\beta Z_i)
\end{aligned} \qquad (4)
$$

Where φ is the cumulative density function for ε. The assumption underlying the distribution of the error term determines the functional form of φ. In our preferred probit model, we assume that the error term follows a normal distribution. Since we assume the decision are interrelated, we use the bivariate probit as it incorporates the correlation between the error terms in both choices. This is crucial because various factors, whether known or unknown, can simultaneously influence both outcomes.

3.5.2 Empirical Model

The conceptualization of the model involving the two binary choices Y_{i1}, and Y_{i2} is given as:

$$
\begin{aligned}
&Y^*_{i1}=\beta_1 X_{i1}+\mu_{i1} \\
&Y_{i1}=1 \; if \; Y^*_{i1}>0 \\
&Y_{i1}=0 \text{ otherwise.}
\end{aligned} \qquad (5)
$$

and;

$$
\begin{aligned}
&Y^*_{i2}=\beta_2 X_{i2}+\mu_{i2} \\
&Y_{i2}=1 \; if \; Y^*_{i2}>0 \\
&Y_{i2}=0 \text{ otherwise}
\end{aligned} \qquad (6)
$$

Analytically, there is no concrete theoretical foundation for deciding whether mobile phone ownership or agricultural market participation should come first in a bivariate model. The Agricultural Household Model conceptualizes farmer's decision to own a mobile phone and use it for market-related transactions as jointly determined decisions (Mangole et al., 2025). Scholarly work suggests that both decisions are shaped by household resources, individual preferences, and prevailing market imperfections; for example, farmers may acquire mobile

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phones in anticipation of engaging in markets (Amoussohoui et al., 2024). However, participation in markets can simultaneously be perceived as a farmer's means to mobilize financial resources required to own a mobile phone, implying mutual causality (Nwangwu et al., 2024). Consequently, the empirical specification does not impose a predefined temporal or causal sequence when determining the relationship between the choices being modelled.

Y_{i1} in equation (5) is a binary choice variable for owning a mobile it assumes a value of if a farmer owns the device, and 0 otherwise; X_{i1} is a vector of exogenous variables underlying the ownership and β_1 is a vector of parameters to be estimated, and; μ_{i1} is the residual for i=1, 2 … n, where n is the number of observations.

Y_{i2} in equation (6) is a binary variable representing the probability of a farmer participating in the commodity market; X_{i2} is a vector of exogenous variables underlying market participation decision; β_2 is a vector of the parameter to be estimated; μ_{i2} is the error term. The common assumption is that the errors in equations (5) and (6) are normally distributed with a mean of zero and a variance of one. These errors are perceived to be correlated i.e., $corr\ (\mu_{i1}, \mu_{12}) = \rho$ where $\rho \neq 0$, implying that equations (5) and (6) are dependent. The parameters of both models can be jointly estimated using the maximum likelihood approach. This study examines the factors that influence both mobile phone ownership and market participation among farmers, investigating whether there are common variables impacting these outcomes.

3.5.3 Description of Variables

Grounded in the random utility theory presented in section two, farmers' decisions regarding mobile phone ownership and market participation are assumed to be shaped by observable socio-economic characteristics such as education, asset endowments, and access to financial resources. Gender dynamics manifested through cultural norms and unequal access to resources significantly disadvantage women in Africa, especially regarding land ownership, a critical factor for agricultural success. Studies show that women often have limited access to land, improved technologies and credit, and are less likely to benefit from extension services (Mujeyi et al., 2020; Djurfeldt, 2021). The disparity extends to mobile phone use because men typically have advantages in literacy, skills for effective use of mobile phones, and income-generating opportunities compared to women (Panta et al., 2023; Sekabira & Qaim, 2017). This gives male users a head start in using ICT for agricultural purposes. These advantages in conjunction with their stronger market networks (Dessie et al., 2018), can allow men to leverage mobile phones effectively for faster and more efficient business transactions.

Literature reveals that higher levels of income mitigate the fundamental financial barriers, such as the cost of acquiring handset as well as expenditure on airtime and charging the devices. These expenses normally prevent resource-constrained smallholders from adopting mobile phones, a pattern well-documented in the literature on technology adoption in rural Sub-Saharan Africa (Kabbiri et al., 2018). Income also plays a significant role in farmer's decision to participate in commodity markets. Having a stable income can reduce the risk associated with selling crops or producing specifically for the market (Mkuna & Wale, 2022). This applies not just to income from farming, but also income earned through other means, like off-farm activities (Camara, 2017). With a financial safety net, farmers are more likely to embrace the potential benefits and risks of selling produce in formal markets.

Farmer groups can be powerful tools for overcoming liquidity constraints and other challenges facing individual farmers. While some concerns like agency costs and increased bureaucracy exist (Nilsson, 2018), the advantages accorded through membership could outweigh such challenges. In the context of agricultural marketing; the prospects for farmers to pool their resources, can allow them to gain access to better financial services, equipment, storage facilities, or transportation at a lower cost. Furthermore, through collective bargaining, the group can negotiate better prices with buyers due to larger quantities and potentially improved quality control. Additionally, groups normally work together to gather valuable market information and access essential business support services that might be difficult for individual farmers to obtain on their own (Borda-Rodriguez et al., 2016). These groups are also recognized as suitable platforms for enabling farmers to save and access credit services. The access to credit can enable them to commercialize crop production and obtain mobile phones, thereby enhancing their participation in the commodity market (Kibona & Yuejie, 2021).

Literature reveals a positive association between farmers' land ownership and mobile phone ownership. Land ownership is perceived as an indicator of greater wealth, financial stability, and access to credit, which enables farmers to overcome the significant cost barriers (handset acquisition, airtime and charging) associated with mobile technology. Furthermore, landowners often have larger, more commercialized operations that incentivise them to use phones for market access (Chikuni & Kilima, 2019; Kabbiri et al., 2018; Abafita et al., 2016).

Other variables worth considering include the farmer's age, education level, exposure to business and income opportunities, use of casual labour, and maize price. Age plays a complex role in mobile phone ownership and market participation among farmers. Younger farmers tend to be more receptive to new technologies and embrace new markets. This openness can potentially increase their efficiency and access to markets (Kilima et al., 2016; Subert et al., 2018). On the other hand, older farmers may have accumulated wealth over time. This financial advantage allows them to invest in improved technologies for both production and communication, potentially giving them an edge in

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accessing commodity markets (Awotide et al., 2012). Moreover, the extensive expertise of elderly farmers can be beneficial in navigating market networks and lowering transaction expenses (Haile, 2022; Hlatshwayo, 2022). Thus, the influence of this variable on the probability of observing the joint outcomes hinges on the relative weight of the advantages favouring younger farmers over older ones.

Education equips farmers with the tools they need to succeed in markets. Studies show that educated farmers are better equipped to understand market dynamics, negotiate effectively, and access valuable information through digital platforms (Hlatshwayo et al., 2022; Magesa et al., 2020). This advantage translates to lower transaction costs and a smoother market entry point. Farmers' exposure to business and income opportunities, is perceived to enhance the chances of success (joint probability), as mobile phones have become vital tools for business people. These devices enhance farmers' access to essential business information, support services, and help expand their market reach (Obong et al., 2018). The increased exposure provides valuable experience that eases their entry into and participation in commodity markets.

While working as a paid casual labourer can potentially lead to increased household income, studies suggest that it can also come at a cost. Farmers who are fully engaged in off-farm activities have less time devoted to their crops, potentially leading to lower crop production (Yaro et al., 2017). Additionally, the income earned from these jobs may not be directly invested back into the farm. Instead, it might be used for immediate household needs, with little impact on a household's participation in agricultural markets (Woldeyohanes et al., 2017). Maize price is a critical factor that influences farmers' income. A farmer's income level plays a crucial role in their decision to participate in the market. Higher income can lead to increased motivation and the ability to invest in assets including mobile phones, which can further enhance their livelihoods (Tafesse et al., 2023; Osmani & Hossain, 2015).

The study applied the empirical model (Equations 5 and 6) to evaluate the likelihood of farmers owning mobile phones and participating in maize markets. It investigates whether Tanzanian smallholder farmers gain an advantage in maize markets through mobile phone ownership. To avoid assuming these actions are independent, the study recognizes the potential link between acquiring a mobile phone and actively using it for market engagement. This examination introduces fresh insights into the existing literature on how mobile phone ownership might influence smallholder farmers' market participation. To ensure robust conclusions, the analysis uses national-level data from both mainland Tanzania and Zanzibar, considering various factors (covariates) and their combined effect on the outcomes as outlined in Table 1.

Table 1

Covariates of the Bivariate Probit Model

Variable	**Description**	**Hypothesized effects on the joint probability**
Plot ownership	Ownership of a plot (1= Yes; 0=No)	Positive
Sex	1 = Male 0= Women	Higher for men than women
Age	Age in years	Positive/negative
Non-farm enterprises	Whether a farmer is involved in non-farming activities (1= Yes; 0=No)	Higher for farmers involved
Loan amount	Value of credit (TZS)	Positive
Casual labour	Whether a farmer works as an employee on a salary, wage, or commission (1= Yes; 0=No)	Negative
Unit price of maize	Maize unit price (TZS)	Positive
Education levels	Education level of a farmer as a categorical variable (pre-primary, primary, secondary and tertiary)	Higher for more educated farmers
Belonging to a group with access to credit	Whether a farmer is affiliated with SACCOs and has accessed credit	Positive

Source: Data compilation based on NPS Wave 5 dataset (2020/21)

Operationally, all variables included in the analysis were rigorously validated. The process involved a visual and statistical audit against the original survey instrument to ensure the variables were precisely defined and measured. We conducted a preliminary descriptive analysis to identify and address outliers and missing values. Binary variables were verified to have correct numeric codes and value labels, ensuring the accurate identification of reference and comparison groups. Ordinal categorical variables, such as farmers' education level, were confirmed to reflect a meaningful hierarchical order and were subsequently treated as factor variables in the empirical model, with the lowest category set as the reference group. To facilitate meaningful reporting, we adhere to standard practice: continuous variables are summarized using descriptive statistics (measures of central tendency and dispersion), while categorical variables are presented in frequency tables with percentages. In the bivariate probit model specification, all

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binary and categorical variables are declared as factors. Prior to their inclusion in the empirical model, continuous variables were assessed for their functional form to ensure robust and interpretable results.

3.6 Ethical Considerations

This study involved secondary analysis of existing household survey data. The analysis used anonymised records and did not involve direct interaction with survey respondents. Data were used exclusively for academic research, and no personally identifying information was reported. The study followed the applicable data-access and confidentiality requirements of the survey provider. Ethical approval and informed consent procedures associated with the original survey should be reported in accordance with the survey's official documentation.

IV. FINDINGS & DISCUSSION

4.1 Findings

Table 2 shows that many of the smallholder maize farmers within the sample were men (82.13%) and over 51 years old (52.16%). Additionally, a majority had primary education or lower (85.55%). A significant number of farmers owned plots (66.22%). Only a fraction of the farmers (41.76%), were actively engaged in non-farming activities. The majority of these farmers (92.21%) were neither affiliated with credit groups nor engaged in casual labour (83.84%). A substantial percentage of farmers (93.85%) owned mobile phones although only a minority (28.14%) actively participated in maize markets.

Table 2

Respondents' Characteristics

Variable description	Value	Frequency	Percent
Whether the household head owns a mobile phone	No	97	6.15
	Yes	1481	93.85
	Total	1578	100
Whether the household head participates in maize markets	No	1134	71.86
	Yes	444	28.14
	Total	1578	100
Whether a female household head participate in markets	No	212	75.18
	Yes	70	24.82
	Total	282	100
Whether a male household head participate in markets	No	922	71.14
	Yes	374	28.86
	Total	1296	100
Whether the household head is controlling a farm plot	No	533	33.78
	Yes	1,045	66.22
	Total	1578	100
Sex	Female	282	17.87
	Male	1296	82.13
	Total	1578	100
Whether the household head is involved in non-farm enterprises	No	919	58.24
	Yes	659	41.76
	Total	1578	100
Whether the household head is a member of saving and credit co-operative society (SACCOs)	No	1455	92.21
	Yes	123	7.79
	Total	1578	100
Whether the household head work as casual labour	No	1323	83.84
	Yes	255	16.16
	Total	1578	100
Education status of household head	Primary	1350	85.55
	Secondary	205	12.99
	Tertiary	23	1.46
	Total	1578	100
Age of household head	<=30 years	104	6.56
	31-50 years	651	41.25
	51-70 years	607	38.47
	71-90 years	210	13.31
	>=91	6	0.38
	Total	1578	100.00

Source: Data compilation based on NPS Wave 5 dataset (2020/21)

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Table 3

Results from Bivariate Probit Regression

Description	Coefficient	Robust std. error	z	*p*>|z|	[95% conf. interval]	
Market participation						
Plot ownership	1.075***	0.212	5.070	0.000	0.659	1.491
Sex	0.436**	0.217	2.000	0.045	0.010	0.862
Age	-1.040***	0.145	-7.170	0.000	-1.325	-0.756
Non-farming enterprises	0.158	0.121	1.310	0.192	-0.079	0.395
Engagement in casual employment	-0.522***	0.149	-3.510	0.000	-0.813	-0.231
Unit price of maize	2.711***	0.171	15.860	0.000	2.376	3.045
Loan amount	0.060***	0.012	5.020	0.000	0.036	0.083
Primary education	0.397**	0.187	2.120	0.034	0.030	0.765
Secondary education	0.598**	0.244	2.450	0.014	0.120	1.077
Tertiary education	0.503*	0.273	1.840	0.065	-0.032	1.038
Belonging to a group with access to credit	0.860***	0.205	4.200	0.000	0.459	1.261
Constant	-11.591	1.013	-11.440	0.000	-13.576	-9.606
Phone ownership						
Plot ownership	-0.049	0.085	-0.580	0.564	-0.215	0.117
Age	0.509***	0.099	5.130	0.000	0.314	0.703
Sex	0.294**	0.131	2.250	0.024	0.038	0.550
Non-farming enterprises	0.606***	0.089	6.780	0.000	0.431	0.782
Engagement in casual employment	-0.165	0.113	-1.460	0.144	-0.388	0.057
Unit price of maize	0.042	0.059	0.710	0.478	-0.074	0.157
Loan amount	0.003	0.012	0.230	0.815	0.021	0.027
Primary education	0.547***	0.090	6.080	0.000	0.370	0.723
Secondary education	1.154***	0.182	6.340	0.000	0.797	1.510
Tertiary education	1.017**	0.500	2.030	0.042	0.036	1.998
Belonging to a group with access to credit	5.563***	0.203	27.370	0.000	5.165	5.962
Constant	-1.421**	0.609	-2.330	0.020	-2.615	-0.228
/athrho	0.16*	0.10	1.68	0.094	-0.03	0.36
rho	0.16	0.10			-0.03	0.34
Wald test of rho=0	$chi^2(1) = 2.80749$		Prob > chi^2= 0.0938			
Number of observations	1,578					
Wald chi2(26)	1232.95					
Log pseudolikelihood	-843.63464					
Prob > chi2	0.0000					

***$p<0.01$, **$p<0.05$, *$p<0.1$

Source: Data compilation based on NPS Wave 5 dataset (2020/21)

Table 4

Marginal effects of regressors on joint outcomes

Variable	*dy/dx*	Std. Err.	*z*	*p*>*z*	[95% C.I]	
Plot ownership*	0.178***	0.028	6.410	0.000	0.123	0.232
Sex*	0.082***	0.030	2.770	0.006	0.024	0.140
Age	-0.001***	0.000	-6.540	0.000	-0.001	0.000
Non-farming enterprises	0.044*	0.024	1.800	0.071	-0.004	0.092
Engagement in casual employment*	-0.087***	0.020	-4.340	0.000	-0.126	-0.048
Unit price of maize	0.002***	0.000	23.950	0.000	0.002	0.002
Loan amount	0.012***	0.002	5.510	0.000	0.008	0.016
Primary education*	0.084***	0.031	2.670	0.008	0.022	0.146
Secondary education*	0.172**	0.076	2.270	0.023	0.023	0.321
Tertiary education*	0.148*	0.089	1.670	0.095	-0.026	0.321
Belonging to a group with access to credit *	0.099***	0.015	6.480	0.000	0.027	0.219

(*) *dy/dx* is for discrete change of dummy variable from 0 to 1

Source: Data compilation based on NPS Wave 5 dataset (2020/21)

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Table 3 reveals presence of common variables that drive both decisions. Similarly, the results presented in Table 4 also reveal that many of the variables that influence farmers' ownership of mobile phones also impact their likelihood of market participation. However, the test for rho (ρ) = 0 reveals limited association between the two outcomes. The results presented in Table 3 indicate that some socioeconomic and institutional characteristics are associated with both mobile phone ownership and maize market participation, although their effects differ across the two equations. The Wald test of residual independence ($\chi^2(1) = 2.81$, $p = 0.094$) indicates insufficient evidence to reject the null hypothesis of zero residual correlation at the 10% significance level. This finding does not imply the absence of common observed determinants. Rather, it suggests that the unobserved components of the two decisions are not significantly correlated at the conventional 5% level after accounting for the included explanatory variables.

Results in Appendix 1 show that the decision of Tanzanian smallholder farmers to own a mobile phone is significantly associated with human capital, financial inclusion, and resource accumulation. Higher levels of education are the strongest positive drivers, with secondary education exerting the largest marginal effect (increasing the probability of ownership by 15.2 percentage points). Belonging to a credit group also significantly boosts ownership likelihood by 10.2 percentage points. Furthermore, older age and involvement in non-farming enterprises have significant positive effects, increasing ownership probability by 13.5 and 12.5 percentage points, respectively, highlighting the roles of life-stage resource accumulation and diversified income. Male farmers are six percentage points more likely to own a phone than their female counterparts. Variables such as plot ownership, engagement in casual labour, maize price, and loan amount were not statistically significant predictors in this model.

Results presented in Appendix 2 show that the decision to participate in maize markets is primarily driven by economic capacity, market incentives, and access to capital. However, it also exhibits significant social and demographic constraints. The most powerful driver is the economic incentive, as a higher maize price raises the probability of market participation by 59.1 percentage points. The ownership of productive assets (land), represented by plot ownership, increases participation probability by 19.9 percentage points. Access to capital is also a critical factor, with larger loan amounts raising participation likelihood by 1.3 percentage points per unit. Education also shows a positive effect, with primary and secondary education being significant positive predictors. Conversely, several factors strongly inhibit market entry. Being male increases participation probability by 22.8 percentage points compared to females, and engagement in casual labour reduces it by 9.2 percentage points. Belonging to a credit group has a significant positive association with market participation, increasing the probability by 11.3 percentage points. Age shows a small positive effect (8.2 percentage points), while involvement in non-farm enterprises and tertiary education are not statistically significant predictors.

4.2 Discussion

The positive association between educational attainment and mobile phone ownership is consistent with literature identifying human capital as an important factor in overcoming knowledge and skills barriers to technology adoption. Higher levels of education may strengthen farmers' ability to recognise the potential benefits of mobile phones for communication, information access and business activities (Anadozie et al., 2022). The reported positive association between credit-group membership and mobile phone ownership is also consistent with arguments concerning the importance of financial resources in overcoming technology acquisition and usage costs (Mensah, 2021). Similarly, the positive association between age and mobile phone ownership may reflect the accumulation of financial resources and experience among older farmers (Awotide et al., 2012). Involvement in non-farm enterprises may provide additional income and business-related incentives for owning communication technologies. Furthermore, the positive association between being male and mobile phone ownership is consistent with documented gender inequalities in access to financial resources, education and digital opportunities (Panta et al., 2023; Sekabira & Qaim, 2017).

The findings concerning maize market participation highlight the relevance of economic, productive and institutional characteristics. The reported positive association between maize unit price and market participation is consistent with the economic expectation that favourable market prices may encourage farmers to sell agricultural produce (Tafesse et al., 2023). Likewise, the positive association between plot ownership and market participation suggests that access to productive resources may facilitate market engagement, although plot ownership does not necessarily indicate the quantity of land cultivated or the volume of marketable surplus (Chikuni & Kilima, 2019). The positive association with loan amount may reflect the role of financial resources in supporting agricultural production and marketing activities (Kibona & Yuejie, 2021). Educational attainment is also positively associated with market participation, potentially reflecting farmers' ability to obtain and interpret market information and manage transaction costs (Hlatshwayo et al., 2022; Magesa et al., 2020).

In contrast, the negative association between casual employment and maize market participation may indicate competing demands on household labour and time, particularly where off-farm employment limits involvement in agricultural production and marketing (Woldeyohanes et al., 2017). The reported positive association between being

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male and market participation may reflect differences in access to productive resources and market networks, although these mechanisms are not directly tested in the present analysis (Dessie et al., 2018). Similarly, the positive association between credit-group membership and market participation may be consistent with the role of collective arrangements in facilitating access to finance, information and marketing opportunities (Borda-Rodriguez et al., 2016). The negative association between age and market participation reported in Table 3 may suggest that older farmers face constraints affecting market engagement, although the specific mechanisms require further investigation.

An important finding concerns the relationship between the unobserved components of mobile phone ownership and maize market participation. The Wald test of residual independence does not reject the null hypothesis of zero residual correlation at the 10% significance level ($\chi^2(1) = 2.81$, $p = 0.094$). This result indicates insufficient statistical evidence of residual dependence between the two outcomes after controlling for the included explanatory variables. It does not establish that the outcomes are independent, nor does it imply that they lack common observed determinants. Indeed, the estimated equations suggest that some socioeconomic and institutional characteristics are associated with both decisions.

The finding should also be distinguished from the effect of mobile phone ownership on market participation. Because the non-recursive bivariate probit model does not include mobile phone ownership as a determinant of market participation, it does not directly estimate such an effect. Nevertheless, previous studies suggest that technology ownership does not necessarily translate into effective agricultural marketing. Possible constraints include subsistence-oriented production, reliance on informal communication networks, limited digital capabilities and inadequate supporting infrastructure (Duncombe, 2016; Mpombo et al., 2022; Anadozie et al., 2022; Mensah, 2021). These explanations are consistent with the broader literature but were not directly tested in the present study.

The findings therefore suggest that interventions promoting digital inclusion and maize market participation should consider both shared socioeconomic constraints and barriers specific to each outcome. Measures supporting access to communication technologies may need to be complemented by interventions addressing productive resources, financial access, market opportunities and farmers' capacity to engage in agricultural markets. However, the effectiveness of these interventions requires further empirical assessment.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study examined the socioeconomic and institutional factors associated with mobile phone ownership and maize market participation among smallholder maize farmers in Tanzania using a bivariate probit model. The findings indicate that the two outcomes are associated with both common and outcome-specific determinants. Mobile phone ownership is positively associated with educational attainment, involvement in non-farm enterprises and credit-group membership, highlighting the potential importance of human capital and financial resources in facilitating access to communication technologies. In contrast, maize market participation is positively associated with plot ownership, loan amount and maize unit price, suggesting the importance of productive resources, financial capacity and market incentives in farmers' marketing decisions.

The Wald test of residual independence provides insufficient evidence to reject the null hypothesis of zero residual correlation at the 5% significance level. This finding suggests that the unobserved components of mobile phone ownership and maize market participation are not significantly correlated at this threshold after accounting for the included explanatory variables. However, it does not establish that the two outcomes are independent or that mobile phone ownership has no effect on market participation. The findings instead underscore the importance of distinguishing access to communication technologies from actual engagement in agricultural markets. Previous literature suggests that subsistence-oriented production, reliance on informal communication networks, limited digital capabilities and infrastructural constraints may affect the translation of technology access into productive market use, although these mechanisms were not directly examined in this study.

5.2 Recommendations

The findings suggest that policies promoting digital inclusion and agricultural market participation should address both shared socioeconomic constraints and barriers specific to each outcome. To promote digital inclusion, government agencies, mobile network operators and financial institutions should consider supporting affordable mobile services and practical digital literacy programmes, including through existing farmer organisations and credit groups. Such initiatives could strengthen farmers' capacity to access and use mobile communication technologies for agricultural activities.

To enhance maize market participation, policy interventions should prioritise improved access to productive resources, appropriate agricultural financing and reliable market information. Transparent pricing systems, collective marketing arrangements and stronger market linkages may help farmers respond to market opportunities and reduce transaction-related constraints. Coordinated efforts among government institutions, financial service providers, mobile

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network operators and farmer organisations are therefore important for creating an enabling environment that supports both digital inclusion and agricultural commercialization. Further research should examine whether and how the actual use of mobile phones for agricultural purposes influences market participation, including the roles of digital literacy, market information and institutional conditions.

Declaration of Interest

The authors declare that they do not have any known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1

Marginal Effects of variables hypothesized to influence farmers decision to own mobile phones

Variable	dy/dx	Std. err.	z	P>|z|	[95% C.I.]	
Plot ownership	-0.003	0.0185	-0.1400	0.8880	-0.0388	0.0336
Age	0.135***	0.0292	4.6300	0.0000	0.0778	0.1921
Sex	0.060**	0.0283	2.1100	0.0350	0.0042	0.1149
Non-farming enterprises	0.125***	0.0172	7.2700	0.0000	0.0916	0.1591
Engagement in casual employment	-0.046	0.0285	-1.6300	0.1040	-0.1021	0.0095
Unit price of maize	0.010	0.0128	0.7800	0.4350	-0.0151	0.0351
Loan amount	0.001	0.0026	0.4300	0.6660	-0.0040	0.0062
Primary education	0.128***	0.0234	5.4900	0.0000	0.0825	0.1742
Secondary education	0.152***	0.0138	11.0100	0.0000	0.1250	0.1791
Tertiary education	0.119***	0.0257	4.6300	0.0000	0.0688	0.1696
Belonging to a group with access to credit	0.102	0.0215	4.7600	0.0000	0.0601	0.1442

***$p<0.01$, **$p<0.05$, *$p<0.1$

Appendix 2

Marginal Effects of variables hypothesized to influence farmers decision to participate in maize markets.

Variable	dy/dx	Std. err.	z	P>|z|	[95% C.I.]	
Plot ownership	0.199***	0.0312	6.3600	0.0000	0.1374	0.2597
Age	0.082**	0.0344	2.4000	0.0170	0.0150	0.1496
Sex	0.228***	0.0324	7.0200	0.0000	0.1640	0.2911
Non-farming enterprises	0.032	0.0265	1.2100	0.2260	-0.0198	0.0841
Engagement in casual employment	-0.092***	0.0216	-4.2800	0.0000	-0.1348	-0.0501
Unit price of maize	0.591***	0.0524	11.2800	0.0000	0.4883	0.6937
Loan amount	0.013***	0.0026	4.9300	0.0000	0.0076	0.0176
Primary education	0.083**	0.0353	2.3500	0.0190	0.0136	0.1518
Secondary education	0.166**	0.0778	2.1400	0.0330	0.0137	0.3186
Tertiary education	0.146	0.0901	1.6200	0.1050	-0.0306	0.3225
Belonging to a group with access to credit	0.113	0.0168	6.7300	0.0000	0.0803	0.1463

***$p<0.01$, **$p<0.05$, *$p<0.1$

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