Digital Agriculture: Mobile Phones, Internet Agricultural Development in Africa

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2018

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DIGITAL AGRICULTURE: MOBILE PHONES, INTERNET & AGRICULTURAL DEVELOPMENT IN AFRICA

This study examines the non-linear relationship between mobile phones, internet and agricultural development in Africa for the period 2001-2015 using system generalized method of moments. The empirical results show a non-linear relationship between mobile phones, internet and agricultural development. Mobile penetration and squared mobile penetration have significant positive effects on agricultural value added, implying that mobile penetration has an increasing effect on agricultural value added. In contrast, internet usage has significant negative effects on agricultural value added, but squared internet usage has significant positive effects. Mobile phones and internet play significant roles in agricultural development, as agricultural development also plays important roles in the expansion of mobile phones and internet.

Еванс Оланії

ЦИФРОВЕ СІЛЬСЬКЕ ГОСПОДАРСТВО: МОБІЛЬНІ ТЕЛЕФОНИ, ІНТЕРНЕТ І РОЗВИТОК СІЛЬСЬКОГО ГОСПОДАРСТВА В АФРИЦІ

В статті розглядаються нелінійні відносини між мобільними телефонами, Інтернетом та розвитком сільського господарства в Африці на період 2001-2015 років з використанням системи загальновідомого методу моментів. Результати показують нелінійну зв'язок між мобільними телефонами, Інтернетом та розвитком сільського господарства. Мобільне проникнення та проникнення мобільних пристроїв надають значну вплив на сільське господарство, Використання Інтернету надає значну позитивну вплив на сільське господарство. Мобільні телефони та Інтернет мають значну роль у розвитку сільського господарства.

Эванс Оланни

ЦИФРОВОЕ СЕЛЬСКОЕ ХОЗЯЙСТВО: МОБИЛЬНЫЕ ТЕЛЕФОНЫ, ИНТЕРНЕТ И РАЗВИТИЕ СЕЛЬСКОГО ХОЗЯЙСТВА В АФРИКЕ

В статье исследуются нелинейные отношения между мобильными телефонами, Интернетом и развитием сельского хозяйства в Африке на период 2001-2015 годов с использованием системы обобщенного метода моментов. Результаты показывают нелинейную связь между мобильными телефонами, Интернетом и развитием сельского хозяйства. Мобильное проникновение и проникновение мобильных устройств оказывают значительное влияние на сельское хозяйство, Использование Интернета оказывает значительное положительное влияние на сельское хозяйство. Мобильные телефоны и Интернет имеют значительную роль в развитии сельского хозяйства.

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Introduction. Digital agriculture can be defined as digitization of the different aspects of the agricultural value chain. It can also be defined as targeted information services helping farmers to use new technology in order to increase productivity and profitability. Digital agriculture supports the development and delivery of timely, targeted information services to farmers on crop planting date, variety sown, real-time weather data and projected market prices. In digital agriculture, mobile phones and internet are important resources for enabling poor farmers to make informed decisions regarding their farming activities, especially in the rural areas of developing countries. Effective mobile penetration and internet usage based on farmers needs and with farmers' rural and socio economic constraints can bridge the knowledge and information divide, provide equitable markets and rural businesses, and contribute to agricultural growth.

While digital agriculture is advanced in developed countries such as the US, it is also applicable to smallholder farmers around the globe, and especially Africa. The agricultural sector is the mainstay of most African economies. It employs nearly 80% of African populations who are mostly small-scale farmers and depend on agriculture for their livelihoods. These small-scale farmers look up to research and extension agents as sources of information (Thiam and Matofari, 2018; Ameru, Odero and Kwake, 2018). However, this traditional approach is overstretched and under-resourced (Masuki et al, 2010; Thiam and Matofari, 2018). The new approach is digital agriculture using internet and mobile phones. In recent years, internet has experienced a fast growth trajectory in Africa, while mobile phones have risen to become the commonest technological device in the history of the continent in a short time, and they are still growing (Figure 1). Moreover, mobile phones and internet have brought various innovations (Evans, 2018a). For example, digital payments such as mobile money has benefitted famers, agricultural value chain actors and rural communities through safer transactions, access to investments, ability to save and eventual growth of agri-businesses (Potnis, Demissie and Rahman, 2017; Schuster, 2017; Evans, 2018a; Kabbiri et al, 2018; Shepherd, Turner, Small and Wheeler, 2018).
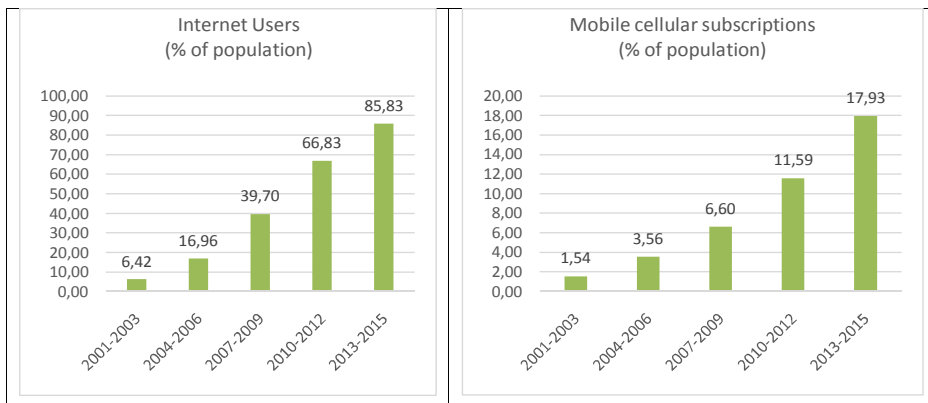

Figure 1. **Mobile Phones and Internet in Africa (2001-2015),** *World Bank (2017)*

Speculations and optimism have therefore been aroused that mobile phones and the internet can speed the way farmers in rural areas of Africa get, exchange and use information on agricultural decisions such as timely land preparation, planting, irrigation, weeding, harvesting, storage and marketing (Muriithi et al, 2009; Kabbiri et al, 2018). In other words, mobile phones and the internet can provide a possible pathway to ameliorate access to agricultural information as a major impediment for raising agricultural productivity among smallholders in Africa (Muriithi, Bett and Ogaleh, 2009; Aker and Ksoll, 2016; Karanasios and Slavova, 2018; Misaki, Apiola, Gaiani and Tedre, 2018).

As a result of these speculations, a variety of innovations that integrate mobile phones and the internet into the dissemination of agricultural information to farmers have been developed at local, national and regional levels in Africa (Asenso-Okyere and Mekonnen, 2012). For example, the Ethiopian Commodity Exchange (ECX) transmits information on commodity prices to farmers in real time, directly feeding market data to farmers via electronic display boards in 31 centers across Ethiopia and on its website. Market data is also provided via SMS and calls. Also using mobile phones to send price data to its database using the wireless application protocol, Manobi in Senegal provides access to price data on various crops, collected from different markets across the country. Farmers can use their mobile phones to query the database. Also, Market Information Systems and Traders' Organizations of West Africa in partnership with the private sector have developed an online platform to exchange market information online or by SMS on market prices, and an online space for producer and trader organizations to interact. In Ghana, Cargill purchased cocoa beans from farmers through digitised procurement records using a bar code tagging mechanism while farmers' payments are processed through a mix of e-Zwitch and MTN and Tigo's mobile money services.

While these initiatives are commendable, in the literature, few studies have debated the effects of mobile phones and the internet on agriculture, especially in Africa (e.g., Masuki et al, 2010; Furuholt and Matotay, 2011; Dlodlo and Kalezhi, 2015; Tadesse and Bahiigwa, 2015; Aker and Ksoll, 2016). The findings in the literature are at best ambiguous. Moreover, most of the studies are conceptual and micro-based, with little empirical attention to the non-linear relationship between mobile phones, internet and agriculture (e.g., Masuki et al, 2010; Furuholt and Matotay, 2011; Asenso-Okyere and Mekonnen, 2012; Duncombe, 2016). Even though this lack of rigorous empirical studies is attributed as the main cause of inadequate policy guidance in enhancing ICTs (Urquhart et al., 2008; Walsham, 2013; Evans, 2018a), little or nothing has been done to address this gap empirically.

This study thus fills the gap by examining the non-linear relationship between mobile phones, internet and agriculture across a panel of 44 African economies using system Generalized Method of Moments (GMM). Such identification and enquiry is key to any effort to understand and anticipate the potentials of mobile phones and the internet for agriculture in the continent.

The layout of this article is as follows. Section 2 reviews the theory and literature. Section 3 describes the data, models and methods. Section 4 presents the results. Section 5 is the discussion while section 6 concludes.

Theory & Literature Review. Diverse theories and models in the literature explain users' intention to use technology: theory of reasoned action, innovation diffusion theory, the social cognitive theory, theory of planned behaviour, the motivational model, technology acceptance models, the model of perceived credibility utilisation and a hybrid model combining constructs from technology acceptance models and theory of planned behaviour (Venkatesh et al., 2012; Tarhini, El-Masri, Ali and Serrano, 2016; Mansoori, Sarabdeen and Tchantchane, 2018). A review and synthesis of these eight models led to the unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003). UTAUT has been validated as a predictor of adoption behaviour with emphasis on performance expectancy and voluntariness as key drivers of acceptance (Tarhini et al, 2016). In relation to the current study, UTAUT is applicable because farmers accept and use mobile phones and internet if the technologies fit their needs and improve their performance. One of the constructs, performance expectancy, is key to the adoption of mobile phones and internet in agriculture. By enabling digital safer transactions, access to investments and ability to save for famers and agricultural value chain actors, and eventual growth of agri-businesses and rural communities, mobile phones and internet are expected to have huge impacts on agriculture.

Mobile phones and internet are widely recognized as a potentially transformative technology platform for developing nations (Asongu and Nwachukwu, 2016; Deichmann, Goyal and Mishra, 2016; Evans, 2018b). Various studies have therefore attributed numerous benefits to mobile phones and internet (Bhavnani, et.al., 2008; Lee and Lee, 2015; Asongu and Nwachukwu, 2016; Evans, 2018a; Evans, 2019). For example, Evans (2018b) found that internet usage has significant positive effect on economic wellbeing. The author also showed that there is bi-directional causality between internet usage and economic wellbeing in the short and long run, meaning that internet usage plays significant roles in increasing economic wellbeing in the short and long run. Also, Evans (2018a) found that internet and mobile phones have significant positive relationship with financial inclusion, meaning that rising levels of internet and mobile phones are associated with increased financial inclusion. Internet connectivity using mobile phone is an opportunity that the farmer in any rural area could explore to improve financial inclusion and communication with the outside world. Increase in mobile banking facilities such as M-Pesa, Z-Pesa, Zap and the like has provided an opportunity to reduce transaction costs and prevent farmers from travelling all the way to urban centers just for bank services. The Economist (2010) argued that internet can make agricultural markets more efficient, just as mobile phones can. The use of mobile phones and internet has been found to reduce information asymmetries, enabling users to access marketing, trade or arbitrage opportunities (Jensen, 2007; Anand and Kumaran, 2017; Asongu and Biekpe, 2018; Evans, 2018a). Through mobile phones and internet, for example, a farmer in a rural village can get up-to-date information regarding certain farming innovations; an agricultural extension worker can get updates on new technologies, commodity prices, rainfall forecasts, and use that information to advise farmers in rural villages (Asenso-Okyere and Mekonnen, 2012).

In the literature, a few studies have debated the effects of mobile phones and internet on agriculture in Africa (e.g., Jensen, 2007; Aker, 2010; Sekabira and Qaim,

2017; Kabbiri et al, 2018) For example, using market and trader-level data, Aker (2010) estimated the impact of mobile phones on price dispersion across grain markets in Niger. The author found that the introduction of mobile phone service between 2001 and 2006 explains a 10 to 16 percent reduction in grain price dispersion and the effect is stronger for market pairs with higher transport costs. Masuki et al (2010) found that farmers were excited about using mobile phone to access information on agriculture, natural resources management and marketing. Jensen (2007) found that the adoption of mobile phones by fishermen and wholesalers is associated with a dramatic reduction in price dispersion and the complete elimination of waste. For Uganda, Muto and Yamano (2009) found that, after the expansion of the mobile phone coverage, the proportion of the farmers who sold banana increased in communities more than 20 miles away from district centers.

Lwoga (2010) found that there was low use of internet for knowledge acquisition, while cell phones were becoming popular for farmers to communicate with telecenter operators and rural radio in case of emergency or advice regarding farming activities. Furuholt and Matotay (2011) showed that the improved access to mobile phones affects the entire cyclic farming life during the year and has resulted in considerable changes in livelihood, increased opportunities and reduced risks for rural farmers. There are a few other studies that have debated the effects of mobile phones and the internet on agriculture in Africa (e.g., Duncombe, 2016; Misaki, Apiola, Gaiani and Tedre, 2018; Kabbiri et al, 2018; Karanasios and Slavova, 2018). However, the findings in the literature are ambiguous. Moreover, most of the studies are conceptual and micro-based, with little empirical attention to the non-linear relationship between mobile phones, internet and agriculture. This study fills the gap.

Data and Methodology. The annual panel data used in this study covers the period from 2001 to 2015 for 44 African countries[1]. The data on official exchange rate, individuals using the internet (% of population), mobile cellular subscriptions (% of population), primary school enrollment, gross fixed capital formation (% of GDP), general government final consumption expenditure (% of GDP), domestic credit to private sector (% of GDP), agriculture value added (% of GDP), and GDP per capita growth are sourced from World Bank (2017) database. Data on corruption, regulatory quality and political stability and absence of violence are collected from Economist Intelligence Unit (2016).

Model. The objective of this study is to examine the non-linear relationship between mobile phones, internet and agriculture. There are many non-linear econometric models, but the Cobb-Douglas production function (the most recognized among them) is considered for this study (Cobb and Douglas,1928). It is given as:

$$Y = AK^{\alpha}L^{\beta} \tag{1}$$

Where *Y* is total income, *K* is capital, *A* is total factor productivity and *L* is labor. α and β are the elasticities of capital and labour respectively.

The logarithmic form is:

$$\ln Y = \ln A + \alpha \ln K + \beta \ln L \tag{2}$$

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[1] The list of countries is in the appendix.

Equation 2 can be applied to agriculture as follows,

$$Agr_t = \omega_0 + \omega_1 Gcf_t + \omega_2 Enr_t \tag{3}$$

Where *Agr* is agriculture value added, *Gcf* is gross capita formation (proxy for capital) and *Enr* is primary school enrollment (proxy for labour). Primary school enrollment is used as proxy for labour because basic education is required to be able to use mobile phones and internet as sources of agricultural information.

Based on the objectives of the study and the literature, the baseline model for the study is formed by including the quadratic function of the mobile penetration and internet usage variables:

$$Agr_{it} = \omega_0 + \omega_1 Gcf_{it} + \omega_2 Enr_{it} + \omega_3 Mobp_{it} + \omega_4 Mobp_{it}^2 \\ + \omega_5 Intt_{it} + \omega_6 Intt_{it}^2 + \varepsilon_{it} \tag{4}$$

Where *i* and *t* are indices for individual countries and time, *Mobp* is mobile cellular subscriptions (% of population) and *Intt* is individuals using the internet (% of population).

In order to preclude the omitted variable bias, the model used in this study follows the literature in including appropriate explanatory variables in the model (Gujarati 2003). Control factors which may affect agriculture include the economic and governance features of the countries (Bachev, Ivanov, Toteva and Sokolova, 2016; Elias, Nohmi, Yasunobu and Ishida, 2016; Garсна-Llorente, 2016; Wang et al, 2016) The following economic variables are introduced: growth of GDP per capita rate, bank credit/GDP, Government spending/GDP, interest rate and exchange rate.

$$Agr_{it} = \omega_0 + \omega_1 Gcf_{it} + \omega_2 Enr_{it} + \omega_3 Mobp_{it} + \omega_4 Mobp_{it}^2 + \omega_5 Intt_{it} + \omega_6 Intt_{it}^2 \\ + \omega_7 Cred_{it} + \omega_8 Intr_{it} + \omega_9 Gov_{it} + \omega_{10} Excr_{it} + \varepsilon_{it} \tag{5}$$

Where growth of *Cred* is bank credit/GDP, *Intr* is lending interest rate, *Gov* is Government spending/GDP, and *Excr* is exchange rate.

The second group of variables is classified as governance factors. These are political stability, regulatory quality and corruption.

$$Agr_{it} = \omega_0 + \omega_1 Gcf_{it} + \omega_2 Enr_{it} + \omega_3 Mobp_{it} + \omega_4 Mobp_{it}^2 + \omega_5 Intt_{it} + \omega_6 Intt_{it}^2 \\ + \omega_7 Cred_{it} + \omega_8 Intr_{it} + \omega_9 Gov_{it} + \omega_{10} Excr_{it} + \omega_{11} Pols_{it} + \omega_{12} Regq_{it} \\ + \omega_{13} Cor_{it} + \varepsilon_{it} \tag{6}$$

Where *Pols* is political stability, *Regq* is regulatory quality and *Cor* is corruption.

Econometric Technique. Arellano and Bover (1995) and Blundell and Bond (1998) proposed a system GMM estimator which combines differences with the regression in levels and using the lagged values of the dependent and other explanatory variables as the instruments for the regression in differences and the lagged differences of the explanatory variables as the instruments for the regression in levels. In this study, the system GMM is used for the estimations. The advantage of the system

GMM is that it avoids the problems of heteroscedasticity, autocorrelation, causality inverse and biasedness from omission of explanatory variables. There are two robustness tests in GMM estimation: the Sargan test and Arellano−Bond test. In this study, the Sargan test is used to test for over-identifying restrictions while Arellano−Bond test is used to test for autocorrelation.

Empirical Results. The descriptive statistics of the variables of interest for the 44 African countries are presented in Table 1. The means of agricultural value added (% of GDP), mobile cellular subscriptions (% of population) and internet users (% of population) are 21.04%, 48.48% and 9.61% respectively. The standard deviation is a measure of the amount of variation of a set of data values. For the sample of 44 countries, the standard deviations of mobile cellular subscriptions (% of population) and number of internet users (% of population) are high, depicting the level of digital divide. In addition, the correlation matrix of the variables is presented in Table 2. It can be seen that agriculture is positively correlated with mobile penetration and internet usage. Moreover, none of the values of the correlation coefficients between the explanatory variables is more than 0.7, meaning that multi-collinearity would not be a problem in the estimations.

Table 1. **Descriptive Statistics,** *author's*

	Agr	Cor	Cred	Enr	Excr	Gcf	Gov	Intt	Mobp	Pols	Regq	Intr
Mean	21.04	0.26	28.16	104.54	395.98	22.94	15.85	9.61	48.48	0.50	0.43	20.17
Median	19.83	0.25	17.13	105.97	77.02	22.27	15.19	4.29	39.96	0.50	0.40	15.77
Std. Dev.	13.80	0.21	29.01	18.20	672.00	7.25	5.77	12.44	40.42	0.18	0.14	32.45
Skewness	0.49	0.44	2.33	0.02	3.16	0.76	1.21	1.91	0.68	-0.04	-0.01	11.76
Kurtosis	2.50	2.80	8.87	3.10	16.40	4.46	5.41	6.05	2.62	2.71	3.16	175.53

Table 2. **Correlation Matrix,** *author's*

	Agr	Cor	Cred	Enr	Excr	Gcf	Gov	Intt	Mobp	Pols	Regq	Intr
Agr	1.00											
Cor	-0.43	1.00										
Cred	0.45	0.41	1.00									
Enr	0.08	0.12	0.01	1.00								
Excr	-0.42	-0.22	-0.31	0.28	1.00							
Gcf	0.24	0.25	0.01	0.03	0.06	1.00						
Gov	0.36	0.40	0.21	0.12	-0.22	0.31	1.00					
Intt	0.42	0.34	0.49	0.08	-0.24	0.27	0.25	1.00				
Mobp	0.35	0.33	0.36	0.05	-0.15	0.32	0.21	0.67	1.00			
Pols	-0.41	0.62	0.34	0.15	-0.20	0.31	0.34	0.27	0.32	1.00		
Regq	-0.08	0.51	0.32	0.09	-0.04	0.06	0.24	0.13	0.15	0.45	1.00	
Intr	-0.01	0.06	-0.04	-0.01	-0.09	0.02	-0.03	0.02	-0.04	0.12	0.07	1.00

To ensure that the results are robust to different specifications, three different estimations are carried out: the baseline model (I), the baseline model with macroeconomic variables (II) the baseline model with macroeconomic and governance variables (III). The results are presented in Table 3. Mobile penetration and squared mobile penetration have significant positive effects on agricultural value added, implying that an increase in mobile penetration is associated with an increase in agri-

Table 3. **System GMM Estimates,** *Agricultural value added (Agr)*

Variable	I		II		III	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
Gcf	0.06	0.08	0.34*	0.08	0.23*	0.08
Enr	0.22*	0.02	0.11*	0.03	0.08**	0.03
Mobp	0.15**	0.06	0.10**	0.05	0.09***	0.05
$Mobp^2$	0.10**	0.05	0.10***	0.06	0.09*	0.03
Intt	-1.25*	0.21	-0.81*	0.18	-0.70*	0.17
$Intt^2$	0.02*	0.00	0.01*	0.00	0.01*	0.00
Cred			0.68	0.71	0.71	0.71
Intr			-0.12*	0.02	-0.12*	0.02
Gov			0.02	0.10	0.03	0.10
Excr			-0.01*	0.00	-0.01*	0.00
Pols					1.16	0.36
Regq					0.21*	0.04
Cor					-0.93**	-0.33
R-squared		0.66		0.74		0.89
Adjusted R-squared		0.65		0.73		0.88
Sargan Test		0.31 [0.70]		1.11 [0.80]		1.25 [0.45]
AR(2)		2.10 [0.75]		0.68 [0.15]		[0.42]

Note: *, ** and *** denote the significance level of 1%, 5% and 10% respectively. denote p-value.

cultural value added. Likewise, internet usage has significant negative effects on agricultural value added, but squared internet usage has significant positive effects, implying a nonlinear relationship. Macroeconomic variables such as lending interest rates and exchange rates have significant negative effects. Among the governance variables, political stability has significant positive effects while corruption has significant negative effects.

It is important to determine the causal relations between mobile penetration, internet usage and agricultural value added. The results of the panel Granger causality analysis are presented in Table 4. The causality analysis suggests the existence of uni-directional causality from mobile penetration (Mobp) and internet usage (Intt) to agricultural value added. However, there is bi-directional causality between squared mobile penetration (Mobp2), squared internet usage (Intt2) and agricultural value added (Agr).

Table 4. **Panel Granger Causality Test Results,** *author's*

| *Direction of Causality*	*F-stat*
Agricultural value added (*Agr*) ⟶ Mobile penetration (*Mobp*)	**1.49**
Mobile penetration (*Mobp*) ⟶ Agricultural value added (*Agr*)	**3.07****
Agricultural value added (*Agr*) ⟶ Squared mobile penetration (*Mobp^2*)	**1.88**
Squared mobile penetration (*Mobp^2*) ⟶ Agricultural value added (*Agr*)	**2.56*****
Agricultural value added (*Agr*) ⟶ Internet usage (*Intt*)	**8.40***
Internet usage (*Intt*) ⟶ Agricultural value added (*Agr*)	**2.44*****
Agricultural value added (*Agr*) ⟶ Squared internet usage (*Intt^2*)	**11.88***
Squared internet usage (*Intt^2*) ⟶ Agricultural value added (*Agr*)	**2.23*****

Notes: *, ** and *** indicate statistical significance at 1, 5 and 10 percent. The optimal lag length was selected using the Schwarz information criteria.

Discussion and Implications. The objective of this study is to investigate the relationship between mobile phones, the internet and agriculture in Africa. Although the effects of mobile phones and internet on agriculture have been studied in the past, growing mobile phones and internet in the continent may have inspired a new set of behaviors and effects. The study is therefore different in examining the nonlinear relationship between mobile phones, internet and agriculture in Africa.

While most existing studies in the literature have proposed linear effects of mobile phones and internet on agriculture (e.g., Aker and Ksoll, 2016; Duncombe, 2016), this study has gone a step further and expanded the literature by uncovering the nonlinear relationship between mobile phones, internet and agriculture. The empir-

ical results indicate that mobile penetration and squared mobile penetration have significant positive effects on agricultural value added, implying that an increase in mobile penetration is associated with an increase in agricultural value added. In other words, there is an increasing effect of mobile phones as agriculture develops. This finding provides evidence of a non-linear relationship between mobile phones and agriculture. Mobile phones therefore display a quadratic relationship with agricultural development.

Another remarkable result is that internet usage has significant negative effects on agricultural value added, but squared internet usage has significant positive effects. This suggests a U-shaped pattern: internet usage decreases with agricultural value added, stabilizes, and then increases (Figure 2). In other words, as internet usage increases, agricultural development decreases, but after a certain level of internet usage which is the turning point, agricultural development starts to increase.
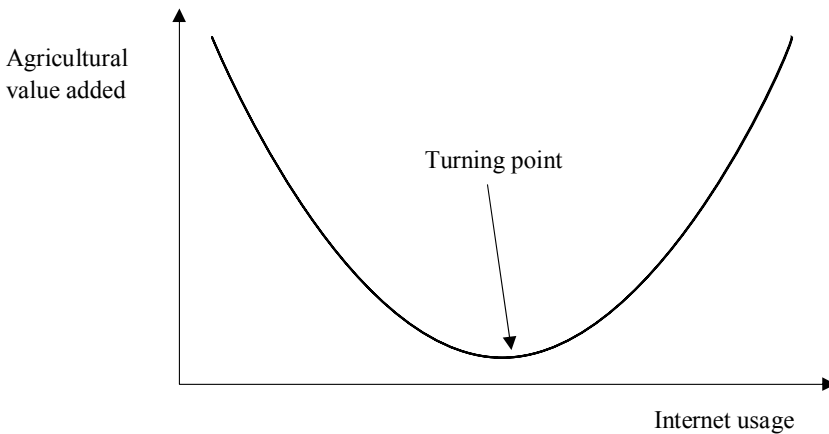
Figure 2. **U-shaped Pattern Between Internet and Agricultural Development**

The U-shaped pattern between internet usage and agricultural development is explained by the fact that at the initial stages, internet infrastructure is scarce in rural areas where agriculture is rife. Other enabling factors such as appropriate macroeconomic and institutional environment were lacking. Many of the rural areas have suffered from badly performing economies, low investment and infrastructures, and debilitating institutions. These have implications for the implementation of networking projects and public policies that foster internet penetration in the continent. Moreover, for low levels of internet penetration rates, the internet service is prioritized for e-commerce and education, leaving the variables associated with agriculture minimized. As the penetration rate increases, some elements linked to agriculture arise. Over time, as the macroeconomic and institutional environment improve, the potentials of the internet are felt more on agricultural development. Moreover, most African countries have made heavy investments into internet infrastructure, improving access to the internet in the last few years. This has aided information sharing,

within the continent and to rural areas, and moreover, has fostered internet usage for agricultural development.

The causality analysis suggests the existence of uni-directional causality from mobile penetration and internet usage to agricultural value added. However, there is bi-directional causality between squared mobile penetration, squared internet usage and agricultural value added. This indicates that mobile phones and internet stimulate agricultural development which, in turn, boosts mobile penetration and internet usage even further in these countries. That is, mobile phones and internet are a function of agricultural development while agricultural development is also a function of mobile phones and internet. This evidence is supported by many studies (e.g., Muriithi, Bett and Ogaleh, 2009; Aker and Ksoll, 2016; Evans, 2018a; Karanasios and Slavova, 2018; Misaki, Apiola, Gaiani and Tedre, 2018) which suggested that digital payments such as mobile money can benefit famers, agricultural value chain actors and rural communities through safer transactions, access to investments, ability to save and eventual growth of agri-businesses. Mobile phones and internet can provide a possible pathway to ameliorate access to agricultural information as a major impediment for raising agricultural productivity among smallholders in Africa. Moreover, through mobile phones and internet, farmers in rural villages and agricultural extension workers can get up-to-date information regarding new technologies, commodity prices, and rainfall forecasts (Asenso-Okyere and Mekonnen, 2012).

The findings of this study is further supported by various studies in the literature which have suggested the benefits of mobile phones and internet to agriculture (Jensen, 2007; Bhavnani, et.al., 2008; Lee and Lee, 2015; Asongu and Nwachukwu, 2016; Kabbiri et al, 2018). For example, Aker (2010) found that the introduction of mobile phone service between 2001 and 2006 explains a 10 to 16 percent reduction in grain price dispersion. Jensen (2007) found that the adoption of mobile phones by fishermen and wholesalers is associated with a dramatic reduction in price dispersion and the complete elimination of waste. Muto and Yamano (2009) found that, after the expansion of the mobile phone coverage, the proportion of the farmers who sold banana increased in communities more than 20 miles away from district centers. Furuholt and Matotay (2011) showed that the improved access to mobile phones affects the entire cyclic farming life during the year and has resulted in considerable changes in livelihood, increased opportunities and reduced risks for rural farmers.

This study has also shown that macroeconomic variables such as lending interest rates and exchange rates have significant negative effects on agricultural value added, meaning that the high levels of lending interest rates and exchange rates in the region have damaging effects on agricultural development. Rising interest rates can affect agriculture in many ways — from operating expenses and farmland values to exchange rates and trade. High rates mean higher costs and decreases in profitability. Because of the high interest rates, many farmers cannot dabble into the use of bank credit. It is important to note that agriculture has not benefited from bank credit in Africa, as shown by the insignificant estimates in the empirical results. Policymakers should therefore pay close attention to movements in interest rates and bank credit how they are influencing the agricultural economy. Changes to the high interest rate environment could transform agricultural economy in Africa. High exchange rates is another headwind for the agricultural sector, as exchange rates remain a critical demand

factor for most agricultural commodities. Exchange rate affects the competitiveness of the agriculture sector by affecting prices of agriculture products and inputs and, therefore, farms' profits. Farmers need to consider the effects of fluctuating currency on their business and look for ways of managing this risk.

The study also shows that among the governance variables, political stability has significant positive effects on agricultural value added while corruption has significant negative effects. Political instability can adversely affect agriculture in several ways. For example, political instability and violence can disrupt the supply and distribution of inputs and outputs, create price shocks and cause huge displacement of labor. These compounding challenges can render agricultural investments difficult to maintain in politically volatile environments (e.g., Gao and Timbuktu in Mali and Borno in Nigeria). Countries in Africa who are experiencing episodes of political instability and internal conflict, should consider stemming the tide in a bid to aid agricultural productivity, investment and development.

Corruption is another conundrum. While governments have provided publicly funded subsidy programs to agriculture in many parts of Africa, fraud and corruption have undermined the subsidy programs. For example, the Nigerian Government spent $5bn dollars on farm input subsidies but only 11% of the farmers received fertilizer, resulting in low yields and low profits. Middle-men siphoned large amounts of the funds out of the system. Transparency is a potent weapon in fighting corruption. African governments should prioritize efforts to institute legal frameworks that encourage transparency and root out corruption. For example, in the Nigerian case, the government later introduced an electronic wallet through which digital vouchers could be directly sent to farmer's mobile phones to buy seeds and fertilizers. This encourages transparency and eliminates corruption in the system. This approach has since been adopted in many countries including Zambia and should be replicated in the rest of Africa. The boom in mobile internet should be used across Africa to reduce the stages subsidy travels through to reach farmers.

Conclusion. This study has investigated the non-linear relationship between mobile phones, internet and agricultural development in Africa for the period 2001-2015 using system GMM. The estimates have shown a non-linear relationship between mobile phones, internet and agricultural development. The empirical results indicate that mobile penetration and squared mobile penetration have significant positive effects on agricultural value added, implying that mobile penetration has an increasing effect on agricultural value added. In contrast, internet usage has significant negative effects on agricultural value added, but squared internet usage has significant positive effects. This suggests a U-shaped pattern: as internet usage increases, agricultural value added decreases, but after a certain level of internet usage which is the turning point, value added starts to increase. The causality analysis suggests the existence of uni-directional causality from mobile penetration and internet usage to agricultural value added. However, there is bi-directional causality between squared mobile penetration, squared internet usage and agricultural value added. This indicates that mobile phones and internet stimulate agricultural development which, in turn, boosts mobile penetration and internet usage even further in these countries. The results therefore provide evidence that mobile phones and internet play significant roles in agricultural development, as agricul-

tural development also plays important roles in the expansion of mobile phones and internet.

The findings of this study have several important policy implications for policymakers. The study has shown increasing effects of mobile phones and internet on agricultural development. The implication is that, to develop African agricultural sectors, investment in internet infrastructures should be seen as important for laying the foundations for increased agricultural development. Considering this, policymakers and stakeholders in the agricultural sector need to maximize mobile penetration and internet usage for agricultural development by collaborating to develop policies, tools, and applications that can take full advantage of the benefits of mobile phones and internet for every farmer and every country, increasing access to mobile phones and internet for farmers and in rural areas, and thereby promoting digital agriculture and agricultural development.

Considering the significant effect of mobile phones and internet for agricultural development found in this study, different governments and institutions in Africa need to encourage and invest in mobile phones and internet. Policy measures for the deployment and diffusion of mobile phones and internet infrastructures and applications need to be planned and implemented in many countries, especially their rural areas where agriculture is the major source of livelihood. Mobile phones and internet usage, which is already in high flux in all parts of the continent, should be encouraged to drive digital agriculture and agricultural development.

The study has several limitations. There are different significance levels regarding the effects of mobile penetration and internet usage on agricultural development in individual countries. The different significance levels are not unexpected as mobile penetration, internet usage and levels of agricultural development are not evenly distributed in the continent. Additionally, there is rapid growth of mobile phones and internet in Africa, which means that the effects are likely to be changing fast. There is therefore a need for future research to investigate policy approaches which can suit the rapid growth, so that they can meet the objectives of digital agriculture and agricultural development.

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APPENDIX

Countries in the Sample:

Algeria, Angola, Benin, Botswana, Burkina Faso, Cameroon, Central African Republic, Chad, Dem. Rep. Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, South Africa, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe, Sierra Leone, Sudan and Liberia.