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The role of ICTs in agricultural production in Africa*

Hopestone Kayiska Chavula

Economic Commission for Africa (ECA), Addis Ababa, Ethiopia.

Over the past two decades Africa has experienced the fastest growth in the global telecommunications market, especially due to the tremendous growth of the mobile telecommunications sector. Studies have shown that ICTs play a significant role in a country's development, and the strategic application of ICTs to the agricultural sector, which is the largest economic sector in most African countries, offers the best opportunity for economic growth and poverty alleviation on the continent. The main objective of this paper is to assess if at all the proliferation of ICTs on the African continent has had any significant impact on agricultural production. The study uses the 2000-2011 panel data for 34 African countries, since this is the period when the spread of ICTs is deemed to have started having an impact on the continent. It applies Antle (1983) methodology and approach by utilizing specific ICTs as input variables. The results suggest that ICTs play a significant role in enhancing agricultural production, despite mobile phones having an insignificant impact while telephone main lines remain a significant contributor to agricultural growth despite the wide proliferation of mobile technologies. The results also suggest that certain socio-economic characteristics such as higher education levels and skills are prerequisites for effective improvements in agricultural production due to the adoption and utilisation of new technologies.

Key words: Information and Communication Technologies (ICTs), agricultural production, ICT utilisation, Africa, agricultural output, agricultural production function and Feasible Generalised Least Squares (FGLS).

INTRODUCTION

African countries have been characterised by decades of unfruitful attempts to shift from the agricultural sector. Based on Western experience, less-developed countries were being pushed to strive for economic emancipation through the transformation of their economies with a decreased reliance on the primary sector (Ansoms, 2008). However, these economies remain predominantly agrarian, with the sector accounting for roughly 15% of the continent's GDP, employing 90% of the rural workforce and 60% of the total labour force (urban plus rural), contributing as much as 40% of export earnings, and providing over 50% of household needs and income (UNECA, 2007; McKinsey, 2011). With this minimal contribution to growth, however, Africa's arable land makes up to 40% of arable land globally, while only 10% is being cultivated (EIU, 2012). This is because the sector has received the least attention, especially in the areas deemed critical to its development from national governments, hence the sector's poor performance. Leading to lack of critical rural infrastructure, inadequate

access to advanced technologies, limited access to affordable financing, markets and unfair market conditions, high production and transport costs, low skills, etc. in the sector.

The share of agriculture in GDP in many African countries is much smaller, often 30% or less indicating low productivity levels in the sector (AfDB, OECD, UNDP and UNECA, 2012). Despite the role played by agriculture in development in Africa, agricultural production and yields have lagged far behind those in developed countries over the past few decades. In accordance with the reasons indicated earlier, this poor sector performance, to a greater extent, has been attributed to the underutilization of improved agricultural technologies, which has remained relatively low in developing countries since the 1970s (Aker, 2011). It should also be noted that a critical force in transforming agriculture in countries such as China and Korea was the investment in transport and communications infrastructure especially information and communication technologies (ICTs)[1], apart from their emphasis on agricultural research and extension, irrigation systems and storage facilities which are essential factors for raising productivity and increasing income for the poor (UNECA, 2012).

Although agriculture and natural resources are deemed to continue being the key drivers of Africa's economic growth, it is the application of modern technologies that is considered to have the most significant impact on the growth trajectories of most African economies. Kimeyi and Moyo (2011) stress that technological innovations and the adoption of new technologies provide great opportunities for growth in service sectors such as agriculture, health, education, banking and insurance. This being the case, countries have identified ICT as an important component in moving the countries' subsistence-based economy to a service-sector driven, high-value added information and knowledge based economy, that can compete effectively on the global market (Ansoms, 2008).

Countries that embrace and invest in and adopt technologies that are suitable for their circumstances will be able to sustain growth and be competitive. The strategic application of ICTs to the agricultural sector, which is the largest economic sector in most African countries, offers the best opportunity for economic growth and poverty alleviation on the continent (World Bank, AfDB and AUC, 2012).

For example, in a recent study by the African Development Bank (AfDB), it is found that Africa could increase its cereal productivity by 75% if it prioritises the use of new high-yield variety seeds, chemical fertilizers and other inputs, hence achieve unique opportunity

higher growth rates and food security.[2] ICTs offer to facilitate technological adoption, to transmit information about new seed varieties, inputs and information about new markets and market prices at a relatively low cost, hence having a significant contribution to agricultural growth.The ICT sector has experienced tremendous progress when compared to other infrastructure sectors in Africa, and its growth has been steadily improving in the past two decades. This has been especially due to the widespread liberalization of the telecommunications market in the region and the developments in mobile technology which have transformed the opportunity costs of communication by greatly reducing time and cost of acquiring and disseminating information. These developments have led to an unprecedented increase in access to ICT services, making Africa the fastest growing region in the global telecommunications market. The sector has grown from less than 2 million people using mobile phones in 1998 to over 400 million in 2009.[3] As of September 2010, the total number of subscriptions as measured by the number of mobile connections reached 620 million, surpassing Latin America, becoming the second largest mobile market in the world after the Asian Pacific (GSMA, 2011), with subscriptions reaching 720 million by 2012[4].

Infrastructure developments, especially the undersea cables have sparked stiff competition in Africa's broadband market, forcing telecommunications prices down in the region, with mobile phone subscribers announcing significant reductions in Internet service prices. According to research findings by AfricaNext Research (an investment research firm), median international wholesale bandwidth prices have fallen by more than 70% in many markets; in sub-Saharan Africa bandwidth supply rose by nearly 300% in 2010, and many countries have raised their international bandwidth intake nearly tenfold (Rao, 2011). In terms of telecommunications investment, spending on African infrastructure rose at a compound annual rate of 17% over the period 1998-2007, up from US$3 billion in 1998 to US$12 billion in 2008, significantly outstripping the growth of the global infrastructure investment. The mobile telephony accounted for more than 30% of the investment over the same period (McKinsey, 2011). The number of mobile subscribers has further room for growth as Africa is being seen to have the world's largest working-age population by 2040, which reflects the economic potential with a younger demography, of which 38% of the working youth in Africa are in the agricultural sector (UNECA, 2012; EIU, 2012; AfDB, OECD, UNDP, UNECA, 2012). These developments will not only help deepen the utilization of ICTs and the telecommunications market, and allow business to operate more efficiently and cost effectively, but will also

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present significant opportunities not only to the agricultural sector, but to the general business sector as a whole.

A number of studies have been conducted on the continent looking at the role and utilization of ICTs in the agricultural sector, mainly focussing on specific country case studies and initiatives (the micro perspective). Mainly with regard to how they have impacted on development and the people's living standards, in the communities where the projects are implemented, among others, through their contribution to the development and growth of the agricultural sector.[5] However, despite all these development initiatives involving the utilization of ICTs, there have been no empirical studies, as far as the author is concerned, to have been conducted to assess the overall impact of such kind of initiatives at a macro level, that is, at country as well as regional level – to assess if at all the utilization of ICTs in the agricultural sector have had an impact on agricultural production. This is done while taking cognizance of the fact that countries are at different levels of development, having different country characteristics including their limited access to energy sources especially electricity, which play a critical role in ICTs utilization.

Therefore, the main objective of this study is to examine the impact of ICTs on agricultural production in Africa. The study is triggered by the desire to establish if at all the proliferation of ICTs on the African continent over the passed decade, especially their utlization in the agricultural sector have had any significant impact on agricultural production. It is argued that a substantial proportion of the differences in aggregate agricultural output across countries could be attributed to significant inter-country performance differences in transport and communication sectors, as well as differences in factor endowments, technical inputs and education (Antle, 1983). This indicates that investments in ICTs could raise agricultural production considerably, as has been the experience with Esoko and M-Pesa among others, as stipulated in the section that follows. Based on the methodological approach by Antle (1983), this study employs the widely-used Cobb-Douglas production function with a focus on ICTs as one of the inputs, in order to explore ICTs' influence on agricultural output growth. The study is envisaged to play a pivotal role in filing the gap that exists on the African continent, especially during this period when Africa has become the fastest growing region in the global telecommunications market.

The role of ICTs in the agricultural sector – Theoretical and empirical perspectives

Increasing agricultural production is critical in reducing

poverty as it can boost farmers' income especially smallholder farmers who have limited resources to leverage in growing and marketing their produce. This could be achieved if there exists an efficient value chain, which entails engaging many stakeholders ranging from farmers growing the crops and raising cattle, to input suppliers and distributors.

However, the existence of efficient value chains depends on the efficient and systematic flow of relevant information, which in turn depends on the existence of an efficient and reliable ICT infrastructure and the associated services to connect to a diverse range of stakeholders along the agricultural value chain (Halewood and Surya, 2012). In this regard, ICTs could provide a unique opportunity to facilitate agricultural related technological adoption and access, provision of information on markets and market prices, weather, transport and agricultural techniques.[6]

The ICT sector has had a significant impact in developing countries, as they are being utilized in the agricultural sector through ICT-enabled solutions for food and agricultural production. ICTs improve access to financial services of which a large body of theoretical and empirical literature suggests could have significant impacts on economic growth and poverty reduction in developing countries (Burgess and Pande, 2005; Levine, 2005a, b). A good example is the use of mobile money through M-Pesa in Kenya, where studies have shown that households with access to mobile money are better able to manage negative livelihood shocks such as job losses, death of livestock, or problems with harvests (Aker and Mbiti, 2010; Sen and Choudhary, 2011). Insurance, credit and savings services are also being developed based on the mature mobile money systems in Africa. For example, Kilimo Salama is a micro-insurance product that uses M-Pesa to provide payouts to smallholder farmers where crops fail. In the second year of its operation in 2011, 12,000 farmers were insured, and 10% of these received payouts of up to 50% of their insured inputs (Sen and Choudhary, 2011), hence having an impact on agricultural growth and people's livelihoods.

ICTs help extension workers and researchers to adopt improved agricultural practices and disseminate them to farmers. They provide agricultural information that is relevant to farmers such as agricultural techniques, commodity prices, and weather forecasts to farmers. The utilization of ICTs, especially mobile technologies, helps agricultural producers, who are often unaware of commodity prices in adjacent markets and rely on information from traders in determining when, where, or for how much to sell their produce, to have relevant and timely information to this regard. Delays in obtaining this information or its misinterpretation by middle traders has serious consequences for agricultural producers, leading to charging low prices or high/low produce supply in the

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[5] For specific example see World Bank, African Development Bank and African Union Commission (2012).

[6] See for example Lio and Liu (2006); Aker and Mbiti (2010) and Aker (2011).

markets.[7] Also, relying on traders or agents creates rent seeking opportunities, adding to the agricultural workers' cost of doing business. As a result of mobile technological developments, especially mobile phones have had some dramatic effects, particularly in rural Africa, for example the utulization of e-Soko in Rwanda.[8] Farmers can compare market prices for the grain they produce and fishermen are able to sell their catch every day and reduce spoilage and waste by locating customers (Aker and Mbiti, 2010; Chavula, 2012). Studies have shown that the benefits of using ICTs in promoting access to price information in Africa have ledto increases of up to 36% of farmers' income, and up to 36% of traders' income in countries such as Kenya, Ghana, Uganda and Morocco (Halewood and Surya, 2012). This is because ICTs facilitate information flow and enhance communication between buyers and sellers leading to lower communication costs, thereby allowing individuals and firms to send and acquire information quickly and cheaper (Aker and Mbiti, 2010). This makes markets operate more efficiently, hence increase the overall production in the agricultural sector and growth of the economy as a whole.

ICTs play also an important role in facilitating agricultural growth because they increase the efficiency of market interactions and provide access to real time information mainly by enhancing farmers' access to markets and their pricing power through the use of trading platforms over the Internet through web/mobile applications (Driouchi et al., 2006). They allow people to obtain information immediately on a regular basis as compared to other information channels. It is argued that the utilization of ICTs, especially by using mobile technologies greatly reduces search costs, as stipulated by the search theory.[9] It is also argued that in markets where traders have local monopoly, increased access to information could improve consumer welfare by disrupting this monopoly power, although it also reduces traders' welfare (Aker and Mbiti, 2010). Also, despite their high initial fixed costs, mobile technologies and their variable costs associated with their use are significantly lower than equivalent travel costs and other opportunity costs.

In their study in Niger, Aker and Mbiti (2010), observed that an average trip to a market located 65 km away can take 2 to 4 h roundtrip, compared to a two-minute phone call. E-soko, a mobile and web-enabled repository of current market prices and a platform through which buyers and sellers interact in Ghana, managed to increase farmers revenue by 10% since they started using the platform in northern Ghana (Halewood and Surya, 2012). These real time market dynamics help farmers deal with external demand directly, hence

capturing more of the products' value. In their study Muto and Yamano (2009) found that mobile phone coverage was associated with a 10% increase in farmers' probability of market participation for bananas, but not maize, in this case suggesting that mobile phones were more useful for perishable goods. Supporting the notion that technology-driven agricultural services have the ability to improve crop yield, expand access to markets, and boost revenue for farmers – thus improving livelihoods and boosting the broader economy.

Especially through connecting farmers with expertise and information on everything from weather, crop selection, and pest control to management and finance. For example, the Ethiopian Commodity Exchange (ECX) provides a virtual market place, accessible online, by phone or SMS, which provides transparency on supply, demand and prices, and increases farmers' share of revenue (McKinsey, 2013 for more details).

In terms of technological developments, increases in agricultural production will depend on the technological capacity to innovate, develop and the diffusion of new technologies and technological techniques which are specifically adapted and utilized based on the existing factor endowments and prices in a particular region or country (Hayami and Ruttani, 1970). One such factor is the level of education which entails the capacity of a country required to engage in the necessary agricultural research, development and extension as well as the ability to acquire, adopt and utilise existing agricultural knowledge and new agricultural related technologies. To enhance the diffusion and utilization of agricultural knowledge and acquisition of the necessary technological skills, there is need to have a diverse range of agricultural skills, by making more investment in education, skills development and life-long learning (Juma, 2006). Advanced skills and higher education play a complementary role to technological advances in this knowledge revolution.

New technologies cannot be adopted in agricultural production without a sufficient education and trained workforce who should be equipped with the necessary skills and knowledge, and also to be able to impart the knowledge and skills acquired to the masses especially, if it involves the less educated especially in the rural areas. Hence agricultural related technological developments may not take place without an educated and therefore demanding customers and consumers, in this case the agricultural population. Even those who do not go into careers that require advanced education in agricultural science and engineering will need basic scientific and technological literacy to function as effective citizens in this environment. This being the case education and skills development affect both the supply and demand side of the agricultural-based knowledge driven economy. Theoretically, higher education allows workers to use existing physical capital more efficiently, it drives the development and diffusion of new knowledge and technologies and also improves the capacity to imitate

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[7] See Aker and Mbiti (2010) and Halewood and Surya (2012) for further details.,
[8] Visit www.esoko.gov.rw for more details.
[9] See Aker and Mbiti (2010) for more details.

and adopt new knowledge and technologies (Dahlan 2007), as well as impart that knowledge to a greater part of the local population. This implies that developing countries need to expand not only primary education, but also secondary and tertiary education in order to enhance the diffusion and utilization of knowledge for agricultural as well as economic development as a whole.

While primary and secondary education have been at the centre of donor community attention for decades, higher education and research have been viewed as essential to development in recent years in Africa. Higher technical education is increasingly recognized as a critical aspect of the development process, especially with the growing awareness of the role of science, technology and innovation (Juma, 2006). Increasing higher education will lead to a rapid development and dissemination of agricultural knowledge, which will lead to more advances in technological innovation as it is becoming a more critical element for the countries' competitiveness and development.

METHODOLOGY

Countries are assumed to produce agricultural output (Q) based on ICTs, level of agricultural related technology (T), human resources (H), and physical capital (P). Following Antel (1983) approach, we assume a Cobb-Douglas agricultural production function with A being the Hicks-neutral productivity level which is dependent on ICTs and level of education, and ε being an identical and independently distributed random variable, and the agricultural production function takes the following functional form:

$$Q = AT^{\alpha} H^{\beta} P^{\delta} \varepsilon \qquad (1)$$

where α, β and δ are constant coefficients such that the concavity of Q is ensured. With this functional form the inter-country agricultural production function for estimation could be specified as:

$$\log Q_{it} = \log A_{it} + \alpha \log T_{it} + \beta \log H_{it} + \delta \log P_{it} + \varepsilon_{it} \qquad (2).$$

It should be noted that T, H, and P encompass the conventional agricultural inputs in the agricultural production function literature. This being the case, in this study as has been the case in a wide range of studies in the agricultural production function literature[10], the level of agricultural related technology (T) is captured by machinery and fertilizer variables which are aimed at capturing the effects of technical inputs on agricultural productivity. Fertilizer consumption which is commonly viewed as a proxy for the whole range of chemical inputs to the sector which is captured by the amount of fertilizer (in kilograms) per hectare of arable land, and machinery which is measured by the number of agricultural tractors.

Physical capital (P) is represented by land and livestock,

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[10] See for example Hayami and Ruttan (1970), Antle (1983), Mundlak et al. (1997), Lio and Liu (2006), and Butzer et al. (2010).

representing a form of long-term internal capital accumulation of inputs primarily supplied by the agricultural sector, with physical infrastructure captured by the existing road networks (in kilometres). Increases in both inputs of land and livestock per worker tend to be associated with low levels of labour and high levels of land per unit of output (Hayami and Ruttani, 1970). Land is measured by hectares of arable land and permanent crops, while Livestock is measured by livestock's gross capital stock (fixed assets) at 2005 US dollar prices. Human capital (H) is represented by the labour force in the agricultural sector, which is captured by the economically active population in the agricultural sector, education which is captured by primary school completion rate (primary), secondary school gross enrolment rate (secondary) and tertiary education gross enrolment ratio (tertiary), and also infant mortality rate, while agricultural output (Q) is measured as agricultural value added at 2000 US dollars in a country.

The most relevant variable of interest is the Hicks-neural productivity level A. As indicated earlier, this is a function of ICT and education. ICT is captured by three variables which include country i's mobile subscribers per 100 people (mobile), country i's number of telephone main lines per 100 people (telephone) and country i's Internet users per 100 people (Internet). Our main area of focus is to examine whether the increase in ICT penetration on the continent (through mobile, Internet and telephone main lines) has had an impact on agricultural production among African countries. Taking cognizance of the countries' being at different levels of development as well as the within country characteristics that might have an effect on ICTs acquisition, access and utilization hence the inclusion if infrastructure as one of the variables.

Our hypothesis is that increased Internet usage should have a greater effect when compared with mobile penetration and telephone main lines penetration individually, since both are being used by the African population to access the Internet. However, we expect the increased mobile rollout to have greater impact on agricultural production than the telephone main lines. Furthermore, we could not assume that there is no reverse causality between agricultural output growth and ICT penetration over the period understudy, hence there is need to examine whether this is true or not, by testing the direction of causality between ICTs and agricultural production. Since growth in agricultural production could also lead to an increase in the adoption and utilization of ICTs and vice versa.

However, it should be noted that while many observations and studies indicate that telecommunications investment could have a positive contribution to economic growth (as indicated above), it is argued that the opportunities that come with these investments may not be fully grasped by people in rural areas of developing countries such as those in Africa. It is suggested that new technologies, such as the Internet, may not have a significant impact as expected. It is observed that the Internet is more expensive than telephone access, it requires a higher level of education and skill to operate than a telephone, the dominant languages of the Internet are generally not those used in the rural areas by the poor, and also the Internet requires a critical mass of users to make it sustainable, which are particularly lacking in the rural areas of developing countries (Roeller and Waverman, 2001; Lio and Liu, 2006). This being the case results from this study might end up rejecting the hypothesis stipulated above about the increased Internet usage and its associated effects.

Data for the variables used for analysis in this study are obtained form a number of cross-country data sets over the period 2000 to 2011, since it has been observed to be only since the late 1990s when the spread of ICTs especially mobile and Internet technologies started having an impact on the continent (Chavula and Chekol, 2010). Data for ICT variables is obtained from the International Telecommunications Union (ITU 2011)-World. Telecommunication Indicators database; the data on agricultural

Table 1. Correlation coefficients for ICT utilization and selected agricultural and education level variables.

Variable	Output	Land	Labour	Fertilizer	Machinery	Infrastructure	Mortality	Mobile	Telephone	Internet	Primary	Secondary
Land	0.7567											
Labour	0.5498	0.8359										
Fertilizer	0.2945	-0.1772	-0.2796									
Machinery	0.6178	0.3849	0.1580	0.3647								
Infrastructure	0.6820	0.7391	0.6118	-0.1965	0.3119							
Mortality	-0.0508	0.4817	0.6793	-0.6016	-0.4019	0.3700						
Mobile	0.0575	-0.3089	-0.5727	0.4577	0.3836	-0.1965	-0.6419					
Telephone	0.0514	-0.4443	-0.6793	0.6236	0.3937	-0.3347	-0.9108	0.6121				
Internet	0.0932	-0.3734	-0.6315	0.4993	0.4571	-0.2644	-0.8220	0.8961	0.8172			
Primary	0.2172	-0.2735	-0.5065	0.5069	0.4966	-0.0804	-0.7672	0.7374	0.7299	0.8082		
Secondary	0.2432	-0.2858	-0.5510	0.5452	0.4746	-0.1122	-0.8208	0.6844	0.7992	0.7960	0.9440	
Tertiary	0.3300	-0.1911	-0.4985	0.4518	0.3641	-0.0675	-0.7879	0.6966	0.7343	0.8001	0.7291	0.7890

inputs is obtained from the Food and Agricultural Organization's statistical database (FAOSTAT), while the data on education variables came from the World Bank's World Development Indicators database (EduStat). However, due to the unavailability of data on some of the variables such as rainfall and research and development in the agricultural sector, it was not possible to include these variables during the estimation process, despite recognizing very well the significant role these variables play in the development of the agricultural sector.

With the discussion in the preceding sections, it is worth examining the correlation between the status of ICT utilization andsome important agricultural related variables such as those related to agricultural output, the level of education, land, labour, fertilizer, machinery, infrastructure and mortality rate. Table 1 show that all the variables are positively related to agricultural output, except for mortality rate which exhibits a negative relationship. The table also shows that land, labour, mortality rate and infrastructure are negatively related to both ICT and education related variables. The correlation between fertilizer and mobile subscription, telephone main lines and Internet users is 0.46, 0.63 and 0.50 respectively. This has been attributed to the fact that the adoption of capital intensive production methods is a function of specialization, relying mostly on transaction conditions (Lio and Liu, 2006). However, the relationship between ICT variables and education variables ranges from 0.68 to 0.81 indicating the importance of the

level of education or the stock of human capital in the utilization of ICTs. This is in support of the findings of some of the earlier studies such as Dewan and Kraemer (2000) and Lio and Liu (2006).

However, the table shows that the highest correlation between primary completion rate and ICT is the use of the Internet. This could be in support of the hypothesis that Internet can be utilized through both mobile phones and telephone main lines, hence having the highest correlation coefficient. While the correlation between secondary school enrolment and ICT variables are highest in telephone main lines and the Internet as compared to mobile phone usage. The relatively high correlation is also observed between tertiary education and Internet usage, seconded by telephone main lines followed by mobile phones with the lowest correlation coefficient. This could be emphasizing the need for tertiary education to fully exploit the potential of ICTs especially through the utilization of the Internet to access agricultural information, deliver agricultural extension services and carry out ecommerce related activities. At the same time it is observed that mobile usage has relatively the highest correlation coefficient with Internet usage as compared to telephone main lines, supporting the notion that most of the people are currently using mobile technologies to access the Internet.

However, with the recent developments in ICT innovations, it could be argued that despite ICT being

emphasized to be a function of the level of education among African countries, it could also be true that education may be a function of ICTs, as the population could have access to education or be able to attend courses through distance learning by using ICTs.[11]

EMPIRICAL RESULTS

Table 2 presents results of the impact of ICTs on agricultural output growth involving 34 African countries using unbalanced panel data regression analysis, over the period 2000 to 2011. These countries were included in the analysis based on the availability of data for the required economic variables. Furthermore, due to the missing data on specific variables involved during estimation of the different models, there is a varying number of sample observations in the different models presented. The Hausman specification test was carried out to identify which model (between the fixed and random effect models) best describes

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[11]See McKinsey (2013) for more details on this.

the data generation process among the countries involved in the cross-country analyses. From the diagnostic tests in Table 2 it is observed that almost all the models exhibited the presence of either heteroscedasticity or autocorrelation or both, rendering the estimates unreliable and inefficient.

These led to the use of the feasible generalised least squares (FGLS) estimation method, since the approach assumes that, in the case of panel heteroscedasticity, the error variances vary across countries, but remain constant over time and within each country (Lio and Liu, 2006). generally, the results in Model 1 of Table 2 show that all the agricultural input variables had a positive and significant impact on agricultural output (to some extent supporting the results of the correlation coefficients in Table 1, except for livestock, machinery and mortality rate which were either found to be negative or insignificant. Looking at the inclusion of the ICT variables in the model reveals that only telephone main lines have a positive and highly significant impact on agricultural output, while both mobile subscription and Internet usage have insignificant impact on agricultural output showing the underutilization of the two technologies in the agricultural sector. Despite the proliferation of mobile phones, this result could be showing that these technologies, despite being utilised effectively in certain agricultural activities or initiatives[12], they have not been able to have a significant impact on agricultural production in the sector at country level on the continent. To some extent supporting the findings of the earlier studies by Lio and Liu (2006) in which an ICT adoption index was used and in Antle (1983) where a country's transport and communication output was used.

Comparing the size of coefficients between Model 1 with models 1 and 3; it is observed that when the telephone main lines variable is included in the model (that is, Model 3), the size of the coefficients of the variables such as labour, infrastructure, mortality rate, and primary education significantly increase to 0.39, 0.23, -0.726 and 0.14 respectively in Model 3 showing improvement in these variables. While the coefficients for land and livestock variables are reduced from 0.67 and -0.14 in Model 1 to 0.65 and -0.18 in Model 3 respectively. These results, to a greater extent reveal that, even though their has been a significant increase in mobile penetration on the continent over the passed decade, the use of telephone main lines still remains the most highly utilised form of technology hence its relatively higher and significant contribution to the growth of the agricultural sector in comparison to both mobile phones and the Internet. This is mainly due to the telephone main lines contribution to the impact of labour, infrastructure, mortality rate and education. The effect of the ICT variables on the coefficient of labour could be attributed to the fact that in countries with higher ICT penetration,

the labour force in the agricultural sector tends to be smaller, while the levels of specialization and division of labour is higher. Hence, leading to the underestimation of the elasticity of labour if the ICT variables are omitted (Lio and Liu, 2006).

In terms of technological developments, increases in agricultural production will depend on the technological capacity to innovate, develop and the diffusion of new technologies and technological techniques which are specifically adapted and utilized based on the existing factor endowments and prices in a particular region or country. Hence the level of education will capture the opportunities and potential that exists in a country for its citizens to acquire the necessary skills as well as their utilization and access to agricultural related knowledge, we tried to capture this by replacing the primary education variable with secondary school and tertiary education variables. Despite the change in the education variables the results from equation 1 across Table 1 and 2 and three show that the education variables have a highly significant impact on agricultural production.

Looking at the impact of education in Model 1 across Tables 2 to 4, the results reveal that, as was the case with the inclusion of ICT variables, all the educational variables are found to exert a positive impact on agricultural output, except for the livestock and machinery variables which are found to be negative and insignificant in some cases. Comparing the size of the coefficients of the conventional agricultural input variables when the educational variables are included in the model, the results show that the size of the coefficient for land decreases as the level of education increases across the results of Model 1 in Tables 2 to 4. With the size of the coefficient being higher in the model with primary education (Table 2, Model 1), and the coefficient for land being reduced from 0.67, to 46 and 0.42 for primary, secondary and tertiary education respectively. This could be due to the fact that after acquiring relatively higher levels of education there tends to be higher levels of migration from rural to urban areas joining non-agricultural sectors, hence leading to reduction in the utilization of agricultural resource endowments leading to reduction in overall agricultural output (Aker and Mbiti, 2010). The same coefficient size reduction is observed for fertilizer as it is reduced from 0.04 in Model 1 in Table 2, to 0.03 in Model 1 in Table 3 for primary and secondary education variables respectively. However the fertilizer coefficient increases to 0.17 when the primary education variable is replaced by the tertiary education variable, which could entail an increase in the utilization of modern technologies and industrial inputs such as the use of higher yielding varieties due to the attainment of tertiary education (Hayami and Ruttan, 1970).[13] On the other hand, livestock is found to have an insignificant impact when associated with secondary and tertiary

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[12] See for example McKinsey (2013) for more details.

[13] See Hayami and Ruttan (1970) for a related discussion.

Table 2. Agricultural production function estimates and ICTs, 2000-2011.

Variable	Model 1	Model 2	Model 3	Model 4
Constant	15.92 (0.787)***	15.91 (0.539)***	13.9 (0.549)***	15.2 (0.749)***
Land	0.67 (0.059)***	0.65 (0.062)***	0.65 (0.049)***	0.67 (0.067)***
Labour	0.27 (0.042)***	0.27 (0.043)***	0.39 (0.045)***	0.31 (0.057)***
Fertilizer	0.04 (0.011)***	0.05 (0.011)***	0.04 (0.011)***	0.05 (0.013)***
Livestock	-0.14 (0.043)***	-0.12 (0.046)**	-0.18 (0.037)***	-0.14 (0.060)**
Machinery	0.004 (0.012)	-0.004 (0.012)	-0.0006 (0.011)	0.001 (0.016)
Infrastructure	0.22 (0.041)***	0.21 (0.042)***	0.23 (0.038)***	0.23 (0.051)***
Mortality	-1.06 (0.095)***	-1.03 (0.099)***	-0.726 (0.098)***	-1.06 (0.127)***
Primary	0.11 (0.063)*	0.11 (0.073)	0.143 (0.055)***	0.20 (0.127)
Mobile		-0.006 (0.018)		
Telephone lines			0.198 (0.041)***	
Internet				0.005 (0.033)
Hausman test (Prob>x^2)	0.3123	0.0009***	0.0143**	0.1299
Wald test for heteroscedasticity		0.0000***	0.0000***	
Wooldridge test (Prob>F)	0.0046	0.0179**	0.0001***	0.0067***
Breusch and Pagan test (Prob>x^2)	0.0000***			0.0000***
No. of observations	138	135	138	138
No. of countries	30	30	30	30

The standard errors are in parenthesis; and *,** and *** denote significance levels below 10, 5 and 1% respectively.

Table 3. Agricultural production function estimates and ICTs, with secondary education, 2000-2011.

Variable	Model 1	Model 2	Model 3	Model 4
Constant	14.93 (0.643)***	15.01 (0.638)***	13.36 (0.896)***	14.97(0.674)***
Land	0.46 (0.061)***	0.47 (0.060)***	0.50 (0.060)***	0.48 (0.065)***
Labour	0.40 (0.049)***	0.42 (0.048)***	0.42 (0.050)***	0.38 (0.053)***
Fertilizer	0.03 (0.009)***	0.03 (0.010)***	0.03 (0.010)***	0.03 (0.009)***
Livestock	0.03 (0.047)	0.02 (0.046)	0.05 (0.046)	0.44 (0.049)
Machinery	0.01 (0.010)	0.01 (0.011)	0.010 (0.010)	0.010 (0.010)
Infrastructure	0.14 (0.042)***	0.15 (0.041)***	0.13 (0.041)***	0.14 (0.044)***
Mortality	-0.77 (0.136)***	-0.81 (0.137)***	-0.52 (0.168)***	-0.76 (0.142)***
Secondary	0.01 (0.003)***	0.01 (0.003)***	0.010 (0.003)***	0.01 (0.003)***
Mobile		-0.002 (0.001)		
Telephone lines			0.033 (0.013)**	
Internet				0.004 (0.005)
Hausman test (Prob>x^2) Prob>x^2	11.97 (0.3123)	14.15 (0.1172)	12.19 (0.2029)	11.14 (0.26060)
Wald test for heteroscedasticity				
Wooldridge test (Prob>F)	8.656 (0.0073***)	8.613 (0.0074***)	33.057 (0.0000***)	8.867(0.0067***)
Breusch and Pagan test (Prob>x^2)	210.95 (0.0000***)	208.40 (0.0000***)	207.78 (0.0000***)	205.74 (0.0000***)
No. of observations	130	129	130	130
No. of countries	26	26	26	26

The standard errors are in parenthesis; and *,** and *** denote significance levels below 10, 5 and 1% respectively.

education, while it is found to be negative and highly significant at conventional levels when associated with primary education. This could be due the fact that in most rural areas where peoples' livelihood depends entirely on agriculture, students are encouraged to take care of their livestock at the expense of schooling hence the negative impact. The same result is observed as machinery is found to have a negative and significant effect only when associated with tertiary education variable. This to some extent could be showing that the human capital

Table 4. Agricultural production function estimates and ICTs, with tertiary education, 2000-2011.

Variable	Model 1	Model 2	Model 3	Model 4
Constant	13.34 (0.320)***	13.34 (0.336)***	9.98 (0.649)***	12.5 (0.413)***
Land	0.42 (0.033)***	0.42 (0.06)***	0.69 (0.060)***	0.44 (0.038)***
Labour	0.29 (0.021)***	0.29 (0.024)***	0.20 (0.034)***	0.26 (0.025)***
Fertilizer	0.17 (0.012)***	0.17 (0.013)***	0.04 (0.011)***	0.16 (0.013)***
Livestock	0.01 (0.023)	0.01 (0.027)	0.51 (0.030)*	0.04 (0.025)
Machinery	-0.004 (0.015)**	-0.04 (0.016)**	-0.0006 (0.009)	-0.05 (0.015)***
Infrastructure	0.37 (0.022)***	0.37 (0.022)***	0.29 (0.031)***	0.37 (0.025)***
Mortality	-0.57 (0.076)***	-0.58 (0.078)***	-0.32 (0.107)	-0.42 (0.086)***
Tertiary	0.03 (0.005)***	0.03 (0.005)	0.023 (0.006)***	0.03 (0.005)***
Mobile		0.001 (0.001)		
Telephone lines			0.09 (0.011)***	
Internet				0.03 (0.004)***
Hausman test (x^2) (Prob>x^2)	76.85 (0.0000***)	34.14 (0.0001***)	47.61 (0.000****)	48.15 (0.0000***)
Wald test for hetero. (x^2) (Prob>x^2)	1892.28 (0.0000***)	7.8e+28 (0.0000***)	9.0e+23 (0.0000***)	3.0e+28 (0.0000***)
Wooldridge test (F(1,18)) (Prob>F)	2.557 (0.1272)	2.605 (0.1239)	9.527 (0.0064***)	2.520 (0.1298)
Breusch and Pagan test (Prob>x^2)	0.0000***			
No. of observations	116	115	113	116
No. of countries	28	28	25	28

The standard errors are in parenthesis; and *,** and *** denote significance levels below 10, 5 and 1% respectively.

development might not be fully supporting the technological acquisition, assimilation and utilization since machinery and fertilizer are capturing the effects of the whole range of inputs supplied by the industrial sector which carry modern mechanical and biological technologies (Hayani and Ruttan, 1970).

It has been argued theoretically and empirically that human capital has direct influence on agricultural productivity by affecting the way in which inputs are used and combined by farmers (Mundlak et al., 2008). It also affects one's ability to adapt and utilize technology to a particular situation or changing needs of individuals or communities. It has also been argued that improvements in human capital affect the acquisition, assimilation and utilization of ICTs (Juma, 2006). To substantiate the correlation between ICTs and human capital variables, which is exhibited to be very high in Table 1, we try to assess to what extent this relationship impacts agricultural production. In general, as was the case with the findings by Lio and Liu (2006), when educational variables are included as a measure of human capital in the agricultural production function together with ICT variables, the results reveal a considerable variation in the size of the coefficients of ICT variables. Among the three ICT variables, the results reveal that telephone main lines exert, relatively, the highest impact on agricultural productivity irrespective of the level of education. This could be mostly be due to the wide spread of telephone main lines as they remain accessible to the rural masses whose livelihoods mostly depend on

the agricultural sector and does not really require some exceptional educational skills to be utilised. However, the size of its coefficient is largest when associated with primary education, than when associated with secondary and tertiary education (with the second largest) levels. And also the Internet has a statistically significant impact on agricultural production at conventional levels only when it is associated with tertiary education.

However, when mobile phones are included as an ICT variable, the results show that mobile penetration does not have any significant impact on agricultural output when associated with any of the educational levels. This in some cases should mean that people (no matter their level of education) do not effectively put mobile phones to their productive use in the agricultural sector in Africa, especially by exploiting their technological potential to the benefit of the sector, taking into consideration also the challenges in having access to electricity in the rural areas where a greater percentage of the population involved in agricultural activities is based. To a greater extent this could mean that despite the wide spread of mobile phones on the continent, mobile technologies have not been effectively utilized in the agricultural sector to enhance agricultural production. The different countries have not fully utilized the potential that comes with the utilization of the Internet for agricultural growth, as the continent, relatively, still makes more use of telephone main lines. Also, scaling up for most of existing technology based services is a difficult issue and also the penetration of smart phones and tablets among African

farmers remains low, limiting the full exploitation of the potential that comes with ICT-based agricultural technologies. Since a greater part of the population engaged in agricultural activities is in the rural areas, where access to energy sources like electricity is very low, it implies a low usage of some ICT-based technologies e.g. mobile technologies, hence the failure to put them technologies into effective use.

The results also show that the impact of infrastructure is highest when associated with tertiary education, but decreases when telephone main lines are included in the model, while the impact of infrastructure increases significantly with ICTs especially when associated with primary education. With reference to mortality rate, the results show that there is a decreasing impact on mortality rate as the level of education increases, and much more decreases are experienced when mortality rate is associated with the utilisation of ICTs.

Conclusion

The study is triggered by the desire to assess if at all the proliferation of ICTs, especially due to the growth of mobile technologies on the African continent have had any significant impact on agricultural production. This was further motivated by the view that there exists a gap in empirical research with regard to the assessment of the impact of ICTs on agricultural production on the continent. The study uses the 2000 to 2011 panel data for 34 African countries to examine the impact of ICTs on agricultural production, since it was since the late 1990s when the spread of ICTs especially mobile and Internet technologies started having an impact on the continent. It extends the study by Antle (1983) on the impact of the transport and communication infrastructure on agricultural productivity, by applying the methodology and approach to the African continent and by utilizing specific ICT variables which include the number of mobile subscribers, Internet users and telephone main lines among African countries. The study is envisaged to play a greater role in filing the gap that exists on the African continent, especially during this period when Africa has become the fastest growing region in the global telecommunications market.

The empirical analysis results suggest that ICTs play a significant role in enhancing agricultural production, and the use of telephone main lines remains a significant contributor to agricultural growth despite the wide proliferation of mobile phones. The evidence also suggests that despite both mobile phones and telephone main lines being utilized to access the Internet, its impact falls behind that of telephone main lines, to some extent suggesting that there is low usage of ICTs, especially the Internet for carrying out activities with significant contribution to agricultural growth on the continent. Internet usage has not yet reached a "critical mass" that could fully exploit network externalities, hence contribute

significantly to agricultural production in Africa. Therefore, there is need for African governments to continue promoting the use of the Internet in carrying out agricultural activities, so as to reach a "critical mass" of users needed to enable the sector exploit unique opportunities that come with the use of the Internet and hence contribute significantly to agricultural growth.

The empirical evidence from this study also suggests that certain socio-economic characteristics such as higher education levels and skills are prerequisites for effective improvements in agricultural production. This is observed in the analysis when education level variables are included in the agricultural production function as input variables, which in general, considerably reduce the estimated production elasticity of the ICT variables, suggesting to some extent the minimal emphasis with regard to the utilization of ICTs in the sector. However, the results show that despite the level of education, telephone main lines seem to have a relatively higher impact on agricultural output as compared to mobile and Internet usage. The results also show that despite the level of education, mobile penetration does not seem to have any significant impact on agricultural production. This result to a greater extent signifies the lack of innovative capacity or underutilization of mobile technologies in enhancing agricultural production on the continent.

This calls for African governments to invest in technological capacity, especially in higher education, to innovate, develop and disseminate new technologies and technological techniques in order to increase agricultural production. Especially, since it has been observed that given the available technology used by farmers over generations in Africa, agricultural extension does not play a significant role in agricultural productivity unless new profitable technologies are developed (Otsuka, 2006). Human capacity development especially through education is the key element of a knowledge-based, innovation driven economy as it affects both the supply and demand for technological innovation and utilization. Human capital and skilled labour complement technological advances, and new technologies cannot be adopted without a sufficiently educated and trained workforce. Governments should also put emphasis on public policies that support investments in ICT infrastructure.

Furthermore focus on the development and spread, especially through development of broadband technologies, in order to ensure affordable and reliable ICT access to almost all corners of each and every country, as most of the farmers are based in rural areas. This will not only provide new opportunities for rural farmers to have access to information on agricultural technologies, but also to use ICTs in agricultural services such as the countries' agricultural extension services. There is need for governments to increase their commitment to productive investments such as agricultural research, technology and rural infrastructure,

rather than putting more emphasis and committing a lot of resources to direct farm subsidy initiatives.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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