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ICT and agricultural sector performance: empirical evidence from sub-Saharan Africa

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Abstract

ICT infrastructure is considered crucial to performance and overall development of many sectors in sub-Saharan Africa (SSA). Yet, there exists insufficient evidence on the effect of ICT on agriculture real output and export performance in the African continent. This study investigates the effect of ICT infrastructure on agriculture sector performances in SSA using panel autoregressive distributed lag (ARDL) approach. Panel data were collected over the period of twenty-three (23) years (1995–2017) in 39 SSA countries. Two models were specified using agricultural value addition and agriculture products as a percentage of total merchandise export as dependent variables. Key independent variables include mobile-cellular telephone subscription and individual using the internet. The study also introduced important control variables such as livestock production index and crop production index. The results from the estimation provide substantial evidence to show that ICT infrastructure has positive externality on agricultural sector performances in the long run. However, there is no evidence to maintain this position in the short run. The study, therefore, recommends that there should be a cautious approach to increasing investment in ICT infrastructure. Provision of in ICT infrastructure alone may not automatically improve agricultural output. Thus, there is a need for extension services to propagate and educate farmers on the importance of continuous adoption of ICT infrastructure for agricultural practices in SSA.

Keywords: ICT, Infrastructure, Agriculture, ARDL, Sub-Saharan Africa

Introduction

The important position of ICT infrastructure in the social–economic life of any society, especially its contribution to labour productivities through assess and usage, has been well documented in the literature [23, 42, 47]. In an effort to maximize the positive externality of ICT infrastructure, different sectors of the economy have tapped into the abundant opportunities and possibilities created by assess and usage of ICT facilities [15, 20, 44]. This has been reported to substantially increase the efficiency level in different sectors of the economy in many countries [9]. Based on this, many developing countries are working assiduously to internalize ICT to catch up quickly with their developed counterparts. As a matter of fact, rapid adoption of ICT-enabling policies constitutes major policy agenda for many developing countries [42].

Agricultural sector has played a dominant role in SSA economies. In recent times, the vital importance of the sector for broad-based growth, food security, nutrition and poverty reduction has been recognized [18]. In specific terms, agricultural sector contributes more than 35% of the gross domestic product of the sub-region in 2017 and 16.3% of the tangible and intangible commodities exported from the region [50]. The sector also engages more than 60% of active population in the SSA sub-region. Despite this huge contribution from agriculture, the sub-region is not total food secures as about 80% of the SSA population's food requirements are met by regional produce. Given the current population of over 1.1 billion and population growth rate of 2.25% according

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to Worldometer, it is not impossible for the sub-region to be food unsecured in the nearest future. This necessitates the need to employ and apply all available technologies including ICT technology to bring about desired transformation in agricultural sector in the sub-region.

Many developing countries especially in Africa depend heavily on agricultural sector to generate employment and earn foreign incomes. Assess to infrastructural facilities in the area of transportation, irrigation and electricity has been considered to be critical to productivities and output growth in the agricultural sector in these economies [12]. To this effect, many developing countries have invested heavily in transportation, irrigation and electricity infrastructure with aim to stimulating performances in agricultural sector and the entire economy. Apart from the huge investment in these traditional infrastructures, many of these countries including SSA countries are witnessing huge and accelerated investment in ICT infrastructure, and this has reasonably translated to increasing assess and usage of ICT products such as mobile-cellular telephone subscription, individual using the internet, fixed-telephone and active mobile broadband subscription [6].

Existing data from World Development Indicators (WDI 2019) showed increase in volume of ICT usage in the SSA sub-region. For example, Nigeria that is considered as the leading economy in SSA sub-region has increase in number of mobile-cellular subscribers from 18.59 million in 2005 to 172 million in 2018. This represents a growth of 892% over the period. This is followed by Cote d'Ivoire with mobile-cellular subscribers of 2 million in 2015 and 33 million in 2018 representing 930% increment. All the countries in the sub-region show accelerated progress in this area. Data on individuals using the internet (% of population) showed that in 2005, 1.2% of Nigerian population used internet service as against 47.1% in 2018. Virtually, all the countries in the sub-region have put up a good performance using this indicator. The lowest was recorded by Liberia with 7.9% of the population using internet as at 2018. The fundamental question at this juncture is that how has this substantial progress in digital inclusion being utilized to impact on the agricultural sector in the sub-region?

In an effort to unravel Agro–ICT nexus, studies have been carried out both within and outside Africa; however, the bulk of the studies at the aggregate level lies outside Africa [16]. The increasing penetration of ICT products in Africa and SSA countries has attracted some country- and programme-specific studies [2, 3, 36, 46]. Nevertheless, couple of empirical studies exist at the aggregate on Agro–ICT nexus in Africa notably [11, 30]. Despite the array of existing studies in this area, substantial gap still exists for a study of this nature in the light of emerging data on ICT assess and usage. The data are of higher quality and wider coverage in the sub-region, and this has created a unique opportunity for aggregate study like this. More importantly, the leading position of SSA countries in ICT penetration by virtue of Nigeria huge population necessitates a special attention for the sub-region. These and many more are the areas where this study will add value to the literature.

Apart from this introductory part of the study, this paper is disaggregated into four sections. Section one focuses on the review of extant literature relevant to this study. The next section dwells on the method of analysis employed to dissect the inherent link between the ICT and agricultural sector performance. This is followed by presentation and discussion of results, and the last section presents the conclusion and recommendation emanating from the study.

Literature review

The contribution of ICT adoption to agricultural sector in sub-Saharan countries

The key drivers of Africa's economic growth have been identified to be through agriculture and natural resources (World Bank, 2017), which in recent times have been revamped through technological innovation and the adoption of new technology basically from ICTs [11], Kimenyi and Moyo [55]. The first application of ICT to agriculture dates back to the 1960s Serbulova [56]. The subject of e-agriculture was addressed at the world summit on information society in 2003 with the aim of prioritizing the application of Information and Communication Technology to agricultural development [24]. Studies from [51] have revealed that the application of ICTs to the agricultural sector, which is mostly considered as the largest economic sector in Africa, has resulted into increase in productivity, usage of new high-yield variety seeds, chemical fertilizers and other inputs. More so, ICTs have presented the need for technological adoption in terms of information on new seed varieties, inputs, new market and market prices at a low cost, thereby facilitating increase in agricultural growth [11, 43]. One of the major identified contributions of ICT to agricultural resources has been in the reduction of agricultural resources such as fertilizers, pesticides, energy and water as well as assisting in the reduction of external environmental externalities Bonanni [54]. An increasing combination of technologies that are used to control information and back up communication can be referred to as information and communication technologies [35]. Examples of such technologies are software, hardware, CD-ROMs, e-mail, telephone, radio, television, media for collection, storage, processing, digital cameras, presentation of transmission in any format such as voice, data, text and image [29, 38]. In the last two decades, the advent of the internet, mobile telephone and personal computers has contributed to a much broader options in processing, storage, collection, presentation and transmission of information in numerous configurations to connect multiple specification and expertise of person [14].

A study by Schmid [45] showed that adoption of technology performs an important function within the agricultural sector in Africa as the number of mobile subscribers in sub-Saharan Africa steadily increases in the last decade, thereby causing a transformation in the methods farmers used in cultivating their fields and sell their products. Several studies across SSA region have identified ICTs to have relationship with increase in efficiency, productivity and communication existing between buyers and sellers with the end result of reducing waste and price dispersion [1, 4, 14, 31]. A study by PEW research centre (2017) revealed that there exist as many mobile phones in Ghana and Kenya as there exist in the USA, which is an indication that sub-Saharan Africa is an emerging region for the fastest growing markets for mobile applications in the world. This has been supported by a published report of e-learning Africa (2015) that 90% of farmers having affirmed it that ICTs have improved food security and sustainability in SSA. Specific studies from Tanzania, South Africa and Mozambique have identified various contribution of ICT to farmers such as it has facilitated virtual business opportunities [7, 14, 27].

A study by Nwagwu and Famiyesin [33] has revealed that ICTs play an important role in the development flow, exchange of agricultural information and data identity of agriculture. Panda et al. [39] showed that an enormous prospect for agricultural and allied sectors growth is the adoption of ICTs as it has the potential of converting farming into profitable and enjoyable deeds, recalling of farmers back into farming and enticing the rural youth into agriculture. More so, categories of farmers in recent times based on the advancement of ICTs have access to well-timed, precise, relevant information services. In Senegal, a study revealed that through the creation of website, communities that are at risk have being able to get information on climate-change adaptation [50]. Also, a study from Rural Niger which revealed that through mobile phones, agricultural price information obtained have abridged search costs by 50% [3]. Studies from Malawi, Uganda and Tanzania pointed out the role of ICT to source information and knowledge basically on post-harvest handling methods, mechanism for pest and disease control, market information, information on weather and applications of fertilizer, which is essential to improve on productivity and maintain food security status of the resource vulnerable communities [5, 26, 28].

Empirical literature

In recent times, studies across sub-Saharan Africa have been able to empirically examine the use of ICTs as a mean to boost the agricultural sectors in the countries under the region. A study by Olaniyi [57] examined the nonlinear relationship among mobile phones, internet and agricultural development in Africa for the period of 2001–2015. Through the use of system generalized method of moment, empirical findings revealed a nonlinear relationship among mobile phones, internet and agricultural development. Freeman and Mubichi [14] provide evidence of information and communication technology (ICT) use by smallholder farmers in sub-Saharan Africa. Eight focus groups were used to draw qualitative data segmented by gender with the inclusion of adult farmers in two villages in central Mozambique. Findings revealed that cell phone and radio use are prevalent due to the characteristics of ICTs, which also varied by ICT type. This showed that diffusion of innovation is not only enough but the practical use. In another review, Nakasone et al. [32] examined the state of information and communication technologies (ICTs) on agricultural development in developing countries. The study revealed that the spread of mobile phones in rural areas has led to important changes in the agricultural sector as it leads to improved agricultural market performance at the macro-level with impact at the micro-level being mixed.

A study by [11] used the 2000–2011 panel data for 34 African countries through the application of [8] methodology and approach and utilized ICTs as input variables. Findings from the study revealed that ICTs play a significant role in enhancing agricultural production through the channel telephone main lines. Also, other socio-economic characteristics such as higher education levels and skills contributed to improved agricultural production in the continent. In a bid to evaluate the potential of video on mobile phones as a tool for farmer-to-farmer exchange and agricultural extension in West Africa, Sousa, Nicolay and Home [49] interviewed 460 farmers in Mali and Burkina Faso. The study revealed the presence of third-generation (3G) mobile phones with video and Bluetooth technology in the two countries. Findings showed that the use of video on mobile phones is a novel approach to farmer-to-farmer exchange of ideas and contributed to extension efforts. Thus, they enable the amplification of land use with all-encompassing and independent farming systems.

A study was conducted in Kapiri Mposhi district of central province in Zambia by Ali et al. [5]. The study made use of multiple-stage random sampling technique with the aim of finding out the impact of ICTs on agricultural productivity, net profit per acre and farmers sources of finance. Through the use of ordinary least square, findings revealed that the use of ICTs along with seed, fertilizer and amount borrowed on agricultural productivity was positive. The study suggested that there should be the development of ICT skills among agricultural extension workers and farmers. A similar study was also conducted by Oladele [36] in South Africa to determine the effect of Information Communication Technology (ICT) on agricultural information access among extension officers in North West Province. The technique of simple random sampling was used to select 169 officers to elicit information. Findings revealed the effect of education use of ICT tools and e-readiness on ICT information access among extension officers.

A study by [34] examined an ICT-based intervention through the use of ICT to integrate smallholder farmers into agricultural value chain embedded in DrumNet project in Kenya. The study accessed the design of the project with the aim of resolving the smallholder's farmers' idiosyncratic market failures and member-farmers' marketing margins. The study found out that successful ICT-based interventions help farmers integrate into higher value agricultural value chains giving the requirements of integrated approach to tackling smallholder's farmers' constraints. Another study from Uganda by Harris and Achora [17] designed ICT for Agriculture (ICT4A) innovations for smallholder farmers in the bid to solve the challenges that providers of information and communication technologies for agriculture (ICT4A) in the developing world currently face as well as some of the Human Computer Interaction designs that can solve the problem.

A similar study from Nigeria by [37] investigated the accessibility and relevance of information and communication technologies (ICTs) among cassava farmers. With data gathered through surveyed interview, the study identified radio, television, video recorder, audio cassette, mobile phone (GSM), computer and camera as ICT tools relevant to cassava production activities. The study recommended that extension institutions in Nigeria should be directed towards the usage of the identified ICT tools in order to improve cassava production. Another study from Nigeria by [13] examined what role ICT plays on agriculture by exploring the application of the theoretical prescriptions of the model on diffusion to production of crops. Through the use of ordinary least square technique, findings revealed that adoption of ICT has strong influence on crop production.

The aim of Kante et al. [21] in their study is to bring out the factors affecting the use of ICTs on agricultural input information in developing countries. Ground theory was used in the study to access the use of ICTs on agricultural input information access. Findings revealed that the perception of the farmers in terms of relative advantage, compatibility, simplicity, observability and social influence of ICTs and information quality has positive effect on agricultural input information in developing countries. In a similar study, Kante et al. [22] proposed an ICT model for increased adoption of farm input information in developing countries. With the use of a convenient sample of 300 small-scale cereal farmers and the technique of partial least squares structural equation model, findings revealed that the model can be used to predict ICT-based farm input information in the country as a means of adoption of ICT in agriculture.

In the bid to bring out the policy implication of promoting the use of information and communication technologies (ICTs) for agricultural transformation in sub-Saharan Africa, Ajani [1] recommended the establishment of agricultural communication networks with the involvement of active participation of all stakeholders in agriculture. Also, public institutions in agriculture were advised through the findings from the study to be involved in the development of a curriculum in ICTs for agricultural development and more so support ICT platforms towards the facilitation of farmers' access to quality agricultural information. A study by Showole and Hashim [48] determined the influence of information communication technologies in dissemination of information to urban farmers. Primary data were obtained by random sampling of 60 respondents. The study recommended that agricultural sectors should be well funded so that they can subscribe to outstanding databases, also power supply that will meet the needs of agricultural researchers. The study further recommended that ICT infrastructures and the larger part of its bandwidth should be released to the agricultural sector to reduce the cost of using commercial cybercafés. Kabbin et al. (2018) extended the applicability of the technology acceptance model (TAM) to adoption of mobile phones in farming communities in sub-Saharan Africa. Relying on a sample of 300 dairy farmers in Uganda and application of structural equation modelling, findings revealed that promotion of mobile phone usage in farming communities transcend beyond normal.

In the string of more recent studies, Ayim et al. [52] offer a systematic review of literature on ICT adoption in agriculture. The review reveals that mobile-based services have improved the access to information on best practices in agricultural activities; however, the service is constrained by poor technological infrastructure and farmers' low capacity. Nevertheless, from the studies empirically reviewed above, it was discovered that most of the studies from the region on the interaction between information and communication technologies (ICTs) and the agricultural sector are still being conducted conceptually and at the micro-level with few studies being conducted at the macro-level. This gap in the literature calls for new studies in the area to be conducted as this will reveal the contribution of ICTs to the agricultural sector, hence this study.

Methods

For the purpose of model estimation, data were sourced majorly from World Bank Development indicators (WDI), Food and Agricultural Organization (FAO) and International Labour Organization (ILO) for 39 SSA countries. Specifically, data on percentage of agricultural output in GDP, agriculture products as percentage of total merchandise export, mobile-cellular telephone subscription, individual using the internet, fixed-telephone, active mobile broadband subscription and School enrolment were sourced from WDI. Similarly, data on number of agricultural tractor available and amo.nt of fertilizer available (in kilograms) per hectare of arable land, hectares of arable land permanent crops and livestock's gross capital stocks were sourced from (FAO). Lastly, data on active population engage in agricultural practices were obtained from (ILO). Data were collected annually covering the period between 1997 and 2018. This choice of period was informed partly by data availability and accelerated ICT penetration in the SSA.

The theoretical framework of this study stems from Cobb–Douglas production with the following specification:

$$Y = AT^{\propto}H^{\beta}P^{\delta}\varepsilon \quad (1)$$

In the equation one as stated, the agricultural output of the country is regarded as (Y), the relevance of level available technology in agricultural sector is denoted by (T), while human resource and physical capital are represented by (H) and (P). Hicks' neutral productivity level is considered to be influenced by the level of education and ICTs, and it is captured by (A). In addition,$\propto$, β and δ represent the constant co-efficient to guarantee the concavity of Y in the equation. For the purpose of estimation within the panel data analysis, equation one can be re-specified as follows:

$$\log Y_{it} = \log A_{it} + \propto \log T_{it} + \beta \log H_{it} + \delta \log P_{it} + \varepsilon_{it} \quad (2)$$

Following similar study in this area such as [11], *T, H*, and *P* capture traditional agricultural input employ in the agricultural production function. This representation has been quite popular in the literature of agricultural production. In empirical literature, the level of technology which (T) symbolizes has been proxied by machinery and fertilizer variables, which are considered to be technical inputs. Similarly, physical capital (P) has been proxied by land and livestock, while human capital (H) has been proxied by percentage of economically active population engage in agricultural practices.

In this study, while these traditional definitions and measurements are largely maintained, (Y) that is a measure of agricultural output is proxied by two variables and thus necessitates the specification of two models. The variables are agricultural value addition measured by percentage of agricultural output in GDP and agricultural export measured by agriculture products as percentage of total merchandise export. The two models are operationally specified as follows:

$$\begin{aligned}\log AGO_{it} = &\log ICT_{it} + \propto \log MF_{it} \\ &+ \beta \log LAB_{it} + \delta \log LL_{it} + \varepsilon_{it}\end{aligned} \quad (3)$$

$$\begin{aligned}\log AGE_{it} = &\log ICT_{it} + \propto \log MF_{it} \\ &+ \beta \log LAB_{it} + \delta \log LL_{it} + \varepsilon_{it}\end{aligned} \quad (4)$$

In Eq. 4, *AGO* represents the agricultural sector output proxy by agricultural real output in and ICT represents the information technology variables proxied by two variables mobile-cellular telephone subscription and individual using the internet. Similarly, MF represents the technological inputs proxied by numr of agricultural tractor available and amount of fertilizer available (in kilograms) per hectare.of arable land. LAB also represents the human capital proxied by active population engage in agricultural practices and primary school enrolments, while LL represents the physical capital available in the agriculture sector of the economy. The variable is proxied by hectares of arable land permanent crops and livestock's gross capital stocks. In the similar version, Eq. 4 retains all the independent variables as explained in Eq. 3; however, dependent variable AGE is a measure of agricultural export proxied by agriculture products as percentage of total merchandise export. Apart from agriculture products as a percentage of total merchandise export introduced as a measure of external exposure of agricultural sector in SSA, all other variables have extensively used in similar models [11, 53].

The model as specified in Eqs. 3 and 4 is estimated using panel ARDL because of the expected endogeneity in the model and the need to investigate the long-run parameters. Within the panel ARDL, decision to use either pooled mean group (PMG) or mean group (MG) can be contentious sometimes. Following Oyelami [58], this decision to use either PMG or MG was guided by specification tests inherent in PMG estimation technique.

Based on Pesaran, Shin and Smith [41], the general form of (PMG) can be stated as follows:

$$y_{it} = \sum\nolimits_{j=1}^{n} \lambda_{ij} y_{i,t-j} + \sum\nolimits_{j=0}^{q} \delta_{ij} x_{i,t-j} + \mu_{it} + \varepsilon_{it} \quad (5)$$

Given Eq. 5, the cross sections are represented by i = 1, 2,…,N and t = 1,2,…T, Also, $x_{i,t-j}$ represents the vector of K * 1 regressors. λ_t and δ_t denote the coefficients of vectors for scalars and exogenous variables, while μ_t stands for group-specific effect. Furthermore, ε_{it} is the representation of the disturbance term and if co-integration exists, the disturbance term assumes I(0) process. Reparametrizing Eq. 5 to account for error correction will produce Eq. 6:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \dot{\theta}_t \mathrm{X}_{i,t-1} + \sum\nolimits_{j=0}^{q-1} \dot{\delta}_{ij} x_{i,t-i} + \mu_{it} + \varepsilon_{it} \quad (6)$$

φ represents the error correction parameter and by implication denotes the speed of adjustment. If this parameter produces zero value, it indicates no long-run relationship. More importantly, the usual expectation is that the parameter should be negative and statistically significant to show evidence of long-run equilibrium in case of divergence. Developing Eqs. 3 and 4 to produce the pooled mean group (PMG) version of panel ARDL employs for estimation in this study which take the form of Eqs. 7 and 8:

$$\begin{aligned}\Delta AGE_{ij} = \lambda_0 &+ \sum\nolimits_{j=1}^{n1} a_{ij} \Delta ICT_{t-j} + \sum\nolimits_{j=1}^{n2} b_{ij} \Delta MF_{t-j} \\ &+ \sum\nolimits_{j=1}^{n3} c_{ij} \Delta LAB_{t-j} + \sum\nolimits_{j=1}^{n3} d_{ij} \Delta LL_{t-j} \\ &+ \theta_1 ICT_{t=1} + \theta_2 MF_{t=1} + \theta_3 LAB_{t=1} \\ &+ \theta_4 LL_{t=1} + \varepsilon_{t=1}\end{aligned} \quad (8)$$

Apart from the ARDL symbols that have been explained earlier, all the variables retain their explanation as provided in Eqs. 3 and 4.

Results

Summary statistics of variables

The descriptive characteristics of data are presented in Table 1. Total number of observations recorded for the variables ranges from 766 for agricultural export and 878 for agricultural output. Also, the mean value ranges from 0.1 for fixed telephone and 21.0 for agricultural output. Agricultural export has the least minimum value of -13.6, while the agricultural output has the highest minimum value of 16.9. Similarly, the maximum value ranges from 2.7 to 25.5 for mobile subscription and agricultural output, respectively. The skewness scores from the table show that the data for each of the variable are either positively skewed or negatively skewed. However, some of the

$$\begin{aligned}\Delta AGO_{ij} = \lambda_0 &+ \sum\nolimits_{j=1}^{n1} a_{ij} \Delta ICT_{t-j} + \sum\nolimits_{j=1}^{n2} b_{ij} \Delta MF_{t-j} + \sum\nolimits_{j=1}^{n3} c_{ij} \Delta LAB_{t-j} + \sum\nolimits_{j=1}^{n3} d_{ij} \Delta LL_{t-j} \\ &+ \theta_1 ICT_{t=1} + \theta_2 MF_{t=1} + \theta_3 LAB_{t=1} + \theta_4 LL_{t=1} + \varepsilon_{t=1}\end{aligned} \quad (7)$$

Table 1 Descriptive analysis of data

	Agicexport	Agricemployment	Permanent_ cropland	Livestock_ production	Enrolment	Agricrealoutput	Mobile_ cellular	Internet_ users	Crop_ production
Mean	1.0	3.8	− 0.4	4.6	4.5	21.0	2.1	0.2	4.6
Median	1.5	4.0	− 0.2	4.6	4.6	21.2	3.1	0.7	4.6
Maximum	4.5	4.5	2.7	5.5	5.1	25.5	5.2	4.1	5.5
Minimum	− 13.6	1.5	− 6.3	3.9	3.3	16.9	− 6.9	− 11.0	3.7
Std. Dev	2.5	0.6	2.1	0.2	0.3	1.5	2.7	2.6	0.3
Skewness	− 2.0	− 1.5	− 0.7	0.3	− 1.3	− 0.1	− 1.1	− 0.9	0.1
Kurtosis	9.0	4.9	3.0	4.0	5.3	3.6	3.1	3.6	3.4
Jarque–Bera	1506.8	463.7	71.4	49.1	368.3	15.1	157.5	142.4	7.6
Probability	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	658.1	3335.8	− 338.5	3959.8	3481.9	17,309.7	1721.9	154.0	3960.0
Sum Sq. Dev	4191.0	338.6	3947.2	48.9	64.2	1852.1	6001.5	5863.7	59.1
Observations	766	874	858	858	766	823	836	859	858

Source: Author's Computation

data are close to being considered symmetry. Furthermore, the results from Jarque–Bera tests indicate that the hypotheses of normal distribution can be rejected for most the series. This is not unexpected in panel analysis like this due the heterogeneous nature of different economies involved in the analysis.

Correlation analysis

In effort to forestall multi-collinearity in model estimation, correlation analysis was conducted to determine variables with high correlational value, which has been considered as a recipe for multi-collinearity in model estimation. Based on the results as presented in Table 2, most variables show moderate correlational value (less than or equal to 0.6) with the exception of mobile subscription and internet users (0.94), employment in agriculture and fixed phone subscription (− 0.82), livestock production and mobile subscription (0.69). Given these results, ICT variables were introduced into the models differently. In a similar manner, livestock production was removed in the model estimated for mobile subscription.

Econometric properties of data

Unit root test

To determine the econometric of properties data, the issue of unit root tests and co-integration tests readily come to mind. Table 3 shows the results of panel unit root tests conducted based on homogenous panel unit root tests [10, 25] and heterogeneous panel unit root tests [19]. The results show that the data employed for estimation in this study are largely integrated of order one I (1). Specifically, agricultural output, internet users, livestock production, mobile subscribers and enrolment are integrated of order one I (1). This suggests the acceptance of the presence of the unit root hypotheses for the series at level; however, similar hypotheses are rejected for the series at first difference. Apart from these specific variables, all other variables show the mixture of integration of order one I (0) and I (1) depending on the unit root process. With these results, it is inevitable to conclude that data as presented in Table 3 are combination of I (0) and I (1).

Panel co-integration

Sequel to the results obtained from the unit test showing the presence of unit root in many of the series, it is imperative to carry out co-integration test to determine the long-run convergence of the series. To this effect, co-integration tests were carried out on the two models prepared for estimations substituting different ICT variable in each model. This invariably provided room for six combinations of series subjected to co-integration analysis. The tests were conducted based on Pedroni's panel co-integration test, which comprises of four within dimension and three between-group dimensions. Within-dimension are computed values of statistics based on estimators that pooled the autoregressive coefficient across different countries for the unit tests on the estimated residuals [40]. On the other hand, between-dimension reports the computed values of the statistics based on estimators that averaged individually calculated coefficients for each country [40]. In all the four cases, the hypothesis of no co-integration is rejected both within-dimension and between-dimension. This suggests that despite the presence of unit root in most of the series, there is sufficient evidence to establish that the series co-integrate in long run and there is long-run relationship among variables rendered for estimations (Table 4).

Results and discussion

The results of the two models and two estimations performed using panel ARDL are presented in Table 5. As discussed earlier, the two model have two independent variables (agricultural output and agricultural export) selected to measure agricultural sector performances in two interrelated dimensions. Two estimation were performed on each of the model to circumvent multi-collinearity problem due to high correlation value between mobile subscription and internet users. The results from the first estimation show that the mobile subscription as proxy for ICT access and usage, permanent crops and livestock's gross capital stocks, which are proxy physical capital in agriculture and Enrolment proxy for human capital development in agriculture, do not have statistically significant effect on agricultural output in the short run. In fact, school enrolment has negative sign, which suggests that schooling may reduce the amount of labour and man power available for agricultural purposes. However, in the long-run mobile subscription, permanent crops and livestock's gross capital stocks and school enrolment have statistically significant positive effect on agricultural output in SSA. This gives an inclination that investment in ICT may not produce instant impact on agricultural output until the products of ICT are substantially utilized for agricultural purposes.

In the second estimation, almost the same set of variables were estimated except the mobile subscription that was substituted for internet users. The introduction of internet users in the second estimation improved co-efficient value of permanent crops in long run. However, it decreased the coefficient value of enrolment. Similarly, in the short run a noticeable increase and decrease in co-efficient values are observable. Importantly, the second estimation produced a replica of the first estimation. In the long run, mobile subscription, permanent crops and school enrolment have statistically significant positive

Table 2 Correlation analysis

	Agicexport	Agricemployment	Permanent_ cropland	Livestock_ production	Enrolment	Fixed_ telephone	Agricrealoutput	Mobile_ cellular	Internet_users	Crop_ production
Agicexport	1.00									
Agricemploy-ment	0.29**	1.00								
Permanent_ cropland	0.29**	0.22	1.00							
Livestock_pro-duction	− 0.02	− 0.03	0.05	1.00						
Enrolment	− 0.13	− 0.22**	0.13	0.41***	1.00					
Fixed_telephone	− 0.34**	− 0.82***	− 0.34**	− 0.05	0.19	1.00				
Agricrealoutput	0.35**	0.31**	0.32**	0.14	− 0.09	− 0.38**	1.00			
Mobile_cellular	− 0.20*	− 0.39**	− 0.12	0.69***	0.48***	0.39**	− 0.03	1.00		
Internet_users	− 0.22*	− 0.48***	− 0.08	0.63***	0.50***	0.47***	− 0.03	0.94***	1.00	
Crop_produc-tion	− 0.02	0.02	− 0.04	0.63***	0.32***	− 0.04	0.14	0.62***	0.55***	1.00

*,**,*** indicate rejection of the null hypothesis of unit root at 10%. 5% and 1% significant level

Source: Author's computation

Table 3 Unit root test results

Variables		Level			First Difference		
			With intercept	**With trend & intercept**	**With intercept**	**With trend & intercept**	**Level of integration**
Agricexport	Homogenous unit root process	LL C	− 7.29***	− 31..3***			I(0)
		Breitung	–	3.3	–	− 11.47***	I(1)
	Heterogeneous unit root process	ADF	− 5.31***	− 4.59***			1(0)
		IP S	− 5.68***	− 4.51***	–		1(0)
Agricouput	Homogenous unit root process	LL C	7.78	− 0.56	21.08		I(1)
		Breitung	5.58	–	–	3.41**	I(1)
	Heterogeneous unit root process	ADF	8..82	1.25	15.26	6.87***	1(1)
		IP S	9.83	1.16		− 8.58***	1(1)
Agricemployment	Homogenous unit root process	LLC	10.69	− 0.17	− 10.26***	28.26***	I(1)
		Breitung		12.84		13.79***	I(1)
	Heterogeneous unit root process	ADF	14.62	5.33	19.48***	− 21.22***	1(1)
		IP S	17.28	5.3	–	24.45***	1(1)
Crop production	Homogenous unit root process	LLC	− 0.19	− 5.87**	10.00	− 17.69***	I(0)
		Breitung		− 1.85**		8.78***	I(1)
	Heterogeneous unit root process	ADF	2.28	− 4.48***	10.44		1(0)
		IP S	2.32	5.19***			1(1)
Internet users	Homogenous unit root process	LLC	21.90	10.43	25.35	− 21.02***	I(1)
		Breitung		18.95		− 11.97***	I(1)
	Heterogeneous unit root process	ADF	24.64	16.01	23.29	− 16.38***	1(0)
		IP S	32.54	20.13		− 4.40***	1(1)
Livestock production	Homogenous unit root process	LLC	− 1.61*	0.61	14.18	− 5.88***	I(1)
		Breitung	1.17			0.29	I(1)
	Heterogeneous unit root process	ADF	3.77	2.16	14.47	− 4.20***	1(1)
		IP S	3.72	2.02		7.31***	1(1)
Mobile cellular	Homogenous unit root process	LLC	11.33	− 1.24	19.28		I(1)
		Breitung		9.00		− 15.12***	I(1)
	Heterogeneous unit root process	ADF	15.74	3.69	18.00	− 11.83***	1(1)
		IP S	17.45	3.65		− 13.83***	1(1)
Permanent crops	Homogenous unit root process	LLC	− 5.38***	− 1.58*	6.35		I(1)
		Breitung		3.11		− 15.12***	I(1)
	Heterogeneous unit root process	ADF	0.14	2.15	8.56	− 11.83***	1(0)
		IP S	− 0.53	1.86		− 13.83***	1(1)
Enrolment	Homogenous unit root process	LLC	− 3.08***	0.05	2.14		I(0)
		Breitung	5.87			5.23	I(1)
	Heterogeneous unit root process	ADF	− 0.68	3.13	1.92	7.99***	1(1)
		IP S	-0.77	3.15		3.69***	1(1)

*,**,***Indicate rejection of the null hypothesis of unit root at 10%. 5% and 1% significant level

Source: Author's computation

Table 4 Panel co-integration tests results

Within-Dimension					Between-Dimension		
	v-stat	**p-stat**	**pp-stat**	**Adf-stat**	**p-stat**	**pp-stat**	**Adf-stat**
Estimation 1	(log (Agricoutput)	log(Agricemployment)		log(permanent crop)	log(Internet)	log(enrolment)	log(livestock)
Model 1	− 2.37	4.42	− 0.53	− 3.56***	6.28	− 3.52***	− 3.90***
Estimation 2	(log (Agricoutput)	log(Agricemployment)		log(permanent crop)	log(Mobile)	log(enrolment)	log(livestock)
Model 1	− 4.09	5.74	− 2.27***	− 1.63*	7.05	− 10.25	− 2.68
Estimation 1	(log (Agricexport)	log(Agricemployment)		log(permanent crop)	log(Internet)	log(enrolment)	log(livestock)
Model 2	7.62	4.71	− 17.33***	0.71	6.32	− 15.81***	− 0.31
Estimation 2	(log (Agricexport)	log(Agricemployment)		log(permanent crop)	log(Mobile)	log(enrolment)	log(livestock)
Model 2	− 7.79	4.48	− 20.23***	3.49	6.58	− 22.74***	− 2.32

The test statistics are normalized so that the asymptotic distribution is standard normal. *, **, *** indicate rejection of the null hypothesis of non-co-integration at the 10%,5% and 1% significance levels

Source: Author's computation

effect on agricultural output. But, in the short run, all the variables failed to exert significant effect on agricultural output as expected. This may corroborate the study by 11 that reported underutilization of ICT products in the sub-region as the reason for poor performances of ICT variables in his analysis. With the use of panel ARDL with inherent capability to classify the effect into long run and short run, it is crystal clear that most of these hypothesized relationships between agricultural output and ICT products only exists in the long run.

The results of the estimation of the second model are presented in the lower part of Table 5. The dependent variable in the model is agricultural export. This model was introduced to gain a deeper understanding of the ICT on agricultural sector performances in SSA. The results from the two estimations majorly followed the trajectory of the estimation performed in the first model. However, unlike in the first model where the two ICT variables (mobile subscription and Internet users) exert positive effect on agricultural output in the long run, the two variables exert statistically significant opposite effect on agricultural export in the long run. While mobile subscription's variable has positive effect on agricultural export, internet users' variable has negative effect on the agricultural export in the sub-region. Unlike what obtained in the long run, these two variables have positive effect on agriculture export in the short run. However, these effects are not statistically significant. The situation in the long run may simply reflect the underutilization of internet for agricultural products marketing and sales at the global level. This may be traceable to low level of awareness and education on the use of internet for productive engagement in the area of marketing and sales of agricultural produce.

To validate the appropriateness of the model estimated, we carried out Hausman specification test to compare MG and PMG models. The results of the tests are reported for each of the estimation. This test is particularly important because if true model is heterogeneous, estimation of PMG may produce an inconsistent result. If the test is significant (Prob-chi < 0.05), this indicates PMG is wrongly specified otherwise PMG it is appropriately specified. The results from Hausman specification test shows that PMG is the preferred specification model as the probability value of chi-square is greater than 0.05 for the two models and the four estimations performed.

Conclusion and policy recommendations

The study has provided a careful analysis of the interconnectedness of (ICT) infrastructure and agricultural sector performances using agricultural real output and agricultural export as focused variables. Data from SSA were sourced and estimated following econometric procedures. The established procedure of estimation was followed to prevent inconsistent results. Data used cover the period of twenty-three years (1995–2017) in 39 SSA countries. The selection was majorly based on data availability; nevertheless, it takes care of geo-economic interest in the sub-region. It is discernable from the study that the SSA has witnessed increasing investment in ICT infrastructure, and this has brought about increased access and usage of ICT products in the sub-region. It is also observable from the data employed for this study

Table 5 Models estimation results (Source: Author's computation)

Variables	Estimation 1	Estimation 2
Agricultural Output(Model 1)	**Long-Run**	**Long-Run**
Permanent_Cropland	0.32(0.00)***	0.90(0.00)***
Mobile_Cellular	0.04(0.00)***	
Livestock_Production	0.09(0.02)***	
Enrolment	0.21(0.00)***	0.12(0.00)***
Internet_Users		0.07(0.00)***
	Short-Run	Short-Run
ECT	**− 0.35(0.00)**	**− 0.30(0.00)**
Permanent_Cropland	0.02(0.87)	0.03(0.40)
Mobile_Cellular	0.01(0.29)	
Livestock_Production	0.11(0.26)	0.088(0.45)
Enrolment	− 0.0(0.97)	0.14(0.34)
Internet_Users		− 0.002(0.87)
Prob > chi	0.1955	0.1243
Agricultural Export (Model 2)	Long-Run	Long-Run
Permanent_Cropland	0.18(0.61)	− 1.14(0.00)***
Mobile_Cellular		0.05(0.00)***
Livestock_Production	0.93(0.00)***	
Enrolment	0.16(0.631)	1.56(0.00)***
Internet_Users	− 0.12(0.03)***	
	Short-Run	Short-Run
ECT	**− 0.48(0.00)*** **	**− 0.60(0.00)*** **
Permanent_Cropland	0.67(0.74)	0.26(0.84)
Mobile_Cellular		0.005(0.97)
Livestock_Production	0.97(0.56)	0.23(0.85)
Enrolment	− 1.57(0.48)	1.10(0.49)
Internet_Users	0.17(0.28)	
Prob > chi	0.1455	0.1353

*,**,***Indicate rejection of the null hypothesis at 10%. 5% and 1% significant level

that usual non-stationarity issues surfaced; however, co-integration analysis provided the necessary succor. Beyond country-specific study, the results from the estimations provide evidences to establish that provision of ICT infrastructure that guarantee increased access and usage of ICT products have positive influence on agricultural sector performance in SSA in the long run. However, this discernable benefit is not instantaneous. This suggests that a reasonable period of gestation might be required before this positive interaction to takes effect. This waiting period might be characterized by extensive education and training necessary for the adoption and application of ICT products in agriculture. Despite this positivity, this is tiny evidence to show underutilization of ICT products in the sub-region in terms of leveraging on the ICT technology to attract global markets for agricultural products. This evidence surfaced in the estimation of the second model for this study.

The key recommendations arising from this study are that government should encourage ICT-related investment in SSA as this can strengthen agricultural sector performance in the sub-region. However, to fully harness and optimize the inherent positive externality of ICT investment in the sub-region serious effort needs to be invested in the area of education and training of farmers to adopt and apply ICT products across the value chains of agriculture. Furthermore, given the level of poverty in the sub-region, government should endeavour to make ICT products affordable for the poor who constitutes the larger part of rural farmers to guarantee access and adoption for agricultural activities.

Abbreviations

ICT: Information and Communications Technology; ARDL: Autoregressive Distributed Lag; PMG: Pool Mean Group; WDI: World Bank Indicators; FAO: Food and Agriculture Organization; SSA: Sub-Saharan Africa; GDP: Gross domestic products; ILO: International Labour Organization.

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Author contributions

The idea of the project was conceptualized by Dr. Lukman Oyelami who also gathered the data and carried out the analysis. Dr. Sofoluwa prepared the introduction, while Dr. Ajegbe prepared the literature review. All authors have read and approved the manuscript.

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Availability of data and materials

Materials datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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