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Enhancing Information Technology for Value Added Across Economic Sectors in Sub-Saharan Africa

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Enhancing Information Technology for Value Added Across Economic Sectors in Sub-Saharan Africa

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Abstract

This study investigates how enhancing information and communication technology (ICT) affects value added across sectors in 25 countries in Sub-Saharan Africa using data for the period 1980-2014. The empirical evidence is based on the Generalised Method of Moments. The following findings are established. First, the enhancement of mobile phone and internet penetrations respectively have net negative effects on value added to the agricultural and manufacturing sectors.Second, enhancing ICT (i.e. mobile phone penetration and internet penetration) overwhelmingly has positive net effects on value added to the service sector. From an extended analysis, enhancing ICT in the agricultural and manufacturing sectors should exceed certain thresholds for value added, notably: 114.375 of mobile phone penetration per 100 people for added value in the agricultural sector and 22.625 of internet penetration per 100 people for added value in the manufacturing sector.

JEL Classification : E23; F21; F30; L96; O55

Keywords: Economic Output; Information Technology; Sub-Saharan Africa

1. Introduction

The premise of this research on enhancing information technology for value added across economic sectors in Sub-Saharan Africa (hence SSA) is motivated by two relevant factors in the scholarly and policy-making arenas, notably: the contemporary relevance of information and communication technology (hence ICT) in outcomes of economic development and gaps in the extant contemporary literature. The research expands the two factors in turn.

First, while ICT has been in existence in contemporary times and has also been a crucial element of economic systems, changes over the last decade have been quite significant in increasing value added across economic sectors through *inter alia*: diminishing the cost of production, enhancing output, boosting competitiveness, ameliorating public sector management and improving capacities of production (Chadwick, 2005; Sassi & Goaied, 2013; Hong, 2016) as well as boosting innovation (Oliva et al., 2019), knowledge exchange (Singh, Mittal, Sengupta, & Pradhan et al., 2019) and knowledge management (Al Ahbabi, Singh, Balasubramanian & Gaur, 2019) that are relevant in both public sector and private sector performance. ICT's relevance in improving economic development in developing countries is consistent with evidence in SSA, as documented in contemporary economic development literature (Tchamyou, 2017; Asongu & Nwachukwu, 2018; Abor, Amidu & Issahaku, 2018; Isszhaku, Abu & Nkegbe, 2018; Minkoua Nzie, Bidogeza & Ngum, 2018; Gosavi, 2018; Asongu & Odhiambo, 2019a; Efobi, Tanankem & Asongu, 2018). The comparative importanceof ICT in SSA relative to other regions of the world builds on the evidence that compared to other regions of the world, SSA is the region with the least penetration in ICT and the most potential for ICT penetration (Penard, Poussing, Yebe & Ella, 2012; Asongu, 2013; Afutu-Kotey, Gough & Owusu, 2017; Asongu & Boateng, 2018; Humbani & Wiese, 2018; Gosavi, 2018; Asongu & Odhiambo, 2019b). The present study which is positioned on extending this strand of literature is also motivated by, to the best of our knowledge, the absence of a study that has focused on how increasing ICT penetration affects value added across sectors in SSA.

Second, the attendant literature on value chains in Sub-Saharan Africa has fundamentally focused on: (i) smallholder farming and the agricultural sector (Lutz & Olthaar, 2017). Within this framework: Van Rijsbergen, Elbers, Ruben and Njuguna (2016) are concerned with the effect of coffee certification on the welfare of farmers in Kenya; Lutz and Tadesse (2017) focus on inclusiveness versus competitiveness in African farmers' market organisation and global value chains; Olthaar and Noseleit (2017) focused on a comparative analysis of farmer cooperatives to non-members in SSA; Metzlar (2017) investigated the strategic position and intents of smallholder farmers in the Ghanaian cocoa industry while Vermeire, Bruton and Cai (2017) are concerned with global value addedin Africa and development avenues for poor landowners. (ii) As it relates to the manufacturing sector: Ruben, Bekele and Lenjiso (2017) investigate quality upgrading and value addedin the diary sector of Ethiopia; trade-oriented regional value addedin SSA within the framework of the Leather sector are also examined by Banga, Kumar and Cobbina (2015) while Van Lakerveld and Van Tulder (2017) focused on the transition management of sustainable supply chain practices in the light of leading Dutch corporations in SSA. (iii) Studies on value addedin the service sector are sparse. In this category, Beerepoot and Keijser (2015) have focused on outsourcing of the service sector as a determinant of economic development with evidence on ICT from Ghana. The purpose of this research is to complement this attendant literature by assessing how improving ICT affects value creation/added in the three main economic sectors, namely: agricultural, manufacturing and service sectors.

To increase the policy relevance of the study, forecasted thresholds for technology spillovers are also provided. This focus of the study departs from contemporary technological spillovers and forecasting literature which has largely been concerned with *inter alia*: challenges in forecasting business prospects (Amankwah-Amoah, 2016; Amankwah-Amoah & Sarpong, 2016; Amankwah-Amoah, Osabutey & Egbetokun, 2018); the impact of technological spillovers for small and medium sized corporations (Del Giudice, Scuotto, Garcia-Perez & Petruzzelli, 2019); the importance of inter-sectoral knowledge spillovers in technology-related innovation (Stephan, Bening, Schmidt, Schwarz, & Hoffmann, 2019); learning technology and diffusion at local and global spheres (Zhang, Bauer, Yin & Xie, 2020); technology spillovers from trade and patent markers (Cai, Sarpong, Tang & Zhao, 2020); the influence of knowledge spillovers in sustainable energy production (Miremadi, Saboohi & Arasti, 2019) and enhancing information technology for inclusive development (Asongu & le Roux, 2017) and environmental sustainability (Asongu, le Roux & Biekpe, 2018). The focus of this study is closest to the last strand of technological forecasting and social change literature because it aims to assess how enhancing information technology affects value added across various economic sectors. The focus of the study also departs from the attendant strand of literature by going beyond establishing nexuses between information technology and macroeconomic outcomes, to providing or forecasting information technology policy thresholds needed for a favourable influence on value added across various economic sectors.

The theoretical underpinning supporting the importance of ICT in value added across economic sectors is consistent with neoclassical economic development models (Kwan & Chiu, 2015; Asongu & Odhiambo, 2018). Accordingly, neoclassical foundations of economic development maintain that information technonolgy is imperative for economic development in developing countries (Abramowitz, 1986; Bernard & Jones, 1996; Asongu Nwachukwu & Aziz, 2018).The theoretical fundamentals have motivated a recent strand of literature on the importance of ICT in promoting economic prosperity when nations are at the beginning levels of industrial development (Muthinja & Chipeta, 2018; Bongomin, Ntayi, Munene & Malinga, 2018; Uduji & Okolo-Obasi, 2018a, 2018b; Asongu, le Roux, Nwachukwu & Pyke, 2019; Asongu, Nwachukwu & Pyke, 2019).

The rest of the research is organised in the following manner. Section 2 provides insights into theoretical underpinnings and forecasting of technological spillovers. Section 3 discusses the data and methodology while the empirical findings and corresponding discussion are disclosed in Section 4. The research ends in Section 5 with a concluding section that recapitulates the forgoing, before suggesting future research directions.

2. Technology accumulation and forecasting technological spillovers

Innovation and information technology are important drivers of value creation in the competitiveness and performance of nations and corporations (Acharya, Singh, Pereira, & Singh, 2018; Gupta, Kumar, Singh, Foropon & Chandra, 2018; Nair, Chellasamy & Singh, 2019; Nguyen, Siengthai, Swierczek & Bamel, 2019). In the light of contemporary information technology spillover literature (Asongu & Acha-Anyi, 2020), the theoretical basis for the linkage underlying information technology and macroeconomic outcomes (such as value added across various economic sectors as it is the case within the framework of this study), is in accordance with the neoclassical framework for economic development by means of technological progress (Grossman & Helpman, 1991; Kwan & Chiu, 2015; Asongu & Odhiambo, 2018). Accordingly, the underlying theoretical basis is sympathetic to the position that an essential factor driving economic development in developing countries and by extension, facilitating the catch-up process (i.e. between developing and developed countries) is information technology (Abramowitz, 1986; Bernard & Jones, 1996). The attendant neoclassical framework has motivated an evolving strand of technological forecasting and social change literature (Del et al., 2019; Stephan et al., 2019; Zhang et al., 2020; Cai et al., 2020; Miremadi et al., 2019).

Building on Hussien, Ahmed and Yousaf (2012), a great number theoretical frameworks emphasize how productivity and value added to various economic sectors, are associated with, *inter alia,* better industrial resource allocation by means of technological spillovers, economies of scale and learning by doing. In the light of the attendant theoretical and empirical literature (Hussien et al., 2012; Asongu & Acha-Anyi, 2020), given that not all countries have absorptive capacities for research and development (R&D) that are related to activities of production (and by extension, added values to various sectors), boosting information technology in less developed countries (i.e. as it is the case with this study), enables cross-country catch-up in economic development, including the primary (i.e. agriculture), secondary (i.e. industry) and tertiary (i.e. service) sectors. The technological framework for economic development catch-up is consistent with the empirical and theoretical studies on the subject, *inter alia*: Grossman and Helpman (1991), Parente and Prescott (1994) and Holmes and Shimitz (1995).

Given the above insights, ameliorating information technology is in line with the theoretical framework underlying the importance of absorptive capacity in technology accumulation for technological spillovers in terms of value added across various economic sectors. It is worthwhile to also articulate that the fundamental perspective related to the attendant endogenous theories of economic prosperity rests on the basis that, long term growth is driven by productivity and the manner in which various economic sectors accumulate value, which depend on progress in technology (Asongu & Odhiambo, 2020a). In what follows, this study links the theoretical underpinnings with the estimation technique to be adopted in the study and the elements to be adopted in the conditioning information set that are also relevant to the theoretical framework.

Furthermore, the discussed theoretical framework has articulated the imperative of cross-country catch-up in economic development, resulting from cross-country changes in technological levels (i.e. by means of technological accumulation) in developing countries. Linking the insight to the modelling technique in this research, the adoption of the Generalised Method of Moments (GMM) which involves control variables or elements in a conditioning information set, requires that cross-country differences are apparent in the elements of the conditioning information set (Narayan, Mishra & Narayan, 2011). Hence this form of catch-up modeling within a GMM framework that involves control variables is known as conditional catch-up (Narayan et al., 2011). The adopted control variables in this study (i.e. population, education, remittances and private domestic credit) are also broadly in accordance with the literature on productivity and economic development in various sectors

(Cameron, 2003; Howitt, 2000; Coe & Helpman, 1995; Aghion, Bloom, Blundell, Griffih & Howitt, 2005; Savvides & Zachariadis, 2000; Asongu, 2020). Nexuses between the adopted control variables and the outcome variables are discussed in the data section of the study.

Given that the GMM estimation approach is based on quadratic regressions, it is possible to forecast technological spillovers by computing information technology thresholds required to achieve favourable effects on various sectors of the economy. The computation of such thresholds for favourable technological spillovers is consistent with attendant theoretical literature on the importance of absortive capactity in such spillovers (Blomström, Kokko & Zejan, 2000; Howitt, 2000; Asongu & Acha-Anyi, 2020). It follows that the computed thresholds are critical masses of information technology required for the achievement of favorable value-added outcomes in the engaged macroeconomic sectors. Hence, policy makers in the sampled countries can forecast value added externalities from the technology spillovers by targeting the specific critical masses or thresholds. This empirical framework is consistent with the theoretical framework on local or initial conditions (Arrow, 1969) and absorptive capacity of other factors of production in the conditioning information set (i.e. population, education, remittances and private domestic credit), required for value added in various economic sectors (Griffith, Redding & Van Reenen, 2003, 2004; Fagerberg, 1994).

3. Data and Methodology

3.1 Data

Consistent with the motivation of the study, the focus of this research is on 25 countries in SSA using data from various sources spanning the period 1980-2014[1]. The geographical and temporal emphasis of the scope are determined by constraints in the availability of information at the time of the study. In the light of the inappropriateness of the datastructure for the empirical strategy being considered, the research felt the need to restructure the dataset in terms of data averages within the framework of non-overlapping intervals. This process of restructuring providesa datastructure that conforms to a primary requirement for the employment of the Generalised Method of Moments (GMM) empirical strategy, notably: N>T (Tchamyou, Asongu & Nwachukwu, 2018). For the underlying structure, two options of non-overlapping intervals are considered, notably: (i) seven five-year and (ii) five seven-year averages. It is apparent from an exploratory analysis that seven five-

[1]The countries, selected on data availability are: Benin; Botswana; Burkina Faso; Burundi; Cameroon; Central African Republic; Cote d'Ivoire; Gabon; Kenya; Lesotho; Mauritania; Mauritius; Mozambique; Namibia; Niger; Nigeria; Rwanda; Senegal; Sierra Leone; South Africa; Sudan; Swaziland; Tanzania; Togo and Zimbabwe.

year data averages produce less efficient estimated coefficients compared to the five seven-year data averages. This is essentially because, the use of the latter does not result in instrument proliferation in post-estimation diagnostics tests even when the option used to collapse instruments is engaged in the estimation exercise. Therefore, the following are the retained intervals: 1980-1986; 1987-1993; 1994-2000; 2001-2007; 2008-2014.

In line with the motivation of the study, three main outcome variables are adopted for the study, notably: value added in the agricultural sector, value added in the manufacturing sector and value added in the service sector. The choice of these variables from the World Development Indicators of the World Bank and the United Nations Conference on Trade and Development Database is consistent with recent value–added literature on SSA (Meniago & Asongu, 2019). In line with contemporary African information technology and economic participation literature, mobile phone penetration and internet penetrationfrom the World Development Indicators of the World Bank are employed as measures of ICT (Tchamyou, 2017; Efobi *et al*., 2018).

To account for variable omission bias, two elements are adopted in the conditioning information set, namely: population, inclusive education, remittances, and private domestic credit. The first-three is from World Development Indicators of the World Bank while the fourth is from the Financial Development and Structure Database of the World Bank.The choice of these indicators is also motivated by the attendant economic development and productivity literature, notably: Becker, Laeser and Murphy (1999), Barro (2003), Heady and Hodge (2009), Sahoo, Dash and Nataraj (2010) and Ssozi and Asongu (2016a, 2016b), Elu and Price (2010, 2017) and Dunne and Masiyandima (2017)[2].

While these variables are anticipated to positively effect productivity in the economic sectors, the expected signs can also be negative if, *inter alia*: (i) much of the population is not used to promote activities in the primary, secondary and tertiary economic sectors owing to high unemployment; (ii) as a corollary to the preceding point, inclusive education is not translated into employment opportunities in the attendant economic sectors; (iii) a substantial proportion of remittances is used for consumption than for productive ends and (iv) owing to information asymmetry and other financial access constraints, enough credit may not be allocated to economic operators for investment activities. Hence, while the research expects the control variables to significantly influence the outcome variables, the anticipated signs cannot be

[2] Other growth and productivity studies supporting the relevance of adopted control variables include: Nyasha and Odhiambo (2015a, 2015b); Kreuser and Newman (2018); Kumi, Muazu and Yeboah (2017); Maryam and Jehan (2018); Muazu and Alagidede (2017); Okafor, Piesse and Webster (2017) and Yaya and Cabral (2017).

established with full accuracy. Appendix 1 provides the definitions and sources of variables whereas the summary statistics and correlation matrix are respectively disclosed in Appendix 2 and Appendix 3.

3.2 Methodology

3.2.1 Specification

The adoption of the GMM empirical strategy is consistent with the motivation outlined in the data section pertaining to the data structure. We further substantiate this justification with complementary requirements for the implementation of the estimation approach as apparent in contemporary literature (Tchamyou, 2020; Tchamyou, Erreygers & Cassimon, 2019a). First, following the justification already clarified in the previous section, the restructuring of the dataset has enabled the datastructure to be such that the number of cross sections is higher than the number of non-overlapping intervals in each cross section (i.e. N>T). Second, in the light of the panel datastructure underpinning the research, cross-country differences are taken on board in the estimation exercise. Third, the paramount concern of endogeneity is addressed from two principal angles: (i) simultaneity or reverse causality is taken on board with the employment of internal instruments and (ii) time invariant variables are engaged to account for heterogeneities that are unobserved.

Equation (1) and Equation (2) below disclose the system GMM process that is employed to assess the relevance of enhancing ICT for value added across different sectors.

$$VA_{i,t} = \sigma_0 + \sigma_1 VA_{i,t-\tau} + \sigma_2 IT_{i,t} + \sigma_3 ITIT_{i,t} + \sum_{h=1}^{4} \delta_h W_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

$$VA_{i,t} - VA_{i,t-\tau} = \sigma_1 (VA_{i,t-\tau} - VA_{i,t-2\tau}) + \sigma_2 (IT_{i,t} - IT_{i,t-\tau}) + \sigma_3 (ITIT_{i,t} - ITIT_{i,t-\tau}) + \sum_{h=1}^{4} \delta_h (W_{h,i,t-\tau} - W_{h,i,t-2\tau}) + (\xi_t - \xi_{t-\tau}) + (\varepsilon_{i,t} + \varepsilon_{i,t-\tau}) \quad , (2)$$

where $VA_{i,t}$ is value added across a sector (i.e. agricultural sector, manufacturing sector and service sector) of country i in period t; IT represents information technology (i.e. mobile phone penetration or internet penetration); $ITIT$ is the quadractic interaction of ICT variables (“mobile phone penetration” × “mobile phone penetration”; “intenet penetration” × “internet penetration”); σ_0 is a constant; τ is the degree of auto-regression which is one or a seven year lag because such sufficiently captures past information; W is the vector of control variables (*population, inclusive education, remittances* and *private domestic credit),* η_i is the country-specific effect, ξ_t is the time-specific constant and $\varepsilon_{i,t}$ the error term.

The GMM empirical strategy adopted within the framework of this analysis is the option with forward orthogonal deviations of Roodman (2009) which is an extension of the difference GMM methodology of Arellano and Bover (1995). This alternative empirical approach has been documented in the contemporary scholarship to provide more robust estimated coefficients (Boateng, Asongu, Akamavi & Tchamyou, 2018; Tchamyou, 2019). The adopted process of estimation is the *two-step* specification which is more robust when compared to the *one-step* process that exclusively accounts for homoscedasticity, compared to the *two-step* process that is homoscedasticity consistent.

3.2.2 Identification, simultaneity, and exclusion restrictions

This section is fundamental in GMM estimation to clarify the robustness of the empirical analysis. The identification process is such that, the outcome, endogenous explaining and strictly exogenous variables are clarified. The corresponding process of exclusion restrictions entails a clarification of how the outcome variable is influenced by the strictly exogenous variables by means of the predetermined or endogenous explaining variables. Consistent with the narrative in the data section, the outcome variables are: added value in the agricultural sector, added value in the manufacturing sector and added value in the service sector. The endogenous explaining variables are the ICT and control variables while the strictly exogenous variables are years. It is worthwhile to note that the adoption of years as strictly exogenous variables is consistent with the argument of Roodman (2009) who has maintained that it is appropriate for years to be considered as such because they cannot be endogenous in first difference. The process of identification is also in accordance with contemporary GMM-centric literature (Tchamyou& Asongu, 2017; Meniago & Asongu, 2018; Tchamyou*et al*., 2019a).

Contingent on the above emphasis, the GMM specification is tailored such that, instrumental variables (iv or *ivstyle*) reflect strictly exogenous variables while the *gmmstyle* is employed to articulate the endogenous explaining variables. It is worthwhile to emphasize that assumptions underpinning exclusion restrictions are based on the influence of the outcome variable by the strictly exogenous variables exclusively via the exogenous components of the endogenous explaining variables. Still building on the relevant GMM-oriented studies in the previous paragraph, the Difference in Hansen Test (DHT) for the exogeneity of instruments is employed to assess the validity of the exclusion restriction assumption. Moreover, for this assumption to hold, the null hypothesis of the underying test should not be rejected (Tchamyou, Asongu & Odhiambo, 2019b).

4. Empirical results

4.1 Presentation of results

The empirical findings are reported in Tables 1 to 3 in this section. In essence, Table 1, Table 2 and Table 3 respectively focus on linkages between "ICT and value added in the agricultural sector", "ICT and value added in the manufacturing sector" and "ICT and value added in the service sector". Each table is characterized by two main specifications pertaining to "mobile phone"-oriented and internet-related specifications in the left-hand and right-hand side respectively. Each ICT-centric category of the specification is characterized by five main specifications: one without a conditioning information set and the remaining four with one variable each. It is relevant to note that the adoption of limited control variables in order tofurther avoid concerns pertaining to instrument proliferation is not uncommon if the purpose of doing so is to obtain valid models. Examples of such literature include: Osabuohien and Efobi (2013) and Asongu and Nwachukwu (2017).

Four fundamental criteria of information are used to investigate if the estimated models are valid or not[3]. Based of these criteria for models' validity, the estimations in Table 1 and Table 3 are overwhelmingly valid while some models in Table 2 are not valid because of the presence of second order autocorrelation in difference and/or the rejection of the null hypothesis of the Hansen test.

Following contemporary literature on interaction regressions, in order to assess the overall incidence of enhancing ICT on value added across economic sectors, net effects are computed from the unconditional effects of ICT and conditional or marginal effects of the corresponding ICT on the value added across economic sectors (Asongu & Odhiambo, 2020b; Agoba, Abor, Osei & Sa-Aadu, 2020; Tchamyou *et al*., 2019a). To put this point into more perspective, in the fourth column of Table 1, the net impact on value added to the agricultural sector from the enhancement of mobile phone penetration is -0.157 (2×[0.0008× 15.806] + [-0.183]). In the underlying computation, the average value of mobile phone penetration disclosed in the summary statistics is 15.806, the unconditional effect is -0.183, the corresponding conditional effect is 0.0008 while the leading 2 is from the quadratic derivation.

[3] "*First, the null hypothesis of the second-order Arellano and Bond autocorrelation test (AR (2)) in difference for the absence of autocorrelation in the residuals should not be rejected. Second the Sargan and Hansen over-identification restrictions (OIR) tests should not be significant because their null hypotheses are the positions that instruments are valid or not correlated with the error terms. In essence, while the Sargan OIR test is not robust but not weakened by instruments, the Hansen OIR is robust but weakened by instruments. In order to restrict identification or limit the proliferation of instruments, we have ensured that instruments are lower than the number of cross-sections in most specifications. Third, the Difference in Hansen Test (DHT) for exogeneity of instruments is also employed to assess the validity of results from the Hansen OIR test. Fourth, a Fisher test for the joint validity of estimated coefficients is also provided*" (Asongu & De Moor, 2017, p.200).

The following findings can be established from Tables 1-3. First, the enhancement of mobile phone penetration has a net negative effect on value added in the agricultural sector. Second, enhancement of internet penetration also has a net negative impact of value added in the manufacturing sector. Third, the enhancement of ICT (i.e. mobile phone penetration and internet penetration) overwhelmingly has positive net effects on value added to the service sector. Third, the control variables are also significant for the most part.

Table 1: Agricultural value added and ICT

	Dependent variable: Agricultural value added									
	The mobile phone penetration channel (Mobile)					**The internet channel (Internet)**				
Agriculture (-1)	**1.012*** (0.000)**	**0.987*** (0.000)**	**0.891*** (0.000)**	**0.997*** (0.000)**	**0.950*** (0.000)**	**0.949*** (0.000)**	**0.956*** (0.000)**	**0.864*** (0.000)**	**0.990*** (0.000)**	**0.977*** (0.000)**
Mobile	-0.105 (0.161)	-0.086 (0.219)	**-0.183*** (0.001)**	-0.046 (0.266)	**-0.086* (0.063)**	---	---	---	---	---
Mobile × Mobile	**0.0005* (0.095)**	0.0004 (0.229)	**0.0008*** (0.004)**	0.0001 (0.456)	**0.0004* (0.079)**	---	---	---	---	---
Internet	---	---	---	---	---	-0.328 (0.131)	**-0.313* (0.097)**	**-0.357** (0.043)**	-0.219 (0.134)	-0.264 (0.184)
Internet × Internet	---	---	---	---	---	0.007 (0.224)	0.007 (0.188)	0.007 (0.131)	0.003 (0.375)	0.007 (0.205)
Population	---	0.187 (0.601)	---	---	---	---	-0.034 (0.912)	---	---	---
Education	---	---	-5.692 (0.188)	---	---	---	---	**-8.633* (0.050)**	---	---
Remittances	---	---	---	**-0.124*** (0.000)**	---	---	---	---	**-0.115*** (0.000)**	---
Private Credit	---	---	---	---	**-0.040** (0.035)**	---	---	---	---	-0.027 (0.386)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	na	na	-0.157	na	-0.073	na	na	na	na	na
AR(1)	(0.010)	(0.024)	(0.034)	(0.012)	(0.011)	(0.027)	(0.031)	(0.083)	(0.018)	(0.025)
AR(2)	**(0.213)**	**(0.214)**	**(0.217)**	**(0.487)**	**(0.310)**	**(0.284)**	**(0.290)**	**(0.310)**	**(0.575)**	**(0.444)**
Sargan OIR	**(0.241)**	**(0.453)**	**(0.698)**	**(0.842)**	**(0.428)**	**(0.137)**	**(0.361)**	**(0.653)**	**(0.755)**	**(0.478)**
Hansen OIR	**(0.103)**	**(0.216)**	**(0.498)**	**(0.555)**	**(0.113)**	**(0.185)**	**(0.382)**	**(0.408)**	**(0.310)**	(0.072)
DHT for instruments										
(a)Instruments in levels										
H excluding group	---	**(0.209)**	**(0.247)**	**(0.613)**	(0.023)	---	(0.098)	(0.089)	**(0.301)**	(0.046)
Dif(null, H=exogenous)	**(0.112)**	**(0.241)**	**(0.538)**	**(0.474)**	**(0.352)**	**(0.293)**	**(0.562)**	**(0.614)**	**(0.305)**	**(0.167)**
(b) IV (years, eq(diff))										
H excluding group	(0.055)	**(0.321)**	**(0.496)**	**(0.385)**	(0.031)	(0.089)	**(0.401)**	**(0.451)**	**(0.161)**	(0.042)
Dif(null, H=exogenous)	**(0.343)**	**(0.180)**	**(0.396)**	**(0.666)**	**(0.870)**	**(0.445)**	**(0.330)**	**(0.315)**	**(0.686)**	**(0.409)**
Fisher	**596.28***	**1079.47***	**611.84***	**610.92***	**2039.54***	**3416.17***	**7199.35***	**513.26***	**2373.00***	**2023.23***
Instruments	14	18	18	18	18	14	18	18	18	18
Countries	23	23	23	23	23	23	23	23	23	23
Observations	92	92	80	82	90	92	92	80	82	90

***,**,*: significance levels at 1%, 5% and 10% respectively. DHT: Difference in Hansen Test for Exogeneity of Instruments Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) & AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests. Gov't: Government. na: not applicable because at least one estimated coefficient required for the computation of net effects is not significant. The mean value of mobile phone penetration is 15.806 while the mean value of internet penetration is 3.053. Constants are included in all regressions.

Table 2: Manufacturing value added and ICT

	Dependent variable: Manufacturingvalue added									
	The mobile phone penetration channel (Mobile)					The internet channel (Internet)				
Manufacturing (-1)	**0.852***** **(0.000)**	**0.883***** **(0.000)**	**0.967***** **(0.000)**	**0.921***** **(0.000)**	**0.855***** **(0.000)**	**0.889***** **(0.000)**	**0.858***** **(0.000)**	**1.051***** **(0.000)**	**0.822***** **(0.000)**	**0.886***** **(0.000)**
Mobile	-0.034 (0.143)	-0.024 (0.402)	**-0.055*** **(0.086)**	-0.00003 (0.999)	-0.013 (0.531)	---	---	---	---	---
Mobile × Mobile	**0.0002**** **(0.042)**	0.0001 (0.233)	0.0002 (0.111)	0.0001 (0.312)	0.0001 (0.147)	---	---	---	---	---
Internet	---	---	---	---	---	0.105 (0.240)	0.075 (0.371)	**-0.181***** **(0.009)**	0.208 (0.104)	0.100 (0.197)
Internet × Internet	---	---	---	---	---	-0.001 (0.402)	-0.0008 (0.629)	**0.004***** **(0.000)**	-0.004 (0.140)	-0.001 (0.504)
Population	---	-0.048 (0.905)	---	---	---	---	-0.054 (0.843)	---	---	---
Education	---	---	0.191 (0.954)	---	---	---	---	-1.942 (0.537)	---	---
Remittances	---	---	---	**0.074***** **(0.000)**	---	---	---	---	**0.055***** **(0.000)**	---
Private Credit	---	---	---	---	**-0.020*** **(0.086)**	---	---	---	---	**-0.028***** **(0.009)**
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	nsa	nsa	na	nsa	nsa	nsa	nsa	-0.156	na	na
AR(1)	**(0.133)**	**(0.126)**	**(0.146)**	**(0.156)**	**(0.129)**	**(0.108)**	**(0.131)**	**(0.151)**	**(0.106)**	**(0.158)**
AR(2)	(0.053)	(0.071)	**(0.129)**	(0.092)	(0.095)	(0.081)	(0.073)	**(0.160)**	**(0.102)**	**(0.105)**
Sargan OIR	(0.624)	**(0.583)**	**(0.524)**	**(0.171)**	(0.043)	**(0.623)**	**(0.559)**	**(0.208)**	**(0.139)**	(0.021)
Hansen OIR	(0.094)	**(0.116)**	**(0.106)**	**(0.460)**	**(0.122)**	**(0.378)**	**(0.211)**	**(0.248)**	**(0.313)**	**(0.126)**
DHT for instruments										
(a)Instruments in levels										
H excluding group	---	**(0.109)**	**(0.210)**	**(0.106)**	(0.003)	---	**(0.152)**	**(0.170)**	(0.072)	(0.017)
Dif(null, H=exogenous)	**(0.250)**	**(0.173)**	**(0.115)**	**(0.646)**	**(0.775)**	**(0.627)**	**(0.269)**	**(0.301)**	**(0.527)**	**(0.435)**
(b) IV (years, eq(diff))										
H excluding group	**(0.213)**	**(0.100)**	(0.030)	**(0.251)**	**(0.117)**	**(0.150)**	**(0.290)**	(0.093)	**(0.315)**	(0.074)
Dif(null, H=exogenous)	(0.097)	**(0.305)**	**(0.845)**	**(0.772)**	**(0.269)**	**(0.677)**	**(0.198)**	**(0.844)**	**(0.328)**	**(0.465)**
Fisher	**2538.06 *****	**5078.91 *****	**188.41 *****	**423.46 *****	**374.55 *****	**739.23 *****	**1103.73 *****	**948.70 *****	**225.91 *****	**189.76 *****
Instruments	14	18	18	18	18	14	18	18	18	18
Countries	23	23	23	23	23	23	23	23	23	23
Observations	92	92	80	82	90	92	92	80	82	90

***,**,*: significance levels at 1%, 5% and 10% respectively. DHT: Difference in Hansen Test for Exogeneity of Instruments Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) & AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests. Gov't: Government. nsa: not specifically applicable because the estimated model is not valid. na: not applicable because at least one estimated coefficient required for the computation of net effects is not significant. The mean value of mobile phone penetration is 15.806 while the mean value of internet penetration is 3.053. Constants are included in all regressions.

Table 3: Service sector value added and ICT

	Dependent variable: Service sector value added									
	The mobile phone penetration channel (Mobile)					**The internet channel (Internet)**				
Service sector (-1)	**0.716*** **	**0.680*** **	**0.542*** **	**0.780*** **	**0.541*** **	**0.655*** **	**0.608*** **	**0.620*** **	**0.756*** **	**0.680*** **
	(0.000)	**(0.000)**	**(0.001)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile	0.070	**0.088***	**0.138*** **	**0.109*** **	**0.541***	---	---	---	---	---
	(0.157)	**(0.089)**	**(0.004)**	**(0.002)**	**(0.064)**					
Mobile × Mobile	-0.0003	**-0.0004***	**-0.0006****	**-0.0004***	**-0.0004****	---	---	---	---	---
	(0.149)	**(0.079)**	**(0.025)**	**(0.088)**	**(0.013)**					
Internet	---	---	---	---	---	**0.674*** **	**0.734*** **	**0.808*** **	**0.849*** **	**0.548*** **
						(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.001)**
Internet × Internet	---	---	---	---	---	**-0.015*** **	**-0.016*** **	**-0.020*** **	**-0.022*** **	**-0.011*** **
						(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.003)**
Population	---	0.006	---	---	---	---	0.110	---	---	---
		(0.998)					(0.757)			
Education	---	---	-0.187	---	---	---	---	**-5.199***	---	---
			(0.962)					**(0.093)**		
Remittances	---	---	---	**-0.058*** **	---	---	---	---	-0.038	---
				(0.006)					(0.141)	
Private Credit	---	---	---	---	**0.062*** **	---	---	---	---	0.004
					(0.000)					(0.835)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	na	0.075	0.119	0.096	0.528	0.582	0.710	0.685	0.714	0.480
AR(1)	(0.031)	(0.039)	(0.090)	(0.031)	**(0.124)**	(0.025)	(0.023)	(0.064)	(0.022)	(0.046)
AR(2)	**(0.521)**	**(0.528)**	**(0.724)**	**(0.936)**	**(0.599)**	**(0.493)**	**(0.414)**	**(0.438)**	**(0.609)**	**(0.611)**
Sargan OIR	(0.000)	(0.001)	(0.002)	(0.063)	(0.006)	(0.007)	(0.015)	(0.034)	(0.014)	(0.002)
Hansen OIR	**(0.217)**	**(0.413)**	**(0.248)**	**(0.171)**	**(0.140)**	**(0.494)**	**(0.143)**	**(0.360)**	**(0.375)**	**(0.335)**
DHT for instruments										
(a)Instruments in levels										
H excluding group	---	(0.048)	**(0.187)**	(0.066)	(0.086)	---	**(0.101)**	(0.064)	(0.028)	(0.074)
Dif(null, H=exogenous)	**(0.648)**	**(0.746)**	**(0.291)**	**(0.316)**	**(0.231)**	**(0.868)**	**(0.219)**	**(0.615)**	**(0.803)**	**(0.552)**
(b) IV (years, eq(diff))										
H excluding group	(0.048)	**(0.259)**	(0.072)	**(0.900)**	**(0.256)**	**(0.286)**	**(0.404)**	**(0.174)**	**(0.377)**	**(0.295)**
Dif(null, H=exogenous)	**(0.804)**	**(0.640)**	**(0.990)**	(0.019)	**(0.127)**	**(0.596)**	(0.069)	**(0.774)**	**(0.349)**	**(0.397)**
Fisher	**46.71*** **	**201.15*** **	**15.20*** **	**449.40*** **	**1471.62*** **	**248.84*** **	**8460.76*** **	**177917*** **	**77896*** **	**581.92*** **
Instruments	14	18	18	18	18	14	18	18	18	18
Countries	24	24	24	24	24	24	24	24	24	24
Observations	96	96	82	86	94	96	96	82	86	94

***,**,*: significance levels at 1%, 5% and 10% respectively. DHT: Difference in Hansen Test for Exogeneity of Instruments Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) & AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests. Gov't: Government. na: not applicable because at least one estimated coefficient required for the computation of net effects is not significant. The mean value of mobile phone penetration is 15.806 while the mean value of internet penetration is 3.053. Constants are included in all regressions.

4.2 Extension with ICT policy thresholds: forecasting technological spillovers

The term "forecasting" in this section is understood within the framework of critical masses of ICT beyond which, enhancing ICT engenders positive net effects on value added to the agricultural and manufacturing sectors. Hence, by forecasting, the study provides thresholds of ICT that should be forecasted/targeted for ICT to positively affect value added in the agricultural and manufacturing sectors.

Whereas the results established in Table 3 have positive net effects, those in Table 1 and Table 3 have negative net effects. This implies that while enhancing ICT is enough to increase value added to the service sector, this is not the case with the agricultural and manufacturing sectors. Fortunately, the marginal effects associated with the net negative effects in Tables 1-2 are positive, which implies that enhancing ICT beyond certain critical masses or thresholds can have the desired net positive incidences on added values in the agricultural and manufacturing sectors. Therefore, the empirical analysis is extended with the computation of ICT policy thresholds at which such net effects can be positive.

Given the above emphasis, in the fourth column of Table 1, the mobile phone penetration threshold of 114.375 (0.183/ [2×0.0008]) subscriptions per 100 people is needed to reverse the established net effect from negative to positive. Therefore, at a mobile phone critical mass of 114.375 per 100 people, the net effect is 0 (2×[0.0008× 114.375] + [-0.183]). Hence, above the established critical mass of 114.375, further enhancing mobile phone penetration engenders an overall positive net effect on value added in the agricultural sector. In the same vein, in the sixth column of Table 1, a mobile phone penetration threshold of 107.500 mobile phone penetration per 100 people is the critical mass above which, a positive net effect can be apparent. In Table 2, the internet penetration threshold inthe ninth column is 22.625 (0.181/ [2×0.004]) internet penetration per 100 people. However, in order for the ICT policy thresholds to make economic sense and have policy relevance, they should be within the range disclosed in the summary statistics, notably: (i) 0.000 to 142.980 for mobile phone penetration and (ii) 0.000 to 31.922 for internet penetration. It is important to note that the baseline for the critical mass in each sector is the minimum value disclosed in the summary statistics. This is essentially because, for the critical masses to make economic sense and have policy relevance, they should be within the statistical limits or range (i.e. minimum to maximum values in the summary statistics). Hence, the established ICT policy thresholds make economic sense and have policy relevance because they are within the ranges disclosed in the summary statistics.

The underlying understanding of critical mass for policy implications is consistent with the attendant literature on thresholds or critical mass, notably: inflexion points upon which growing environmental pollution decreases inclusive human development (Asongu, 2018); initial conditions for appealing effects (Cummins, 2000); critical masses for desired effects (Roller & Waverman, 2001; Batuo, 2015) and thresholds of information sharing offices that can reduce the unfavorableincidence of market power on financial access (Asongu, le Roux & Tchamyou, 2019).

Given the established findings, in order to understand cross-sectoral differences in the relevance of ICT in driving value added in the engaged economic sectors, it is worthwhile to clarify the underying factors that are responsible for mobile and internet penetration and how the two variables (possibly due to these factors) could lead to positive or negative effects across the sectors. The underlying factors mainly pertain to complementary features that enable the interaction between mobile phones and internet penetration which are more relevant in the growth of the service sector compared to the agricultural and manufacturing sectors. In essence, a mobile phone that is connected to the internet can be used by most consumers and clients to interact with the service sector, compared to the manufacturing and agricultural sectors. This is essentially because ICT interactions in the agricultural and manufacturing sectors are mostly related to production activities in which the involvement of many customers is limited. However, when the goods have been produced in the agricultural sector and transformed in the manufacturing sector, the distribution of the goods is ensured by the tertiary sector which the public at large interacts more with the services provided by means of ICT.

Some of the underlying factors that facilitate the connection between the engaged ICT dynamics and the services can be understood in the light of: (i) sources of technological innovation in services and (ii) grasping services as users, producers and information technology agents (Giraldo, 2010).

First, on the front of sources of technological improvements in services, the findings are consistent with both contemporary and non-contemporary literature suggesting that sectors differ in ICT innovation as well as in characteristics or patterns and intensity of the ICT adopted (Pavitt, 1984; Chavas & Nauges, C, 2020; Schmidthuber, Maresch & Ginner, 2020). Some of the patterns in technological innovation that distinguish sectors which can be used to explain the relative importance of the service sector benefits from enhancing mobile phone and internet penetration are: (i) "supplier-dominated" in which the source of innovation is largely dominated by suppliers of technical systems and equipment; (ii) "physical and information networks" which entail service firms that are fundamentally focused on the improvement of technologies they employ and (iii) "specialized supplier and science based firms" which constitute relevant technological innovations outputs. Second, the understanding of "services" as users, producers and information technology agents is premised on: (i) the linkage between adoption of information technology and innovation in services which entail the adopting of technology by service firms to improve efficiency in existing processes of technology which decreases attendant costs. (ii) The service sector is a source of technology owing to its inherent feature in technology production and/or co-production in order to avail itself and customers with new technologies (Gallouj & Gallouj, 2000; Nieborg & Poell, 2018). This is very common with software producers and telecommunication companies. (iii) Companies in the service sectors can also benefit from enhanced technology because services by their very nature are agents of technology. For instance tranining services and consultancy firms represent direct agents of ICT while an indirect role is also played by other service companies in the provision and diffusion of knowledge (Miles, Kastrinos, & Flanagan, 1995; Erkko & Helena, 1998; Asongu & Tchamyou, 2020).

5. Concluding implications and future research directions

This study investigates how enhancing ICT affects value added across sectors in 25 countries in SSA using data for the period 1980-2014. Three value added indicators are used, namely: value added in the agricultural sector; value added in the manufacturing sector and value added in the service sector. The engaged ICT indicators include: mobile phone penetration and internet penetration. The empirical evidence is based on Generalised Method of Moments. The following findings are established. First, the enhancement of mobile phone penetration has a net negative effect on value added in the agricultural sector. Second, enhancing internet penetration also has a net negative impact on value added in the manufacturing sector. Third, enhancing ICT (i.e. mobile phone penetration and internet penetration) overwhelmingly has positive net effects on value added to the service sector of the economy.

The findings are improved with an extended analysis in order to assess critical masses at which the net effects on value added to the agricultural and manufacturing sectors can be changed from negative to positive. Critical masses between 107.500 and 114.375 mobile phone penetration per 100 people are required to reverse the net negative effect on value added to the agricultural sector while the corresponding critical mass of internet penetration needed to reverse the net negative effect on value added to the manufacturing sector is 22.625 internet penetration per 100 people. The established ICT policy thresholds make economic sense and have policy relevancebecause they are within the ranges disclosed in the summary statistics.

In summary, from the findings, enhancing ICT is enough to increase added value to the service sector while enhancing ICT in the agricultural and manufacturing sectors should exceed certain thresholds for value added, notably: 114.375 of mobile phone penetration per

100 people for added value to the agricultural sector and 22.625 of internet penetration per 100 people for added value to the manufacturing sector.

Future studies can be tailored to assess if the established findings are relevant within country-specific frameworks. This is essentially because the GMM empirical strategy adopted in this research is designed to eliminate country-specific effects in order to control for the concern of endogeneity arising from the correlation between the lagged outcome variable and country-specific effects. In the suggested future research direction, using the relevant alternative estimation techniques to understand how the engaged ICT variables affect value addition across the regions (e.g. West versus Southern Africa) is worthwhile. The premise of this recommendation is based on the assumption that countries in these regions have different gross domestic products (GDPs), and in the light of this, it might be worth understanding how the level of ICT investment, as a percentage of GDP is driving the sector growth varies across countries. Moreover, the GMM approach in this study is adopted because of the absence of reliable external instruments which can be used for the instrumental variable (IV) methodology that produces more robust causal effects. Hence, in line with the arguments of Farbmacher (2012), future studies should consider avenues of findings reliable external instruments for the more robust IV approach. Another natural caveat of the GMM approach is that it implemented when the number of agents (i.e. N) is approaching infinity while time component in each agent (i.e. T) is fixed. Unfortunately, it is impossible to have the number of countries in the world approaching infinity. Windmeijer (2005) and Danquah and Ouattara (2014) could be considered in addressing the concern of small sample bias.

Conflict of interest statement

The authors have no conflict of interest.

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Appendices

Appendix 1: Definitions and sources of variables

Variables	Signs	Definitions of variables (Measurements)	Sources
Agriculture value added	Agri	Agricval: Agriculture, hunting, forestry, fishing (ISIC A-B)Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs.	WDI
Manufacturing value added	Manu	Manufacturing value added (% of GDP) (ISIC D). Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs.	UNCTAD
Service value added	Service	Service, value added (% of GDP).Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs.	WDI
Mobile Phone Penetration	Mobile phones	Mobile phone subscriptions (per 100 people)	WDI
Internet Penetration	Internet	Internet subscriptions (per 100 people)	WDI
Population	Population	Logarithm of Population (in millions)	WDI
Education	Education	SEPSGPI: School enrollment, primary and secondary (gross), gender parity index (GPI)	WDI
Remittances	Remittances	Personal remittances, received (% of GDP)	WDI
Credit Access	Private credit	Domestic credit to private sector (% of GDP)	FDSD

WDI: World Development Indicators of the World Bank. GDP: Gross Domestic Product.UNCTAD: United Nations Conference on Trade and Development. FDSD: Financial Development and Structure Databaseof the World Bank.

Appendix 2: Summary statistics

	Mean	SD	Minimum	Maximum	Observations
Agriculture value added	26.673	13.910	2.527	56.751	116
Manufacturing value added	12.916	6.933	2.152	36.895	116
Service value added	19.339	7.015	0.000	32.825	120
Mobile Phone Penetration	15.806	29.054	0.000	142.980	120
Internet Penetration	3.053	6.020	0.000	31.922	98
Population	2.515	0.818	-0.242	4.165	125
Education	0.854	0.177	0.465	1.341	107
Remittances	4.768	12.917	0.003	89.354	107
Credit Access	21.009	22.256	2.238	144.397	121

S.D: Standard Deviation.

Appendix 3:Correlation matrix (uniformsample size: 122)

Value Added Dynamics			ICT		Control variables				
Agri	Manu	Service	Mobile	Internet	Pop	Education	Remit	Credit	
1.000	-0.389	-0.167	-0.234	-0.243	0.096	-0.582	-0.211	-0.425	Agri
	1.000	0.220	0.004	0.089	-0.237	0.037	0.021	0.217	Manu
		1.000	0.230	0.327	0.376	-0.211	-0.197	0.190	Service
			1.000	0.742	0.096	0.274	-0.050	0.385	Mobile
				1.000	0.311	0.247	-0.047	0.518	Internet
					1.000	-0.027	-0.067	-0.115	Pop
						1.000	0.412	0.249	Education
							1.000	-0.069	Remit
								1.000	Credit

Agri: Agricultural value added. Manu: Manufacturing value added. Service: Service value added. Mobile: Mobile Phone penetration. Internet: Internet penetration. Pop: population. Gov. Remit: Remittances. Credit: Private Domestic Credit.