A G D I Working Paper

WP/20/008

Enhancing ICT for Productivity in Sub-Saharan Africa: Thresholds for Complementary Policies [1]

Forthcoming: African Journal of Science, Technology, Innovation and Development

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[1] This working paper also appears in the Development Bank of Nigeria Working Paper Series.

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Enhancing ICT for Productivity in Sub-Saharan Africa: Thresholds for Complementary Policies

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January 2020

Abstract

The purpose of this research is to investigate the relevance of enhancing information and communication technology (ICT) on dynamics of total factor productivity (TFP) in 25 Sub-Saharan African countries using data covering the period 1980-2014. The empirical evidence is based on the Generalised Method of Moments. The following main findings are established. First, while enhancing ICT overwhelmingly has net positive effects on productivity, the corresponding marginal effects are negative. Second, anextended analysis is performed to establish thresholds for complementary policies. These thresholds are: 100 % mobile phone penetration for TFP; between 101.214 % and 101.419 % mobile phone penetration for welfare TFP and 15 % internet penetration for welfare real TFP. It follows that approximately 100% mobile penetration and 15% internet penetration are thresholds at which ICT should be complemented with other macroeconomic policies for favorable outcomes on productivity dynamics. Other policy implications are discussed.

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

Keywords: Productivity; Information Technology; Sub-Saharan Africa

1. Introduction

This scholarlship builds on three main insights into contemporary trends in policy-making and scholarly literature, notably: (i) the absence of a consensus in the literature on the importance of productivity, vis-à-vis other development parameters in economic development; (ii) the contemporary role of information and communication technology (ICT) in driving such econonomic development and (iii) gaps in the attendant scholarship. These ciritical motivational aspects are expatiated in thesame chronological order as they are highlighted.

First, whereas it has been documented that aggregate productivity is essential for Africa's economic prosperity, literature is still divided over mechanisms by which such productivity can be improved and maintained for economic development (Tchamyou, 2017; Cheruiyot, 2017; Ssozi & Asongu, 2016a; Baliamoune-Lutz, 2011; Elu & Price, 2010; Baliamoune, 2009). En ensuing debate in the extant literature has been on the relative importance of TFP versus factor accumulation in economic development. There is a strand of the literature which has built on the experience of East Asia to maintain that factor accumulation is more relevant in driving economic development compared to TFP (Young, 1995). Conversely, another strand of the literature supports the thesis that cross-country variations in levels of TFP elucidate cross-country differences in levels of economic development (Abramovitz, 1986; Klenow & Rodriguez-Clare, 1997; Romer, 1986, 1993; Nelson & Pack, 1999; Temple, 1999; Easterly & Levine, 2001; Durlauf, Johnson & Temple, 2005).

Devarajan, Easterly and Pack (2003) have argued that the economic development of Africa is substantially traceable to the low levels of productivity and not necessarily to low investment levels. According to the narrative, policy makers should place more priority in promoting measures that enhance productivity compared to policy initiatives that are designed to promote investment. In essence, according to the thesis, the productivity of investment is more worthwhile compared to the levels of investment. This study improves the extant literature on the debate by investigating how enhancing ICT can improve TFP in the region of Sub-Saharan Africa (SSA). The critical role of ICT in driving productivity is in line with a contemporary strand of literature on the importance of information technology is driving economic development in Africa.

Second, an evolving strand of scholarship on Africa's economic development substantially supports the role of the burgeoning phenomenon of ICT in driving human and economic prosperity on multiple fronts (Tchamyou, 2017; Abor, Amidu & Issahaku, 2018; Asongu & Nwachukwu, 2018; Isszhaku, Abu & Nkegbe, 2018; Gosavi, 2018; Minkoua Nzie, Bidogeza & Ngum, 2018). For instance, information technology has been documented to boosts the productivity of countries (Hong, 2016). Moreover, as supported by Sassi and Goaied (2013), information technology is fundamental in promoting processes of productivity in a country as well as value chains associated with such productivity. The underlying importance of ICT is consistent with the arguments of Asongu, le Roux, Nwachukwu and Pyke (2019) which maintain that it boosts production efficiency, increases competitiveness and the ability of public officials to manage institutions more effectively.

The imperative of information technology in driving SSA's productivity also builds on the comparative potential of ICT penetration in SSA compared to other world regions that are experiencing saturated levels in the growth of information technology (Penard, Poussing, Yebe & Ella, 2012; Asongu, 2013a; Afutu-Kotey, Gough & Owusu, 2017; Asongu & Boateng, 2018; Asongu & Odhiambo, 2018; Humbani & Wiese, 2018; Gosavi, 2018; Efobi, Tanankem & Asongu, 2018; Asongu & Odhiambo, 2019a, 2019b).

It is in view of understanding how the pontential for ICT penetration can be leveraged for more productive ends that this inquiry is positioned on assessing how enhancing ICT affects TFP dynamics in SSA. Such a positioning is also motivated by an apparent gap in the scholarly literature.

Third, the extant scholarship on productivity in Africa has largely focused on *inter alia*: "foreign investment"-oriented productivity outcomes (Dunne &Masiyandima, 2017; Boamah, 2017; Fanta & Makina, 2017); disparities in gender and labour supply (Elu & Price, 2017); the connection underlying manufacturing and exports (Cisse, 2017); schooling features and child intensity in labour (Ahouakan & Diene, 2017); examination of output gaps with respect to future economic prosperity (Fedderke & Mengisteab, 2017); the modulating role of value chains in the effect of foreign direct investment on productivity dynamics and economic development (Meniago & Asongu, 2020); examination of interactions underlying manufacturing corporation and TFP on the premise of variations in levels of cross-sector productivity growth within the manufacturing industry (Kreuser & Newman, 2018) and the relevance of information in TFP catch-up (Maryan & Jehan, 2018).

The study in the engaged literature that is closest to the present exposition is Maryan and Jehan (2018). The paper has assessed drivers of TFP convergence in 91developing countries using data for the period 1960 to 2015. The United States of America (USA) is used as the frontier country and technology diffusion proxies employed in the catch-up process are interactive foreign direct investment and trade openness. Employing the Generalised Method of Moments (GMM), the study finds that high levels of openness are associated with high catch-up and TFP growth with FDI playing a dominant role.

The positioning of this study departs from the underlying in that, ICT dynamics of mobile phone penetration and internet penetration are used to account for information technology instead of relying on openness in capital (i.e. FDI) and trade accounts (i.e. trade openness). Moreover, the study focuses on SSA instead of developing countries with a contingency on the USA as frontier country. Moreover, this study also takes on board, welfare measurements of TFP to complement the mainstream measurement of TFP used in the underlying study. The importance of considering alternative measurements of TFP is consistent with policy challenges towards the attainment of Sustainabe Development Goals (SDGs) in the sub-region. Accordingly, welfare measurements of TFP translate the equitable distribution of productivity across the population such that the research is not only concerned about productivity but also about how the masses benefit from such productivity. The plethora of TFP dynamics engaged include: TFP,real TFP, welfare TFP and real welfare TFP.

Moreover, while Asongu and Odhiambo (2020a, 2020b) have investigated nexuses between information technology, FDI and productivity, very little is still known about how enhancing ICT affects TFP. Moreover, just providing nexuses between ICT and macroeconomic outcomes is less informative for policy makers because it is more worthwhile to provide policy makers with specific ICT thresholds at which they should act upon to influence macroeconomic outcomes. The study addresses this concern by providing ICT critical masses at which policy makers should engage complementary policies in order to leverage on ICT for positive outcomes on productivity in sub-Saharan Africa.

Aganist the above background, the research question the current study aims to address is the following: how does enhancing ICT affect TFP dynamics in SSA and what specific ICT policy thresholds are needed for complementary policies? In addressing this question, the study is organised as follows: The theoretical underpinnings are covered in section 2 while the data and methodology are engaged in section 3. The empirical findings are presented and discussed in section 4. Section 5 concludes with implications and future research directions.

2. Theoretical underpinnings and technology accumulation

The theoretical foundations underlying the connection between information technology and productivity are broadly in line with neoclassical models for economic development (Solow, 1956; Romer, 1990; Grossman& Helpman, 1991; Kwan & Chiu, 2015; Asongu & Odhiambo, 2018). In essence, the corresponding theoretical framework maintains the critical dimension of information technology in driving macroeconomic outcomes such as productivity and output in countries characterised by lower levels of industrialisation (Abramowitz, 1986; Bernard & Jones, 1996; Asongu Nwachukwu & Aziz*,* 2018).The neoclassical underpinnings have motivated a stream of contemporary African information technology literature focusing on linkages between ICT and economic development (Muthinja & Chipeta, 2018; Uduji & Okolo-Obasi, 2018a, 2018b; Bongomin, Ntayi, Munene & Malinga, 2018; Asongu, le Roux, Nwachukwu & Pyke, 2019).

In accordance with Hussien, Ahmed and Yousaf (2012), majority of the extant theories pertaining to how TFP is affected build on, learning by doing, technology diffusion, competition by means of exist and entry, economies of scale, which *inter alia*, facilitate resource reallocation at the industry level. In line with Hussien *et al.* (2012), the body of theoretical and empirical literature shows that because only a select number of countries can financially accommodate the substantial research and development (R&D) investment associated with production activities, cross-country movements of technology allows countries that are lagging in technology to benefit from advances in technology for more efficient production processes. This explains the importance of technology in productivity catch-up in developing countries such as those in SSA, as apparent in the attendant theoretical and empirical scholarship on the subject (Grossman & Helpman, 1991; Parente & Prescott, 1994; Holmes & Shimitz, 1995; Rodriguez-Clare, 1996; Hall & Jones, 1999; Choudri & Hakura, 2000; Miller & Upadyay, 2000; Jonsson & Subramanian, 2001; Melitz, 2003; Alcala & Ciccone, 2004).

In the light of the above, the enhancement of ICT for TFP is consistent with theoretical underpinnings pertaining to technology accumulation for productivity. The principal view surrounding endogenous growth theories is the premise that, in the long term, economic growth is mainly driven by TFP which depends fundamentally on the rate at which technology progresses. In order to adapt the theoretical framework to this study, technological progress is assimilated to information technology in the perspective of ICT in accordance with contemporary literature on the relevance of TFP in economic prosperirty (Asongu & Odhiambo, 2020a). The attendant literature in the first-two paragraphs of this section is consistent with the perspective that cross-country differences in economic prosperity and TFP are also contingent on cross-country differences in factors that drive such economic prosperity. Narrowing the perspective to the modeling approach adopted in this study, the employment of Generalised Method of Moments (GMM) involving elements in the conditioning information set or control variables, requires that adopted elements in the conditioning information set should reflect documented differences in cross-country factors that determine economic property and total factor productivity such as foreign direct investment, population, education, government expenditure and inflation, which are used as control variables in this study (Coe & Helpman, 1995: Howitt, 2000; Cameron, 2003; Savvides & Zachariadis, 2005; Aghion, Bloom, Blundell, Griffih & Howitt, 2005).

Accordingly, education is essential because a relevant level of kowleddge in the workforce is necessary in the acquisition and use of acquired information technology. Foreign direct investment is also important because, the rate of technological diffusion in frontier countries is a relevant driver of TFP growth in the domestic economy (Savvides & Zachariadis, 2005). Moreover, expenditure of the government, macroeconomic stability (e.g. low/stable inflation) and a growing and vibrant population are also documented cross-country factors that improve the ability of a country to leverage on information technology for productivity outcomes (Coe & Helpman, 1995; Howitt, 2000; Aghion et al., 2005). Given these insights, the adopted elements in the conditioning information set in the empirical section takes on board the discussed cross-country factors that are also relevant in driving TFP.

3. Data and Methodology

3.1 Data

The focus of this scholarship is on a sample of 25 countries in SSA with information in terms of annual observations spaning the period 1980 to 2014[2]. The geographical and temporal scopes characterising the study are informed by constraints in the availability of data at the time of the study. The data is further restructured to have properties that conform to the estimation stragegy adopted by the study, notably: the Generalised Method of Moments (GMM). Accordingly, the adoption of this estimation approach requires that the number of cross sections should be higher than the corresponding number of periods (i.e. annual observations as in the present study) in each cross section.

Against the above backdrop, the restructuring process produces seven five-year and five seven-year data averages in terms of non-overlapping intervals. Both types of non-overalapping intervals are employed for an exploratory analysis and upon the assessement, it is apparent that one type of non-overlapping intervals does not produce robust models owing

[2]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.

to concerns of instrument proliferation, even when the option used to collapse instruments is activated, namely: the seven five-year data average. It follows that the five seven-year data average is retained for the study, notably: 1980-1986; 1987-1993; 1994-2000; 2001-2007; 2008-2014.

The four TFP dynamics used in the study are from the Penn World Table database. They are: TFP, real TFP, welfare TFP andreal welfare TFP. The choice of these variables is consistent with contemporary TFP literature in SSA (Asongu, 2020). In accordance with the extant ICT literature in Africa, two main ICT indicators from the World Development Indicators of the World Bank are adopted, namely: mobile phone penetration and internet penetration (Tchamyou, 2017; Efobi *et al.*, 2018; Asongu, Biekpe & Tchamyou, 2019).

In order to account for variable omission bias, five indicators are adopted for the conditioning information set, namely: FDI, population, inflation, education and government expenditure. The first control variable is sourced from the United Nations Conference on Trade and Development (UNCTAD) database while the last-four are obtained from the World Development Indicators of the World Bank. The choice of these variables in the conditioning information set is informed by the attendant scholarship on drivers of output and productivity, notably: Ssozi and Asongu (2016a, 2016b); Sahoo, Dash and Nataraj (2010); Heady and Hodge (2009); Barro (2003) and Becker, Laeser and Murphy (1999); Asongu (2015a), Nyasha and Odhiambo (2015a, 2015b).

As concerns the expected signs from the control variables, it is anticipated that inflation will negatively affect productivity while the other four control variables will reflect a positive association. The justifications for the expected signs are further substantiated in what follows. First, with regard to the role of foreign investment, Hussien *et al.* (2012) and Maryan and Jehan (2018) show that openness dynamics such as FDI and and trade influence TFP as well as TFP catch-up. Second, population has been established to be a determinant of investment and productivity in Africa (Asongu, 2013b, 2015b). Third, high inflation is detrimental to economic activity, output and productivity because it translates a negative atmosphere for investment and by extension an unfavorable investment climate. Accordingly, inflation increases ambiguity and investors have been documented to prefer engaging with economic environments that are less ambiguous (Kelsey & le Roux, 2017, 2018). Fourth, education is a relevant component in driving economic output and productivity (Barro& Sala-i-Martin, 1998; Ssozi & Asongu, 2016a). The choice of an indicator that captures gender inclusive primary and secondary education is consistent with the literature supporting the evidence that compared to the highest level of education; these educational levels are more conducive to promoting socio-economic development outcomes (Petrakis & Stamatakis, 2002; Asiedu, 2014; Tchamyou, 2020)[3]. Fifth, from intuition, expenditure from the government is designed to improve conditions for economic prosperity and productivity.

Information on the definitions and sources of the data are disclosed in Appendix 1, the summary statistics is provided in Appendix 2 while the correlation matrix is disclosed in Appendix 3. The schematique view of the empirical model to bepresented in the following section is shown in Figure 1 below which illustrates nexuses between mobile phone penetration, internet penetration and TFP.

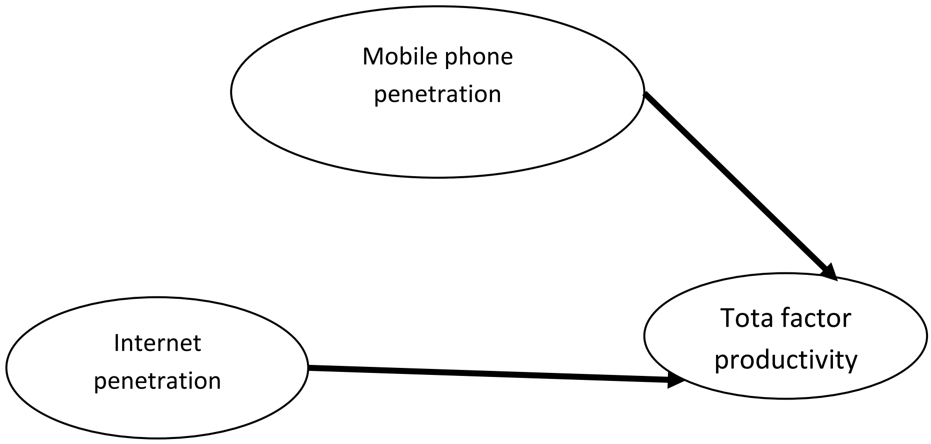

Figure 1: ICT for TFP

3.2 Methodology

3.2.1 Specification

The specification is consistent with the attendant literature on the importance of tailoring the estimation technique to be consistent with data behaviour (Kou et al., 2012, 2014, 2016, 2019a, 2019b; Li et al., 2014, 2016; Zhang et al., 2019).In line with insights into the importance of the GMM approach for the study discussed in the data section, four main motivations supported by the extant literature are used to further justify the choice of the underlying empirical strategy (Tchamyou, 2020; Meniago & Asongu, 2018). First and foremost, as outlined in the data section, the adopted empirical framework is consistent with a datastructure in which, the number of cross sections is higher than the corresponding number of years in each cross section. Hence, after restricting the dataset to five seven-year non-overlapping intervals, the N(i.e. 25)>T(i.e. 5) resulting structure fits the primary requirement for the empirical strategy. Second, the condition for persistence is also fulfilled because the

[3]The adopted education proxy is primary and secondary (gross), gender parity index (GPI).

level and first lag series' of the TFP dynamics overwhelmingly reflect a correlation coefficient that is higher than 0.800 which is the documented threshold for confirming the presence of persistence in the GMM-centric literature (Tchamyou, 2019; Efobi, Asongu, Okafor; Tchamyou & Tanankem, 2019). Third, owing to the panel datastructure of the research, it is apparent that cross-country variations are considered in the regression exercise. Fourth, the issue of endogeneity is handled in the specification process from two fundamental standpoints: on the one hand, the issue of reverse causality is handled by employing internal instruments to account for simultaneity and on the other; the unobserved heterogeneity is taken on board by controlling for time-invariant omitted variables.

Below are the standard GMM-centric equations in levels (1) and first difference (2) employed to assess the importance of enhancing ICT on TFP dynamics.

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

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

where $TFP_{i,t}$ represents a total factor productivity dynamic (i.e. TFP, real TFP, welfare TFP and real welfare TFP) of country i in period t; IT denotes an ICT indicator (i.e. internet penetration or mobile phone penetration); $ITIT$ reflects a quadractic interaction between ICT indicators ("intenet penetration" × "internet penetration"; "mobile phone penetration" × "mobile phone penetration"); σ_0 is a constant; τ is the degree of auto-regression that is one and reflects a seven year lag because such a lag appropriately captures information of the past; W is the set of control variables adopted for the study (*FDI, Population, Inflation, Education and Government Expenditure)*, η_i is the country-specific effect, ξ_t is the time-specific constant and $\varepsilon_{i,t}$ the error term.

The premise of this research on an improved GMM approach based on forward orthogonal deviations is informed by contemporary literature on its relative importance in providing more efficient estimates when compared with more traditional difference and system GMM approaches (Boateng, Asongu, Akamavi & Tchamyou, 2018; Tchamyou, Erreygers, & Cassimon, 2019a). This forward orthogonal option is the Roodman (2009) extension of Arellano and Bover (1995).

3.2.2 Identification, simultaneity and exclusion restrictions

In order to articulate the robustness of the GMM specification, some insights are fundamental, notably: the identification process, how the concern of simultaneity is addressed and the criterion used to assess the exclusion restriction assumption underlying the identification process. These three insights are expanded in the following passages. First, the process of identification entails the definition of three categories of variables, notably: the dependent, the predetermined or endogenous explaining and the strictly exogenous variables. In accordance with the discourse exposed so far, the dependent variables are the engaged TFP productivity dynamics while consistent with the attendant GMM-centric literature, the predetermined variables are ICT channels and the set of control variables while the strictly exogenous variables are years (Meniago & Asongu, 2018; Tchamyou & Asongu, 2017). It is also worthwhile to lay emphasis on the perspective that the choice of the strictly exogenous variable is consistent with Roodman (2009) who has maintained that years are feasible strictly exogenous indicators because they are unlikely to be endogenous upon a first difference. Therefore, the resulting assumption of exclusion restriction underpinning the identification process is that the strictly exogenous variables should affect the dependent variable exclusively via the engaged ICT indicators and adopted elements in the conditioning information set.

Second, with regards to the concern of reverse causality or simultaneity, forward differenced instrumental variables are employed in a process which consists of using Helmet transformations to wipe-out fixed effects which bias the model because they are correlated with the lagged TFP dynamics. The procedure for purging the underlying fixed effects is broadly in lined with the authorative literature on the concern (Arellano & Bover, 1995; Love & Zicchino, 2006; Roodman, 2009). These transformations permit orthogonal or parallel conditions between lagged and forward-differenced observations.

Third, the hypothesis corresponding to the exclusion restrictions discussed in the first strand of the section is investigated using the Difference in Hansen Test (DHT). The null hypothesis of this information criterion is the position that the exclusion restriction assumption holds or the identified strictly exogenous variables influence the outcome variable exclusively via the proposed predetermined variables. Hence, in the empirical results disclosed in the following section, the null hypothesis should not be rejected in order for the attendant restrictive assumption to be valid. The discussed procedure for validating the hypothesis pertaining to the exclusion restriction is not different from the criterion based on the Sargan/Hansen test that is employed in more traditional instrumental variable estimation approaches (Beck, Demirgüç-Kunt & Levine, 2003; Amavilah, Asongu & Andrés, 2017; Tchamyou, Asongu & Odhiambo, 2019b).

4. Empirical results

4.1 Presentation of results

This section reports the findings from the empirical analysis in Tables 1-4. The first table focuses on relationships between TFP and ICT while the second is concerned with nexuses between real TFP growth and ICT. The third table provides findings from connections between welfare TFP and ICT whereas the fourth shows findings pertaining to the relationships between welfare real TFP and ICT. In each table, the left-hand and right-hand sides respectively, show findings on "mobile phone"-oriented and internet-related regressions.

Owing to concerns associated with instrument proliferation, the specifications are tailored such that after estimations, for each specification, the number of cross-sections is higher than the number of instruments. This consideration limits the concern of instrument proliferation which potentially biases the estimated model. Hence, the adoption of only one variable in each of the specifications is informed by this need to avoid instrument proliferation. Moreover, it is important to articulate that, the engagement of limited elements in the conditioning information set is common in the scholarly GMM-centric literature in so far as the purpose for doing so is to achieve robust estimations and by extension avoid the proliferation of instruments upon estimations. Examples in the attendant GMM-centric literature that have employed no control variables are: Osabuohien and Efobi (2013) and Asongu and Nwachukwu (2017).

The research employs four information criteria for the validation of estimated models[4].Based on insights from these criteria: (i) four models are invalid in Table 1; (ii) three estimations are valid in Table 2: (iii) one model is not valid in Table 3 and (iv) two estimations are invalid in Table 4. In the light of the information criteria, the invalidity of these models is treacable to rejection of the null hypothesis of the second order Arellano and Bond autocorrelation test in difference and/or the null hypothesis of the Hansen test.

[4] "*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).

To assess the research question motivating this research, the study is consistent with a stream of contemporary literature on interactive regressions computing net effects which build on the unconditional effects of ICT indicators as well as the conditional or maginal effects of the corresponding ICT indicators on TFP dynamics (Tchamyou & Asongu, 2017; Agoba, Abor, Osei & Sa-Aadu, 2020). Hence, the criteria for assessing the overall effect is tight in the light of Brambor, Clark and Golder (2006) who have cautioned that in interactive regressions, the attendant effects should not exclusively be based on interactive estimated coefficients.

Table 1: TFP and ICT

	Dependent variable: Total Factor Productivity (TFP)									
	The mobile phone penetration channel					**The internet channel**				
TFP (-1)	**0.783***** **(0.000)**	**0.760***** **(0.000)**	**0.797***** **(0.000)**	**0.716***** **(0.000)**	**0.866***** **(0.000)**	**0.742***** **(0.000)**	**0.790***** **(0.000)**	**0.802***** **(0.000)**	**0.725***** **(0.000)**	**0.805***** **(0.000)**
Mobile	**0.002***** **(0.000)**	**0.002***** **(0.000)**	**0.002***** **(0.000)**	**0.005***** **(0.000)**	-0.0009 (0.481)	---	---	---	---	---
Mobile × Mobile	**-0.00001***** **(0.000)**	**-0.00001***** **(0.000)**	**-0.00001***** **(0.002)**	**-0.00003***** **(0.000)**	7.97e-07 (0.918)	---	---	---	---	---
Internet	---	---	---	---	---	0.003 (0.305)	-0.003 (0.130)	0.003 (0.375)	0.001 (0.717)	0.001 (0.648)
Internet × Internet	---	---	---	---	---	-0.00003 (0.767)	**0.0001**** **(0.028)**	-0.00004 (0.733)	0.00002 (0.870)	0.00002 (0.717)
FDI	0.001 (0.285)	---	---	---	---	0.001 (0.174)	---		---	---
Population	---	**0.011**** **(0.020)**	---	---	---	---	0.007 (0.222)		---	---
Inflation	---	---	**-0.00007***** **(0.000)**	---	---	---	---	**-0.00008***** **(0.000)**	---	---
Education	---	---	---	0.147 (0.265)	---	---	---	---	**0.122**** **(0.026)**	---
Gov't Expenditure	---	---	---	---	**0.005***** **(0.000)**	---	---	---	---	0.0007 (0.527)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	0.001	nsa	0.001	nsa	na	na	nsa	nsa	na	na
Thresholds	100.000	nsa	100.000	nsa	na	na	nsa	nsa	na	na
AR(1)	**(0.727)**	**(0.742)**	**(0.281)**	**(0.236)**	**(0.453)**	**(0.667)**	**(0.507)**	**(0.165)**	**(0.278)**	**(0.619)**
AR(2)	**(0.862)**	**(0.930)**	**(0.248)**	(0.053)	**(0.963)**	**(0.631)**	**(0.891)**	**(0.198)**	**(0.736)**	**(0.883)**
Sargan OIR	**(0.237)**	(0.090)	**(0.316)**	**(0.899)**	**(0.330)**	**(0.305)**	**(0.182)**	**(0.263)**	**(0.170)**	**(0.152)**
Hansen OIR	**(0.134)**	(0.063)	**(0.172)**	**(0.200)**	**(0.332)**	**(0.250)**	(0.081)	(0.072)	**(0.220)**	**(0.405)**
DHT for instruments										
(a)Instruments in levels										
H excluding group	**(0.159)**	(0.048)	**(0.161)**	**(0.723)**	(0.039)	(0.077)	(0.082)	(0.023)	(0.088)	(0.054)
Dif(null, H=exogenous)	**(0.166)**	**(0.145)**	**(0.213)**	**(0.142)**	**(0.674)**	**(0.419)**	**(0.138)**	**(0.236)**	**(0.352)**	**(0.711)**
(b) IV (years, eq(diff))										
H excluding group	**(0.165)**	(0.028)	**(0.407)**	**(0.516)**	**(0.197)**	**(0.107)**	(0.069)	**(0.119)**	**(0.500)**	**(0.289)**
Dif(null, H=exogenous)	**(0.207)**	**(0.528)**	(0.090)	(0.078)	**(0.615)**	**(0.762)**	**(0.283)**	**(0.131)**	(0.096)	**(0.550)**
Fisher	**1285.55*****	**1086.53*****	**21626.39*****	**239.23*****	**782.21*****	**1138.21*****	**27092.42*****	**18762.98*****	**1159.18*****	**14033.25*****
Instruments	18	18	18	18	18	18	18	18	18	18
Countries	24	24	24	24	24	24	24	24	24	24
Observations	96	96	94	82	94	96	96	94	82	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 Wald 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.

In the light of the above clarification, in order to assess how increasing ICT influences TFP in the second column of Table 1, the net effect of enhancing mobile phone penetration is 0.001 (2×[-0.00001× 15.806] + [0.002]). In this calculation, the mean value of mobile phone penetration as apparent in the summary statistics is 15.806, the marginal influence of mobile phone penetration on TFP is -0.00001 whereas the unconditional impact of mobile phone penetration is 0.002.

Table 2: Real TFP growth and ICT

	Dependent variable: Real Total Factor Productivity Growth (Real TFP growth)									
	The mobile phone penetration channel (Mobile)					The internet channel(Internet)				
Real TFP growth(-1)	**0.692*** **	**0.637*** **	**0.646*** **	**0.563*** **	**0.680*** **	**0.650*** **	**0.628*** **	**0.615*** **	**0.461*** **	**0.592*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile	0.0003	0.001	0.0006	0.001	0.00009	---	---	---	---	---
	(0.737)	(0.250)	(0.557)	(0.131)	(0.946)					
Mobile × Mobile	-9.36e-06	**-0.00001***	-8.88e-06	**-0.00001****	-8.50e-06	---	---	---	---	---
	(0.135)	**(0.085)**	(0.125)	**(0.016)**	(0.258)					
Internet	---	**---**	---	---	---	**-0.006***	-0.002	-0.001	0.0002	-0.002
						(0.096)	(0.502)	(0.744)	(0.938)	(0.653)
Internet × Internet	---	---	---	---	---	**0.0002***	0.0001	0.00004	9.94e-06	0.00006
						(0.076)	(0.247)	(0.777)	(0.920)	(0.700)
FDI	0.00005	---	---	---	---	0.0003	---	---	---	---
	(0.974)					(0.790)				
Population	---	**0.025****	---	---	---	---	**0.024*** **	---	---	---
		(0.018)					**(0.001)**			
Inflation	---	---	**-0.00009*** **	---	---	---	---	**-0.00009*** **	---	---
			(0.000)					**(0.000)**		
Education	---	---	---	**-0.145****	---	---	---	---	**-0.242***	---
				(0.037)					**(0.054)**	
Gov't Expenditure	---	---	---	---	0.002	---	---	---	---	-0.002
					(0.264)					(0.397)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	na	na	na	nsa	nsa	nsa	na	na	na	nsa
Thresholds	na	na	na	nsa	nsa	nsa	na	na	na	nsa
AR(1)	(0.060)	(0.050)	**(0.117)**	**(0.273)**	(0.066)	(0.082)	(0.052)	**(0.167)**	**(0.406)**	(0.076)
AR(2)	**(0.101)**	**(0.108)**	**(0.133)**	(0.030)	(0.061)	(0.098)	**(0.130)**	**(0.131)**	**(0.394)**	(0.078)
Sargan OIR	(0.085)	(0.001)	**(0.399)**	**(0.383)**	(0.056)	(0.010)	(0.000)	**(0.299)**	(0.014)	(0.001)
Hansen OIR	(0.091)	(0.066)	**(0.336)**	**(0.119)**	(0.019)	**(0.297)**	(0.094)	**(0.471)**	**(0.165)**	(0.023)
DHT for instruments										
(a)Instruments in levels										
H excluding group	(0.077)	(0.011)	(0.059)	(0.051)	(0.001)	**(0.146)**	(0.011)	**(0.178)**	(0.058)	(0.001)
Dif(null, H=exogenous)	**(0.159)**	**(0.311)**	**(0.596)**	**(0.255)**	**(0.451)**	**(0.384)**	**(0.413)**	**(0.562)**	**(0.324)**	**(0.360)**
(b) IV (years, eq(diff))										
H excluding group	**(0.194)**	**(0.153)**	**(0.711)**	**(0.185)**	(0.006)	**(0.148)**	**(0.189)**	**(0.368)**	(0.041)	(0.005)
Dif(null, H=exogenous)	(0.098)	(0.086)	**(0.105)**	**(0.154)**	**(0.579)**	**(0.702)**	**(0.106)**	**(0.528)**	**(0.991)**	**(0.735)**
Fisher	**79.59*** **	**54780.35*** **	**1054.01*** **	**35.12*** **	**94.49*** **	**29.72*** **	**22.08*** **	**3003.84*** **	**44.54*** **	**12.30*** **
Instruments	18	18	18	18	18	18	18	18	18	18
Countries	24	24	24	24	24	24	24	24	24	24
Observations	96	96	94	82	94	96	96	94	82	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 Wald 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.

Based on the underlying net effects, the following findings can be established in Tables 1-3. First, enhancing mobile phone penetration has a net positive incidence on TFP. Second, no significant findings are apparent from the relevance of increasing ICT on real TFP growth. Third, enhancing mobile phone penetration largely has a positive net effect on welfare TFP. Fourth, increasing internet penetration induces a positive effect on welfare real TFP. Fifth, most of the significant control variables have the expected signs.

Table 3: Welfare TFP and ICT

	Dependent variable: Welfare Total Factor Productivity (Welfare TFP)									
	The mobile phone penetration channel (Mobile)					**The internet channel(Internet)**				
Welfare TFP(-1)	**0.866*****	**0.801*****	**0.903*****	**0.758*****	**0.871*****	**0.810*****	**0.828*****	**0.931*****	**0.749*****	**0.761*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile	**0.001****	**0.002*****	0.0008	**0.004*****	**-0.002***	---	---	---	---	---
	(0.020)	**(0.000)**	(0.126)	**(0.000)**	**(0.077)**					
Mobile × Mobile	**-4.94e-06****	**-9.86e-06*****	-4.88e-06	**-0.00002*****	**0.00001****	---	---	---	---	---
	(0.040)	**(0.003)**	(0.130)	**(0.000)**	**(0.045)**					
Internet	---	---	---	---	---	0.0006	-0.004	-0.003	-0.002	-0.0004
						(0.852)	(0.220)	(0.499)	(0.317)	(0.914)
Internet × Internet	---	---	---	---	---	0.00007	**0.0001***	0.0001	**0.0001****	0.0001
						(0.490)	**(0.079)**	(0.407)	**(0.027)**	(0.292)
FDI	**0.003*****	---	---	---	---	**0.002*****	---		---	---
	(0.009)					**(0.011)**				
Population	---	**0.009***	---	---	---	---	0.004		---	---
		(0.074)					(0.514)			
Inflation	---	---	**-0.00007*****	---	---	---	---	**-0.00007*****	---	---
			(0.000)					**(0.000)**		
Education	---	---	---	0.039	---	---	---	---	**0.150****	---
				(0.561)					**(0.013)**	
Gov't Expenditure	---	---	---	---	**0.006****	---	---	---	---	**0.004*****
					(0.018)					**(0.003)**
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	0.0008	0.0017	na	nsa	-0.0016	na	na	na	na	na
Threholds	101.214	101.419	na	nsa	nra	na	na	na	na	na
AR(1)	**(0.782)**	**(0.712)**	**(0.573)**	**(0.277)**	**(0.654)**	**(0.756)**	**(0.814)**	**(0.497)**	**(0.418)**	**(0.675)**
AR(2)	**(0.260)**	**(0.242)**	**(0.952)**	(0.045)	**(0.222)**	**(0.375)**	**(0.353)**	**(0.995)**	**(0.297)**	**(0.462)**
Sargan OIR	**(0.414)**	**(0.117)**	**(0.537)**	**(0.742)**	**(0.731)**	**(0.521)**	**(0.205)**	**(0.585)**	**(0.500)**	**(0.507)**
Hansen OIR	**(0.159)**	**(0.075)**	**(0.147)**	**(0.215)**	**(0.435)**	**(0.160)**	**(0.129)**	**(0.159)**	**(0.320)**	**(0.311)**
DHT for instruments										
(a)Instruments in levels										
H excluding group	(0.057)	(0.014)	(0.065)	**(0.366)**	**(0.126)**	**(0.125)**	**(0.012)**	(0.021)	**(0.194)**	**(0.254)**
Dif(null, H=exogenous)	**(0.316)**	**(0.315)**	**(0.276)**	**(0.191)**	**(0.583)**	**(0.221)**	**(0.517)**	**(0.479)**	**(0.371)**	**(0.325)**
(b) IV (years, eq(diff))										
H excluding group	**(0.481)**	(0.026)	**(0.346)**	**(0.132)**	**(0.301)**	(0.050)	(0.029)	(0.099)	**(0.457)**	**(0.166)**
Dif(null, H=exogenous)	(0.062)	**(0.679)**	(0.090)	**(0.513)**	**(0.587)**	**(0.860)**	**(0.998)**	**(0.463)**	**(0.205)**	**(0.668)**
Fisher	**952.92*****	**1138.29*****	**4660.69*****	**292.33*****	**4108.54*****	**81994.23*****	**92054.93*****	**11216.76*****	**2524.03*****	**64697.50*****
Instruments	18	18	18	18	18	18	18	18	18	18
Countries	24	24	24	24	24	24	24	24	24	24
Observations	96	96	94	82	94	96	96	94	82	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 Wald 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. nra: not really applicable because the marginal effect does not have the right sign.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 4: Welfare real TFP and ICT

	Dependent variable: Welfare Total Factor Productivity (Welfare real TFP)									
	The mobile phone penetration channel (Mobile)					The internet channel (Internet)				
Welfare real TFP(-1)	**0.604*** **	**0.640*** **	**0.611*** **	**0.464*** **	**0.572*** **	**0.527*** **	**0.529*** **	**0.586*** **	**0.509*** **	**0.518*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile	0.0005	**0.003*** **	0.0004	0.002	**-0.001***	---	---	---	---	---
	(0.472)	**(0.004)**	(0.537)	(0.132)	**(0.052)**					
Mobile × Mobile	-2.72e-06	**-0.00001*** **	-1.51e-06	**-0.00001***	**9.69e-06***	---	---	---	---	---
	(0.751)	**(0.006)**	(0.739)	**(0.090)**	**(0.071)**					
Internet	---	---	---	---	---	**0.006***	**0.006*** **	**0.007*** **	0.003	0.001
						(0.056)	**(0.033)**	**(0.001)**	(0.344)	(0.597)
Internet × Internet	---	---	---	---	---	**-0.0002*** **	**-0.0002*** **	**-0.0002*** **	**-0.0001***	-0.00008
						(0.025)	**(0.012)**	**(0.000)**	**(0.098)**	(0.241)
FDI	**0.002*** **	---	---	---	---	**0.003***	---	---	---	---
	(0.035)					**(0.053)**				
Population	---	**0.035*** **	---	---	---	---	0.014	---	---	---
		(0.001)					(0.152)			
Inflation	---	---	**-0.00006*** **	---	---	---	---	**-0.00007*** **	---	---
			(0.000)					**(0.000)**		
Education	---	---	---	-0.038	---	---	---	---	0.016	---
				(0.717)					(0.848)	
Gov't Expenditure	---	---	---	---	**0.005*** **	---	---	---	---	0.0005
					(0.001)					(0.720)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	na	nsa	na	na	-0.0007	0.0047	nsa	0.0057	na	na
Thresholds	na	nsa	na	na	nra	15.000	nsa	15.000	na	na
AR(1)	(0.015)	(0.015)	(0.053)	(0.069)	(0.051)	(0.018)	(0.016)	(0.054)	**(0.100)**	(0.038)
AR(2)	**(0.345)**	**(0.308)**	**(0.359)**	**(0.103)**	**(0.142)**	**(0.228)**	**(0.144)**	**(0.310)**	**(0.168)**	**(0.176)**
Sargan OIR	(0.018)	(0.001)	**(0.205)**	**(0.349)**	**(0.100)**	(0.024)	(0.000)	**(0.396)**	(0.038)	(0.019)
Hansen OIR	**(0.210)**	(0.069)	**(0.281)**	**(0.422)**	**(0.103)**	**(0.756)**	(0.043)	**(0.698)**	**(0.742)**	**(0.511)**
DHT for instruments										
(a)Instruments in levels										
H excluding group	(0.032)	(0.005)	(0.014)	(0.091)	(0.009)	(0.085)	(0.025)	**(0.250)**	**(0.251)**	**(0.239)**
Dif(null, H=exogenous)	**(0.513)**	**(0.478)**	**(0.809)**	**(0.628)**	**(0.501)**	**(0.958)**	**(0.142)**	**(0.754)**	**(0.799)**	**(0.638)**
(b) IV (years, eq(diff))										
H excluding group	**(0.225)**	(0.036)	**(0.184)**	**(0.340)**	(0.027)	**(0.666)**	(0.073)	**(0.602)**	**(0.683)**	**(0.323)**
Dif(null, H=exogenous)	**(0.272)**	**(0.453)**	**(0.524)**	**(0.483)**	**(0.890)**	**(0.617)**	**(0.118)**	**(0.593)**	**(0.564)**	**(0.835)**
Fisher	**47.34*** **	**209.56*** **	**2855.51*** **	**65.75*** **	**87.10*** **	**53.68*** **	**109.63*** **	**9577.73*** **	**30.76*** **	**89.49*** **
Instruments	18	18	18	18	18	18	18	18	18	22
Countries	24	24	24	24	24	24	24	24	24	24
Observations	96	96	94	82	94	96	96	94	82	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 Wald 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. nra: not really applicable because the marginal effect does not have the right sign. 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 ICT Thresholds for complementary policies

Whereas the computed net effects are overwhelmingly positive, the corresponding ICT marginal effects used to compute the net effects are overwhelmingly negative. This is an indication that at certain specific ICT thresholds, the net effect is zero and beyond the attendant thresholds, enhancing ICT no longer induces positive net effects on the engaged TFP productivity dynamics. It further implies that at these established ICT critical masses or thresholds, ICT should be complemented with other policies in order to induce favorable positive effects on productivity dynamics. Moreover, following Asongu and Odhiambo (2020c), in order for the thresholds to make economic sense and have policy relevance, they should be within the statistical ranges (minimum to maximum) of the attendant ICT variables disclosed in the summary statistics.

The computed thresholds are provided immediately after the net effects in the corresponding tables. For instance, in the second column of Table 1, the mobile phone penetration threshold is 100 (0.002/ [2×0.00001]). Hence, at 100 mobile phone penetration (per 100 people), mobile phone penetration should be complemented with other policies in order to have a favorable impact on the engaged productivity dynamic. In the same vein, in the seventh column of Table 4, the corresponding internet penetration threshold is 15 (0.006/ [2×0.0002]). Therefore, at 15 internet penetration (per 100 people), internet penetration should be complemented with other policies in order to have a favorable impact on the corresponding productivity dynamic.

In the light of the above, in summary, the resulting thresholds are: 100 mobile phone penetration (per 100 people) for TFP; between 101.214 and 101.419 mobile phone penetration (per 100 people) for welfare TFP and 15 internet penetration (per 100 people) for welfare real TFP. It follows that approximately 100% mobile penetration and 15% internet penetration are thresholds at which ICT should be complemented with other macroeconomic policies for favorable outcomes on productivity dynamics. The computed thresholds make economic sense and have policy relevance because they are within the statistical ranges of mobile phone penetration (0.000 to 142.980) and internet penetration (0.000 to 31.922) provided in the summary statistics.

4.3 Technology spillovers, absorptive capacity and theoretical insights

The computation of net effects which are used to summarize the incidence of enhancing ICT on TFP is consistent with theoretical underpinnings related to technology spillovers and absorptive capacity (Howitt, 2000; Blomström, Kokko & Zejan, 2000). Hence, it is basically for this purpose that quadratic equations are used to articulate the relevance of absorptive capacity in the spillovers of ICT. Moreover, consistent with the theoretical narrative that in GMM conditional convergence modeling, cross-country differences in TFP and absorptive capacity are also traceable to cross-country differences in documented factors that influence absorptive capactity and TFP, it is apparent from the findings that most of the corresponding variables adopted in the conditioning information set have the expected signs.

This narrative is in line with the adaptation of "absorptive capacity" to local conditions (Arrow, 1969) and the dependence of absorptive capacitiy on factors such as human capital, foreign investment, government expenditure, inflation and population (Nelson & Phelps, 1966; Abromovitz, 1986; Nelson & Wright, 1992; Fagerberg, 1994; Griffith, Redding & Van Reenen, 2003, 2004).

Relating the findings to theoretical knowledge and by extension the theoretical contribution of the study, it can be inferred that the findings related to real TFP growth are consistent with the Neoclassical Growth Model of Solow (1956) because the net effects of ICT on TFP growth are not overwhelmingly apparent. This is essentially because according to the theoretical insights pertaining to the Neoclassical Growth Model, while technological spillovers can affect productivity, they cannot affect productivity growth rate. Hence, the findings in this respect are not in line with the New Theory of Economic Growth which supports the perspective that technology spillovers affect productivity as well as productivity growth (Hassan, 2005; Asongu & Odhiambo, 2020a). It is important to note that this nexus with theoretical insights exclusively focuses on singificance and makes abstraction to the sign of significance. This is essentially because we have computed thresholds for complementary policies, notably: before the thresholds, the net effectsare positive and after the corresponding thresholds, the net effectsare negative. However, insights into the theoretical discussion should be limited to significance because the context of the theoretical insights is based on significance.

Moreover, the positive net effects from nexuses between other TFP productivity dynamics (i.e. in Table 1, Table 3 and Table 4) are broadly consistent with contemporary literature on on the importance of information technology in the improvements of productivity and economic prosperity (Vu, 2011; Minkoua Nzie et al., 2018; Gosavi, 2018; Issahaku et al., 2018; Vu, 2019; Asongu & Odhiambo, 2020b). However, our study departs from this strand of literature because we have established that the incidence of ICT on a macroeconomic outcome is not monotonic because it could both be positive and negative. Hence, complementary policies are required when the incidence is negative in order to induce a favorable effect on the attendant macroeconomic outcome.

5. Concluding implications and future research directions

The following main findings are established. First, enhancing mobile phone penetration has a net positive incidence on TFP. Second, no significant findings are apparent from the relevance of increasing ICT on real TFP growth. Third, enhancing mobile phone penetration largely has a positive net effect on welfare TFP. Fourth, increasing internet penetration induces a positive effect on welfare real TFP. In what follows, the attendant implications are discussed.

Given the negative marginal effects, an extended analysis is performed to establish threshold for complementary policies. These thresholds are: 100 mobile phone penetration (per 100 people) for TFP; between 101.214 and 101.419 mobile phone penetration (per 100 people) for welfare TFP and 15 internet penetration (per 100 people) for welfare real TFP. It follows that approximately 100% mobile penetration and 15% internet penetration are thresholds at which ICT should be complemented with other macroeconomic policies for favorable outcomes on productivity dynamics.

The research has found that the digital revolution is relevant in boosting productivity in SSA and by extension, economic prosperity and economic development. In essence, ICT improves efficiency and the realization of economic processes. Moreover, the fact that itmay equally influence the distribution of economic gains across the population is confirmed in the welfare-oriented dimensions of the findings. Therefore, our findings have shown that the relevance of ICT in economic development is not exclusively a concern of international competiveness and manufacturing, but can also be extended to social equity in that the output also benefits the masses. Hence, in the light of the productivity welfare findings of the study, it is relevant for industrial policy to be tailored towards reducing the potential negative effects of inequalities in information and communication prevalent in production processes.

In the light of the above, policy makers should consolidate the ongoing processes that are aimed at boosting ICT access in order to benefit from enhanced productivity and corresponding welfare externalities. The ICT consolidating policies should entail, *inter alia*: schemes that are favorable to universal ICT access; boosting the relevant infrstracture for ICT penetration and low pricing mechanisms to increase ICT usage. Furthermore, production networks should be analysed prior and corresponding activities that are more responsive to the usage of ICT should be given priority.

Some net negative effects have also been established from the findings. These could be traceable to specificities pertaining to the TFP dynamics *inter alia*: investment that are enclaved, the unequal distribution of fruits of economic development across the population and absence of relevant productive infrastructure.

This research can be expanded by assessing how the established findings are relevant in the building of knowledge economies in African countries. Hence, it would be worthwhile to improve the extant scholarship by linking the nexus between ICT and productivity to the other two main components of the World Bank's knowledge economy index (KEI), notably:

economic incentives and institutional regime and innovation. This is essentially because two main components of the underlying World Bank's KEI have been used, notably: ICT and education.

Appendices

Appendix 1: Definitions and sources of variables

Variables	Signs	Variable Definitions (Measurements)	Sources
TFP1	TFP	Total Factor Productivity (TFP)	Penn World Table database
TFP2	RTFP	Real Total Factor Productivity Growth (RTFPg)	Penn World Table database
TFP3	WTFP	Welfare Total Factor Productivity (WTFP)	Penn World Table database
TFP4	WRTFP	Welfare Real Total Factor Productivity (WRTFP)	Penn World Table database
Mobile Phone Penetration	Mobile phones	Mobile phone subscriptions (per 100 people)	WDI
Internet Penetration	Internet	Internet subscriptions (per 100 people)	WDI
Foreign Direct Investment	FDI	Foreign Direct Investment Inflows(% of GDP)	UNCTAD
Population	Population	Logarithm of Population (in millions)	WDI
Inflation	Inflation	Consumer Price Index (annual %)	WDI
Education	Education	SEPSGPI: School enrollment, primary and secondary (gross), gender parity index (GPI)	WDI
Government Expenditure	Gov't Expenditure	Governments final consumption expenditure (% of GDP)	WDI

WDI: World Development Indicators. GDP: Gross Domestic Product.UNCTAD: United Nations Conference on Trade and Development.

Appendix 2: Summary statistics

	Mean	SD	Minimum	Maximum	Observations
Total Factor Productivity	0.539	0.310	0.121	1.884	125
Real Total Factor Productivity Growth	0.539	0.276	0.123	1.381	125
Welfare Total Factor Productivity	0.984	0.189	0.605	1.664	125
Welfare Real Total Factor Productivity	0.927	0.190	0.456	1.785	125
Mobile Phone Penetration	15.806	29.054	0.000	142.980	120
Internet Penetration	3.053	6.020	0.000	31.922	98
Foreign Direct Investment	1.903	2.795	-3.440	22.118	124
Population	2.515	0.818	-0.242	4.165	125
Inflation	42.868	347.967	-3.601	3820.096	120
Education	0.854	0.177	0.465	1.341	107
Government Expenditure	16.066	5.358	6.085	36.155	122

S.D: Standard Deviation.

Appendix 3: Correlation matrix (uniform sample size:124)

TFP	RTFP	WTFP	WRTFP	Mobile	Internet	FDI	Pop	Inflation	Education	Gov. Ex	
1.000	0.283	0.957	0.075	-0.034	0.095	-0.085	0.018	-0.027	0.411	0.072	TFP
	1.000	0.288	0.635	0.049	-0.014	0.058	-0.221	-0.188	-0.002	0.144	RTFP
		1.000	0.093	0.016	0.130	-0.010	-0.068	-0.029	0.436	0.175	WTFP
			1.000	0.310	0.203	0.185	-0.056	-0.330	-0.048	0.039	WRTFP
				1.000	0.726	0.292	0.066	-0.062	0.370	0.108	Mobile
					1.000	0.125	0.292	0.054	0.324	-0.077	Internet
						1.000	0.036	-0.063	0.181	0.132	FDI
							1.000	-0.009	0.020	-0.362	Pop
								1.000	0.074	-0.044	Inflation
									1.000	0.381	Education
										1.000	Gov. Ex

TFP: Total Factor Productivity. RTFP: WTFP: Welfare Total Factor Productivity. WRTFP: Welfare Real Total Factor Productivity. Mobile: Mobile Phone penetration. Internet: Internet penetration. FDI: Foreign Direct Investment. Pop:population growth. Gov. Ex: Government Expenditure.

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