Mobile Phone Innovation and Technology-driven Exports in Sub-Saharan Africa

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Abstract

The study investigates how education, scientific output and the internet complement mobile phone penetration to affect technology commodity exports in Sub-Saharan Africa for the period 2000-2012. The empirical evidence is based on Generalised Method of Moments. The following main findings are established. First, the internet complements the mobile phone to boost technology goods exports. Second, the internet also complements the mobile phone to boost technology service exports. Third, positive marginal effects are apparent in the roles of educational quality and scientific output on technology goods exports and technology service exports respectively while negative marginal impacts are apparent in the roles of scientific output and educational quality on technology goods exports and technology service exports respectively. Practical and theoretical implications are discussed.

JEL Classification: L59; L98; O10; O30; O55
Keywords: Technology exports; Knowledge Economy; Development; Africa

1. Introduction

The knowledge revolution that has accompanied the phenomenon of globalisation is presenting valuable avenues for the promotion of social, economic and business development. Development in the 21st century is fundamentally centred on the drive towards knowledge-based economies (KBE). The contemporary rate at which knowledge is created and disseminated represents an opportunity for developing countries to make a transition from agriculture-based economies and product-based economies to KBE. A reason for such potential transformation is the substantial surge in ICTs which has considerably reduced the cost of computing power and electronic networking. In essence, while the growing penetration and affordability of modern ICTs has increased knowledge diffusion and efficiency, there is a downside that some countries could be confronted with the inevitable risk of being left-out of the transition to KBE if they cannot adapt to and keep even pace with such transformations. Unfortunately, compared to the rest of the world, the overall knowledge index of Africa has dropped since the beginning of the Third millennium (Tchamyou, 2016).

In the light of the above, assessing the role of mobile phone innovation in technology-driven exports in sub-Saharan Africa (SSA) is motivated by three main trends in scholarly and policy circles, namely: (i) the high penetration potential of mobile phones in SSA compared to the rest of the world; (ii) debates surrounding the impact of innovation on exports and (iii) gaps in the literature.

First, while comparatively more developed countries in Asia, Europe and North America are currently experiencing saturation levels in mobile phone penetration, there is a healthy room for its penetration in SSA (Penard et al., 2012; Asongu, 2015a). This potential for mobile phone penetration can be leveraged by policy to achieve positive intensive and extensive development outcomes. The former includes economic progress that is achieved by means of internally-driven factors whereas the latter embodies extensive-driven strategies like export-led economic prosperity. This inquiry is concerned with the latter, partly because of the debate surrounding the effect of innovation on exports.

The relationship between innovation and exports is still open to much debate. There is a strand of the literature which is of the position that such connection between productivity and exports is not exogenous (Melitz, 2003; Bernard & Jensen, 1999). Another strand of the literature contends that before exporting, corporations improve their productivity, but also benefit from post-entry productivity gains (Aw et al., 2009). According to Harris and Moffat (2011), the causality is both ways because whereas innovation is likely to affect the decision of the corporation to export or not, in turn the 'learning by exporting effect' could affect innovation.

Third, contemporary ICT literature has not engaged the linkage between ICT and technology-driven exports in Africa[1]. On the one hand, the literature on ICT for economic development in developing countries has focused on *inter alia*: standards of living (Chavula, 2013); economic growth (Levendis & Lee, 2013; Qureshi, 2013a); sustainable development (Byrne, 2011); welfare externalities (Carmody, 2013; Qureshi, 2013bc); financial sector development (Kamel, 2005); inclusive development (Asongu & Nwachukwu, 2016a; Asongu & Le Roux, 2017) and better life for all (Kivuneki et al., 2011; Ponelis & Holmner, 2013ab)[2]. On the other hand, the use of ICT for entrepreneurial purposes has included: articulation on entrepreneurs who are constantly innovating due to changing financial resources and skills (Best, 2015); the creation and discovery of new innovation avenues (Hang et al., 2015; Wan et al., 2015); technological improvements that are offering new opportunities because of patent road-mappings (Jeong & Yoon, 2015); opportunities for doing business that are linked to an ageing demography (Kohlbacher et al., 2015) and evolving ecosystems (Overholm, 2015); collaborations in research (McKelveyet al., 2015); opportunities for scientific entrepreneurs (Maine et al., 2015) and the relevance of knowledge spillovers in entrepreneurship (Acs et al., 2013; Hayter 2013; Kuada, 2014; Ghio et al., 2015; Afutu-Kotey et al., 2017); the relevance of social media in promoting entrepreneurship (McCann & Barlow, 2015; Jones et al., 2015; Wang, 2016); using ICT to modulate governance (Asongu et al., 2017) and openness (Asongu & Nwachukwu, 2018) in order to boost conditions for doing business; the employment of social entrepreneurship to boost technology (Mulloth et al., 2016); innovating the mobile phone for entrepreneurship (Asongu & Biekpe, 2017) and knowledge sharing for the success of entrepreneurship (Allen et al., 2016).

This study steers clear of the above literature by assessing how the mobile phone interacts with three policy variables to affect technology-driven exports. The innovation

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[1] The interested reader can find insights into a surveys and policy challenges to entrepreneurship in Africa in Kuada (2009 and Kuada (2015).

[2] The study also steers clear of the stream of ICT literature for social outcomes (Amankwah-Amoah & Sarpong, 2016; Islama & Meadeb, 2012; Brouwer & Brito, 2012; Amankwah-Amoah, 2015, 2016; Mira & Dangersfield, 2012) in both developing nations (Gupta & Jain, 2012; Sonne, 2012) and developed countries (Thakar, 2012).

policy variables which are interacted with the mobile phone are: educational quality, scientific output and internet penetration. Hence, the research question this inquiry seeks to address is: how do education, the internet and scientific output complement the mobile phone in boosting technology-driven exports? The policy relevance of the inquiry is twofold. On the one hand, the growing relevance of knowledge economy in 21st century development we have discussed in the first paragraph (also see Asongu and Tchamyou, 2016). On the other hand, the contribution of SSA's trade to the global economy has declined considerably. We substantiate the latter perspective. According to Harris and Moffat (2011), in spite of a strong nexus between ICT investment and trade, there is very little empirical research in this direction. Moreover, despite the established relevance of trade in economic development both in policy and scholarly circles (IMF, 2008; UNCTAD, 2009; NEPAD , 2010), since the 1970s there has been a decline in Africa's trade (IMF, 2008; UNCTAD, 2009).

The rest of the study is structured as follows. The theoretical underpinnings are discussed in Section 2. Section 3 covers the data and the methodology. The empirical results are disclosed in Section 4 while Section 5 presents concluding implications and future research directions.

2. Theoretical underpinnings

Consistent with Harris and Moffat (2011), two major theoretical models exist in the mainstream macroeconomic literature on the nexus between innovation and exporting, with causality fundamentally running from innovation to exporting. According to the narrative, for the most part, not much distinction is made between research and development (hence R&D) and innovation because inputs from innovation (such as R&D) engender new processes and product outputs. Whereas neo-endowment models focus on specialisation and therefore the competitive advantage with regard to factor endowments (e.g. skilled/unskilled labour, technology and capital), neo-technology models are focused for instance on the product life cycle theory and the technology gap theory on trade.

In accordance with Wangwe (1995), some studies closely linked to long-run growth have emphasised on trade patterns as well as on their nexuses with temporal (or time-dynamic) cross-country and cross-sector innovation patterns. These studies have established robust findings on the effect of innovation on international growth and competiveness. This tendency is also concerned with models of neo-technology which have tried to endogenize progress in technology within the framework of equilibrium open-economy development models (see Spencer, 1981).

A corresponding strand of the literature maintains that exporting can also affect innovation. According to this perspective of endogenous models of growth (see Hobday, 1995; Aghion & Howitt, 1998), there is an imperative for corporations to constantly innovate in order to adapt to evolving competitive challenges in foreign markets. Moreover, there is a 'learning to export effect' owing to increasing exposure to new knowledge and technology. This is consistent with the analysis of Spencer (1981) on a learning curve which has improved narratives on the theory of international trade. More recently, Aw et al. (2009) have used a dynamic model to establish that innovation and exporting are closely related "… *each activity alters the future return from undertaking the other activity, thus current R&D directly impacts the probability of exporting and current exporting alters the return to R&D*" (Aw et. al., 2009, p.3). It is important to note that according to the narrative, productivity is a function of the firm's innovation capacity.

The empirical literature on the nexus between a nation's exporting performance and its innovation capacity has substantially been documented in the literature. Unfortunately, as argued by Harris and Moffat (2011), the literature for the most part has focused on developed countries and some emerging economies outside Africa. In essence, ICT improvements have been established to enhance trade in developed countries (e.g. the United States) and the emerging economies in Asia (e.g. Malaysia, South Korea and Singapore) (Avgerou, 1998; Wang, 1999; Ngwenyama et al., 2006). The underlying literature has established a consensus on the positive relationship between a country's exporting capacity and its innovative activities or knowledge accumulation (Salim & Bloch, 2009; DiPietro & Anoruo, 2006; Leon-Ledesma, 2005). Various studies have articulated the roles of innovation and technology as principal factors for increasing export performance, consolidating competitiveness and easing entry into global markets. To put this point into perspective, Salim and Bloch (2009) have recently shown that causality flows from innovation (e.g. R&D) to exports.

3. Data and Methodology

3.1 Data

The study investigates a panel of forty-nine countries in SSA with data from World Development Indicators (WDI) of the World Bank for the period 2000-2012. The dependent variable captures both the manufacturing and the service sectors. Hence, two main outcome variables are used: technology goods exports and technology service exports. The mobile phone is proxied with the mobile phone penetration rate (per 100 people).

In accordance with recent mobile phone innovation literature (see Asongu & Nwachuwku, 2016b), three of the four dimensions of the World Bank's KEI are employed as innovation variables, namely: educational quality, scientific output and ICT. The choice of the 'pupil-teacher ratio' in primary education as a measurement of the quality of education is motivated by data availability constraints and its comparative relevance in countries at initial stages of industrialisation. On the one hand, there are concerns in degrees of freedom with regards to other measurements of educational quality (e.g. 'pupil-teacher ratio in secondary education'). On the other hand, primary education has been established to be connected to more positive development externalities when countries are at early stages of industrialisation (see Petrakis & Stamatakis, 2002; Asiedu, 2014).

Issues in degrees of freedom related to other indicators of innovation (e.g. patent and trademark applications) motivate the study to proxy for innovation with the number Scientific and Technical Journal Articles (STJA) published annually. The complementary ICT indicator is internet penetration, essentially because the mobile phone can substantially increase its potential if it is connected to the internet.

Consistent with Tchamyou (2016), four main macroeconomic and institutional controls variables are used, namely: Gross Domestic Product (GDP) growth, trade openness, political stability and cost of export. From a preliminary investigation, accounting for more than four control variables leads of concerns about instrument proliferation and/or over-identification that substantially bias the estimated coefficients from the Generalised Method of Moments (GMM). While from intuition, the fourth (first-three) variable(s) is (are) expected to increase (decrease) the dependent variables, the signs may also be contingent on market dynamism and expansion. For instance, if trade openness, GDP growth and cost of exports are not broad-based but skewed towards a few industrial extractive sectors, their effects on technology commodity exports may be counterintuitive.

The definition of variables and corresponding sources are disclosed in Appendix 1 while the summary statistics is provided in Appendix 2. A correlation matrix used to avoid concerns about multicollinearity is provided in Appendix 3.

3. 2 Methodology

A *two-step* Generalised Method of Moments (GMM) estimation approach is adopted for a fourfold reason: (i) the number of countries or cross sections (49) is comparatively higher than the periodicity in respective countries (13); (ii) cross-country variations are not eliminated in the regressions since the GMM estimation technique is compatible with a panel data structure,; (iv) inherent biases in the *difference* estimator are corrected with the *system* estimator; and (v) the estimation procedure accounts for endogeneity by controlling for simultaneity in the explanatory variables using an instrumentation process. Furthermore, the employment of time-invariant variables also increases the bite on endogeneity. The Roodman (2009ab) extension of Arellano and Bover (1995) is adopted in this study because, compared to traditional GMM techniques, it mitigates the proliferation of instruments (or restricts over-identification) and is more efficient in the presence of cross-sectional dependence (Love & Zicchino, 2006; Baltagi, 2008; Boateng et al., 2016).

The following equations in level (1) and first difference (2) summarise the standard *system* GMM estimation procedure.

$$TExp_{i,t} = \sigma_0 + \sigma_1 TExp_{i,t-\tau} + \sigma_2 I_{i,t} + \sigma_3 M_{i,t} + \sigma_4 IM_{i,t} + \sum_{h=1}^{4}\delta_h W_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

$$TExp_{i,t} - TExp_{i,t-\tau} = \sigma_1(TExp_{i,t-\tau} - TExp_{i,t-2\tau}) + \sigma_2(I_{i,t} - I_{i,t-\tau}) + \sigma_3(M_{i,t} - M_{i,t-\tau}) + \sigma_4(IM_{i,t} - IM_{i,t-\tau}) + \sum_{h=1}^{4}\delta_h(W_{h,i,t-\tau} - W_{h,i,t-2\tau}) + (\xi_t - \xi_{t-\tau}) + \varepsilon_{i,t-\tau} \quad (2)$$

where, $TExp_{i,t}$ is a technology export indicator of country i at period t, ∂ is a constant, I is an innovation policy variable (educational quality, internet penetration and scientific output), M represents mobile phone penetration, IM is the interaction between an innovation policy variable and mobile phone penetration, W is the vector of control variables (GDP growth, trade openness, cost of exports and political stability), τ represents the coefficient of auto-regression, ξ_t is the time-specific constant, η_i is the country-specific effect and $\varepsilon_{i,t}$ the error term.

We briefly discuss properties of identification and exclusion restrictions that are important for a sound GMM specification. All explanatory variables are acknowledged as predetermined or suspected endogenous and only time-invariant variables are considered to exhibit strict exogeneity. This is in accordance with recent literature (see Asongu & Nwachukwu, 2016c, Boateng et al., 2016). Furthermore, time-invariant variables or years are unlikely to become endogenous after a first difference (see Roodman, 2009b)[3]. In the light of this emphasis, time invariant variables affect technology exports exclusively through the predetermine indicators. Furthermore, the statistical relevance of the underlying exclusion restriction is assessed with the Difference in Hansen Test (DHT) for the exogeneity of instruments. Accordingly, the null hypothesis of the DHT should not be rejected for the time-invariant indicators to affect the technology exports variables exclusively through the suspected endogenous indicators. Hence, in the results that are reported in section that follows, the assumption of exclusion restriction is validated if the alternative hypothesis of the DHT related to instrumental variables (IV) (year, eq(diff)) is not accepted. This is broadly consistent with the standard IV procedure in which, a rejection of the null hypothesis of the Sargan Overidentifying Restrictions (OIR) test is an indication that the instruments affect the technology export variables beyond the suspected endogenous variable mechanisms (see Beck et al., 2003; Asongu & Nwachukwu, 2016d).

4. Empirical results

Table 1 and Table 2 respectively present findings corresponding to 'technology goods exports' and 'technology service exports'. For each dependent variable, there are three specifications pertaining to each modifying or policy variable, namely: educational quality, internet penetration and scientific output.

Four information criteria are employed to examine the validity of the GMM models with forward orthogonal deviations[4] and the net effect is computed to examine the overall impact of the innovation policy variable on mobile phones for technology exports. For instance, in Table 1 in the last column, the net effect from the interaction between mobile phones and internet penetration is 0.002 ([-0.0007× 4.152] + 0.005), where, the mean value of education is 4.152, the unconditional impact of mobile phone penetration is 0.005 while the conditional impact from the interaction between education and mobile phones is -0.0007.

The following findings can be established. First, the internet complements the mobile phone to boost technology goods exports. Second, the internet also complements the mobile

[3] Hence, the procedure for treating *ivstyle* (years) is 'iv (years, eq(diff))' whereas the *gmmstyle* is employed for predetermined variables.

[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 Fischer test for the joint validity of estimated coefficients is also provided*" (Asongu & De Moor, 2016, p.9).

phone to boost technology service exports. Third, positive marginal effects are apparent in the roles of education quality and scientific output on technology goods exports and technology service exports respectively while negative marginal impacts are apparent in the roles of scientific output and educational quality on technology goods exports and technology service exports respectively. Most of the control variables are significant.

1: Mobile phone innovation and technology goods exports

	Dependent variable: Technology goods exports					
	Education		Scientific Output		Internet	
Constant	-0.018 (0.969)	-1.015 (0.261)	-0.006 (0.969)	**-2.286**** **(0.014)**	0.016 (0.906)	1.492 (0.162)
Technology good exports (-1)	**0.898***** **(0.000)**	**0.569***** **(0.000)**	**0.851***** **(0.000)**	**0.641***** **(0.000)**	**0.843***** **(0.000)**	**0.564***** **(0.000)**
Mobile phones (Mob)	-0.007 (0.130)	-0.005 (0.125)	0.0005 (0.789)	0.001 (0.676)	-0.0008 (0.630)	**0.005**** **(0.045)**
Education	-0.007 (0.230)	**-0.010*** **(0.098)**	---	---	---	---
Innovation (STJA)	---	---	-0.00002 (0.732)	**0.0005**** **(0.034)**	---	---
Internet	---	---	---	---	0.008 (0.528)	**0.063***** **(0.000)**
Education.Mob	**0.0002*** **(0.052)**	0.0001 (0.215)	---	---	---	---
STJA.Mob	---	---	0.000001 (0.206)	**-0.000005**** **(0.035)**	---	---
Internet.Mob	---	---	---	---	-0.00007 (0.665)	**-0.0007***** **(0.000)**
GDP growth	---	-0.011 (0.195)	---	**-0.025***** **(0.000)**	---	-0.007 (0.443)
Trade Openness	---	0.0004 (0.910)	---	-0.0004 (0.885)	---	0.001 (0.736)
Cost to Export (ln)	---	**0.220*** **(0.099)**	---	**0.322**** **(0.021)**	--- ---	**-0.260*** **(0.069)**
Political Stability	---	0.086 (0.308)	---	-0.031 (0.852)		**-0.211**** **(0.029)**
Thresholds						
Net Effects	na	na	na	na	na	0.002
AR(1)	**(0.153)**	(0.092)	**(0.159)**	(0.049)	**(0.196)**	**(0.140)**
AR(2)	**(0.247)**	**(0.938)**	**(0.260)**	**(0.245)**	**(0.206)**	**(0.854)**
Sargan OIR	**(0.999)**	(0.009)	**(0.177)**	(0.081)	**(0.918)**	(0.034)
Hansen OIR	**(0.708)**	**(0.984)**	**(0.296)**	**(0.925)**	**(0.870)**	**(0.891)**
DHT for instruments						
(a)Instruments in levels						
H excluding group	**(0.982)**	**(0.922)**	**(0.372)**	**(0.864)**	**(0.550)**	**(0.788)**
Dif(null, H=exogenous)	**(0.428)**	**(0.937)**	**(0.274)**	**(0.816)**	**(0.866)**	**(0.796)**
(b) IV (years, eq(diff))						
H excluding group	nsa	**(0.976)**	**(0.248)**	**(0.965)**	nsa	**(0.916)**
Dif(null, H=exogenous)	**(0.708)**	**(0.763)**	**(0.339)**	**(0.342)**	**(0.870)**	**(0.497)**
Fisher	**490.95*****	**6006.78*****	**1439.49*****	**2766.47*****	**609.75*****	**9243.45*****

Instruments	25	37	23	35	25	37
Countries	36	35	37	37	37	37
Observations	279	172	279	157	334	210

*,**,***: significance levels of 10%, 5% and 1% 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, Hausman test and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the OIR and DHT tests. nsa: not specifically because of issues in degrees of freedom. na: not applicable because at least one estimated coefficient needed for the computation of net effects is not significant. Mean of educational quality: 43.601. Mean of scientific output: 91.231. Mean of internet penetration: 4.152.

Table 2: Mobile phone innovation and technology service exports

	Dependent variable: Technology service exports					
	Education		Scientific Output		Internet	
Constant	-2.061	7.320	1.098	-16.348	**4.484****	-7.783
	(0.741)	(0.816)	(0.559)	(0.385)	**(0.047)**	(0.687)
Technology service exports (-1)	**0.662*****	**0.487*****	**0.987*****	**0.849*****	**0.694*****	**0.559*****
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile phones (Mob)	**0.092***	0.061	0.013	0.039	**0.070***	0.012
	(0.073)	(0.344)	(0.663)	(0.312)	**(0.050)**	(0.669)
Education	0.175	**0.247*****	---	---	---	---
	(0.164)	**(0.007)**				
Innovation (STJA)	---	---	-0.002	**-0.011****	---	---
			(0.315)	**(0.049)**		
Internet	---	---	---	---	**-0.592*****	**-0.475*****
					(0.000)	**(0.000)**
Education.Mob	-0.001	**-0.001***	---	---	---	---
	(0.140)	**(0.090)**				
STJA.Mob	---	---	0.00002	**0.0001***	---	---
			(0.403)	**(0.077)**		
Internet.Mob	---	---	---	---	**0.002***	0.001
					(0.055)	(0.255)
GDP growth	---	**-0.325***	---	**-0.647*****	---	**-0.321****
		(0.077)		**(0.000)**		**(0.038)**
Trade Openness	---	**0.096****	---	0.001	---	0.027
		(0.039)		(0.978)		(0.408)
Cost to Export (ln)	---	-1.769	---	3.188	---	2.659
		(0.636)		(0.199)		(0.341)
Political Stability	---	**4.287****	---	-0.549	---	**2.974****
		(0.010)		(0.394)		**(0.041)**
Thresholds						
Net Effects	na	na	na	na	0.078	na
AR(1)	(0.011)	(0.012)	(0.008)	(0.003)	(0.003)	(0.005)
AR(2)	**(0.658)**	**(0.688)**	**(0.116)**	**(0.262)**	**(0.714)**	**(0.575)**
Sargan OIR	**(0.581)**	**(0.468)**	**(0.938)**	**(0.535)**	**(0.981)**	**(0.138)**
Hansen OIR	**(0.566)**	**(0.879)**	**(0.658)**	**(0.671)**	**(0.280)**	**(0.824)**
DHT for instruments						
(a)Instruments in levels						
H excluding group	**(0.276)**	**(0.214)**	(0.098)	**(0.244)**	**(0.338)**	**(0.949)**
Dif(null, H=exogenous)	**(0.687)**	**(0.992)**	**(0.986)**	**(0.853)**	**(0.274)**	**(0.552)**
(b) IV (years, eq(diff))						
H excluding group	**(0.318)**	**(0.445)**	**(0.405)**	**(0.288)**	**(0.201)**	**(0.566)**
Dif(null, H=exogenous)	**(0.737)**	**(1.000)**	**(0.928)**	**(1.000)**	**(0.439)**	**(0.995)**
Fisher	**10.27*****	**98.95*****	**119.10*****	**1667.46*****	**112.13*****	**639.02*****

Instruments	20	36	18	34	20	36
Countries	33	33	32	32	33	33
Observations	149	147	117	116	175	172

*,**,***: significance levels of 10%, 5% and 1% 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, Hausman test and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the OIR and DHT tests. na: not applicable because at least one estimated coefficient needed for the computation of net effects is not significant. Mean of educational quality: 43.601. Mean of scientific output: 91.231. Mean of internet penetration: 4.152.

5. Concluding implications and future research directions

The study has investigated how education, scientific output and the internet complement mobile phone penetration to affect technology commodity exports in Sub-Saharan Africa for the period 2000-2012. The empirical evidence is based on Generalised Method of Moments. The following findings have been established. First, the internet complements the mobile phone to boost technology goods exports. Second, the internet also complements the mobile phone to boost technology service exports. Third, positive marginal effects are apparent in the roles of educational quality and scientific output on technology goods exports and technology service exports respectively while negative marginal impacts are apparent in the roles of scientific output and educational quality on technology goods exports and technology service exports respectively. We now discuss the practical and theoretical implications.

While we have established that the internet plays a positive complementary role in boosting technology exports, the magnitude of its complementarity can be increased if internet penetration is enhanced to the range of mobile phone penetration. For instance, based on the summary statistics, internet penetration has a range of 0.005 to 43.605 whereas mobile phone penetration has a corresponding range of 0.000 to 147.202. This is implies, leveraging on the penetration potential of the internet is likely to boost the export of technology commodities. It is important to note that compared to education and scientific output from which significant net effects have not been apparent, the internet complements the mobile phone to enhance knowledge economy. In other words, the internet is comparatively more instrumental in creating, acquiring and disseminating knowledge that is associated with technology exports. Policy can increase such internet penetration potential by dealing with issues related to inadequate infrastructure and affordability of the internet service.

The role of scientific innovation in mobile phones can be improved by adopting more policies of reverse engineering that are fundamental to the development of economies which are at the initial stage of industrialisation. This policy direction aligns with the knowledge economy literature which maintains that the processes of learning and acquiring knowledge in less developed economies are characteristically more adaptive and imitative (see Bezmen & Depken, 2004; Tchamyou, 2016). This policy recommendation builds on narratives that much of the East Asian Miracle was fundamentally achieved by copying technology commodities from more advanced nations (see Kim, 1997; Lee, 2009; Kim et al., 2012; Kim & Kim, 2014). This policy initiative is in line with African literature on measures by which scientific publications can be boosted (Asongu, 2014). Ultimately, such room for alternative property rights (see Kim et al., 2012), especially in technology intensive industries requiring huge investments (see Kim, 1997), can provide countries in the sub-region with the opportunity of leveraging on existing knowledge platforms to improve opportunities of enhancing technology export commodities. The suggested measures should be applied in conjunction with the creation of a favourable environment in order for technology industries to relocate to countries in the sub-region. Furthermore, encouraging locally-tailored scientific innovation, balancing general education with technical education and developing national schemes that promote scientific excellence at the university levels are steps in the right direction.

Whereas significant net effects are not apparent from the complementary role of educational quality, corresponding positive marginal effects (especially on technology goods exports) is an indication that enhancing education quality will potentially improve its complementary relevance on mobile phones in boosting technology goods exports. Such enhancement can be done if more funds are allocated towards adapting academic curricula to development needs from vocational and technical trainings, training of teachers and improvement of educational infrastructure. This recommendation builds on the documented evidence that education plays an essential role in the creation and diffusion of knowledge that are essential in knowledge based economies (see Dakhi & de Clereq, 2007; DunlapHinkler et al., 2010)[5].

The main theoretical contribution of this study is the role of information sharing in reducing information asymmetry that is associated with trade. Assuming the mobile phone is an information sharing mechanism, we have seen that the information sharing can effectively be associated with some knowledge creation and diffusion variables to positively affect

[5] It is also important to note that recent Africa entrepreneurship literature has established the relevance of education in entrepreneurship, notably: Mensah and Benedict (2010) on the quality of entrepreneurship training; Gerba (2012) on Ethiopian undergraduate students; Singh et al. (2011) on female entrepreneurs in Nigeria; Ita et al. (2014) on Nigerian undergraduates; Mensah and Benedict (2010) on quality entrepreneurship training and Oseifuah (2010) on youth entrepreneurship in South Africa.

exports. The essence of the mobile phone in decreasing informational rents and rendering credit markets contestable is consistent with the theoretical framework of financial intermediation efficiency (see Claus & Grimes, 2003) by means of information sharing mechanisms like public credit registries and private credit bureaus. In the light of this underlying analogy, the theoretical framework for improving the efficiency of the banking sector by means of information sharing offices is not so different from the used of mobile phones and knowledge diffusion complements to reduce information asymmetry in the manufacturing industry.

Future research can focus on investigating if the established findings withstand empirical scrutiny when investigated within the frameworks of entrepreneurship and unemployment. This is essentially because the population of Africa is projected to double by 2036 and represent more than 20% of the World's population by 2050 (UN, 2009). Accordingly, unemployment has been documented to represent a major challenge because it would not be accommodated by the public sector in the long term (see Asongu, 2013). Hence, in the light of the sustainable development agenda, assessing how the ICT penetration potential can be leveraged for inclusive development and unemployment are also steps in the right direction.

Appendices

Appendix 1: Definitions of variables

Variables	Signs	Variable Definitions (Measurement)	Sources
ICT good exports	ICTgoodexp	ICT goods exports (% of total goods exports)	World Bank (WDI)
ICT service exports	ICTservexp	ICT service exports (% of service exports, BoP)	World Bank (WDI)
Educational Quality	Educ	Pupil teacher ratio in Primary Education	World Bank (WDI)
Innovation	STJA	Scientific and Technical Journal Articles	World Bank (WDI)
Internet	Internet	Internet penetration (per 100 people)	World Bank (WDI)
Mobile phones	Mobile	Mobile phone subscriptions (per 100 people)	World Bank (WDI)
GDP growth	GDPg	Gross Domestic Product (GDP) growth (annual %)	World Bank (WDI)
Trade Openness	Trade	Exports of goods and services (% of GDP)	World Bank (WDI)
Cost of exports (ln)	Cost of exp.	Ln of Costoexport: Cost to export (US$ per container)	World Bank (WDI)
Political Stability	PolSta	"Political stability/no violence (estimate): measured as the perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional and violent means, including domestic violence and terrorism"	World Bank (WDI)

WDI: World Bank Development Indicators. Ln: logarithm.

Appendix 2: Summary statistics (2000-2012)

	Mean	SD	Minimum	Maximum	Observations
Technology goods exports	0.587	1.741	0.000005	20.944	420
Technology service exports	19.656	14.885	0.221	76.034	252
Mobile phone penetration	23.379	28.004	0.000	147.202	572
Educational Quality	43.601	14.529	12.466	100.236	444
Innovation (STJA)	91.231	360.522	0.000	2915.5	480
Internet Penetration	4.152	6.450	0.005	43.605	566
GDP growth	4.714	6.322	-47.552	63.379	608
Trade Openness	78.109	36.252	20.964	209.874	592
Cost of exports (ln)	7.374	0.503	6.137	8.683	375
Political Stability	-0.543	0.956	-3.323	1.192	578

S.D: Standard Deviation. Ln : logarithm. STJA : Scientific and Technical Journal Articles.

Appendix 3: Correlation matrix (uniform sample size: 107)

ICTgoodexp	ICTservexp	Educ	STJA	Internet	GDPg	Trade	Cost of exp	PolSta	Mobile	
1.000	-0.026	-0.196	0.009	0.169	0.017	0.399	-0.079	0.069	0.136	ICTgoodexp
	1.000	-0.108	-0.146	-0.195	-0.421	0.200	0.008	-0.073	0.101	ICTservexp
		1.000	-0.158	-0.590	0.222	-0.453	0.286	-0.253	-0.627	Educ
			1.000	0.079	-0.068	-0.144	-0.043	-0.014	0.470	STJA
				1.000	-0.024	0.384	-0.368	0.332	0.681	Internet
					1.000	-0.189	0.094	-0.039	-0.308	GDPg
						1.000	-0.231	0.337	0.361	Trade
							1.000	-0.085	-0.193	Cost of exp
								1.000	0.362	PolSta
									1.000	Mobile

ICTgoodexp: ICT goods exports. ICTservexp: ICT services export. Educ: Quality of primary education. STJA: Scientific & Technical Journal Articles. Internet: Internet penetration. GDPg: GDP growth. Trade: trade openess. Cost of exp: cost of exports. PolSta: Political Stability. Mobile: Mobile Phone penetration.

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