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RESEARCH ARTICLE

The dynamic linkage between information and communication technology, human development index, and economic growth: evidence from Asian economies

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Abstract

This study focuses on whether information and communication technology (ICT) contributes to economic growth in countries with better human development index as compared to those with a lower index. The study uses panel data estimation methods those are robust to dependencies across countries and heterogeneity from 1990 to 2016 in developing Asian countries. The results documented that countries with better human development index and mobile phone usage promote economic growth, whereas Internet users do not seem to do so. Despite that, human development index itself is a critical factor that contributes to economic growth in Asian countries. Finally, both mobile phone usages contribute to economic growth, but Internet usage does not seem to do. These new findings recommend that whereas better human development is regarded as crucial for mobile phone usage, it appears to be inappropriate for Internet usage. An additional feature is that the study uses the most robust panel data estimation method that produces more effective and reliable estimates.

Keywords Human development index · Economic growth · ICT · MG estimator · Asian economies

Introduction

Information and communication technology (ICT) has influenced economic activities, such as trade, business, education, services, entertainment, and research knowledge. ICT helps to interchange the culture, exchange information, and affects all the aspects of modern society. Also, due to the ICT sector revolution, a paradigm shift is taking place in the course of human development which refers to the process of expanding the range of choices, such as education, healthy life, and living standard (Yakunina and Bychkov 2015). ICT significantly increases per worker output, and economic growth increases in return (Kumar and Singh 2014). However, Internet usage jumped from 400 million in 2000 to 3.2 billion in 2015. However, the number of mobile users has reached about seven billion, equivalent to almost the entire world's population (ITU 2015). Consequently, humans have been deepened with greater connectivity than ever before in less than two decades (Lee et al. 2017). The advancement of ICT is aimed to improve the living standard of the populace, develop, and improve its competencies in all areas (Mishra and Nathan 2014) and advancement in ICT promote human development in turn (Asongu and Le Roux 2017). Further education plays a significant role in the diffusion of knowledge (Asongu and Nwachukwu 2018). Extending the argument, human development is responsible for uplifting the economic growth because the higher the education levels of the worker, the higher will be the production level. Accordingly, the highly educated workforce leads to more innovation and stimulates economic growth (Ogundari and Awokuse 2018).

In the last two decades, ICT and economic growth nexus have widely been discussed across different countries and various regions of the world (For more detail see Table 1). For instance, Haftu (2018) and Njoh (2018) examined the effect of ICT on economic growth in sub-Saharan Africa

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Table 1 Summary of studies on ICT-Growth nexus

Authors	Area of study	Method	Main results
Haftu (2018)	Sub-Saharan Africa	2006–2015; GMM estimator	The insignificant relationship between Internet penetration and economic growth
Donou-Adonsou (2018)	Sub-Saharan Africa	1993 to 2015; fixed-effects, GMM estimator	Internet helps to boost economic growth in countries with access to education, and mobile phone penetration does not seem to do so
Salahuddin and Gow (2016)	South Africa	1991–2013; ARDL; DOLS	A long run relationship exists between the number of Internet user and economic growth
Ghosh (2017)	15 MENA countries	2001–2014; regression	A positive and significant relationship exists between broadband penetration and economic growth
Pradhan et al. (2016)	21 Asian countries	1991–2012; panel vector autoregressive (VAR) model	Causality found between ICT and economic growth both in short and long run but varies across the region in Asia
Pradhan et al. (2015)	21 Asian countries	2001–2012; panel granger causality	The causal relationship found between ICT infrastructure and economic growth
Mohammed et al. (2017)	Sub-Saharan Africa	1990–2014; PMG and MG	The positive impact of mobile phones on income is more robust as compared to fixed telephone lines; however the latter higher in number
Farhadi et al. (2012)	159 Countries	2000–2009; GMM estimator	The impact of ICT infrastructure on economic growth is greater in high income as compared to other groups.
(Chakraborty and Nandi 2011)	Developing countries	1985–2007; Granger causality	Feedback hypothesis is observed between telecommunication infrastructure and economic growth
Latif et al. (2018)	BRICS countries	2000–2014; OLS with fixed effect; FMOLS; DOLS	Index of measure of ICT has a positive and significant impact on economic growth.
Jin and Moon (2015)	128 Countries	(1999–2012); fixed effects model	The empirical evidence is found for the effect of ICT on economic development.
Niebel (2018)	Developed, emerging and developing countries	1995–2010; pooled OLS; FE; RE	The impact of investment ICT on Growth is insignificant in developing and emerging countries.
Vu (2011)	One hundred two countries	1996–2005; GMM	ICT sector helps to improve economic growth, and the marginal effect of Internet usage is larger as compared to mobile phones usage.
Qureshi and Najjar (2017)	32 Very small island states	2009–2012; regression	The paper identifies the indirect relationship between ICT usage and Economic Growth
Pradhan et al. (2018)	G-20 countries	2001–2012; VECM	The ICT infrastructure such as fixed broadband and Internet users promote economic growth
Sassi and Goaied (2013)	MENA countries	1960 to 2009; GMM estimators	The findings reveal the effect of ICT proxies on economic growth is positive and significant
Sepehrdoust (2018)	OPEC developing countries	2002–2015; panel GMM	The ICT variables cause to boost economic growth
Vu (2013)	Singapore	1990–2008;	The contribution of the ICT sector in the economic growth of Singapore country is noticed.
Shi et al. (2017)	China	1990–2013	The u-shaped relationship is found between \ infrastructure investment and economic growth
Lam and Shiu (2010)	High income; upper middle income; lower middle income; lower income	1995–2004; GMM; panel causality tests	Bidirectional causality between ICT productivity and economic growth in the European Union and developed countries
Ishida (2014)	Japan	1980–2010; ARDL	The insignificant relationship is found between ICT development and economic growth

Table 1 (continued)

Authors	Area of study	Method	Main results
Salahuddin and Alam (2015)	Australia	1985–2012; ARDL	The insignificant relationship is found between Internet usage and economic growth
Ward and Zheng (2016)	31 Provinces of China	1991 to 2010; OLS estimates with two-way fixed effects; SYS-GMM estimates	The uses of mobile phone contribute to economic growth, but this effect diminishes with the development of the provincial economy

ARDL auto regressive distributive lag model; *DOLS* dynamic least square model; *FMOLS* fully modified least square model; *RE* random effect model; *FE* Fixed effect model; *GMM* generalized method of moments; *VECM* vector error correction model; *PMG* pooled mean group; *MG* mean group; *VAR* vector autoregressive model; *ICT* information and telecommunications technologies

countries; Ford (2018) in US counties; Donou-Adonsou (2018) investigated ICT, education, and economic growth in African countries; Salahuddin and Gow (2016) in South Africa; Ravinesh et al. (2015) in small Pacific Island States; Pradhan et al. (2014) in G-20 countries; Salahuddin and Alam (2016) in OECD countries; Kumar (2014) in Vietnam; and Pradhan et al. (2015, 2016) probed ICT, financial development, and economic growth in Asian countries. Apart from it, Mohammed et al. (2017) found a linear and non-linear relationship between ICT and economic growth in sub-Saharan African (SSA) region. Despite that, several potential variables are included in the nexus between ICT and economic growth, for example, financial development (Pradhan et al. 2015, 2016), education (Donou-Adonsou 2018), foreign direct investment and FDI (Latif et al. 2018), and research and development (R&D) expenditure (Shi et al. 2017). However, methodology and data related to cross-sectional dependence, heterogeneity, and serial correlation prevent to conclude the findings in earlier studies. Apart from this, none of the studies in the literature has considered the effect of ICT on economic growth in developing Asian countries. Also, whether in Asia or around the world, previous studies did not consider the effect of the interaction between ICT and human development index on economic growth. Considering this could be significant; the Internet and mobile usage may improve with human development, which in turn contributes to economic growth. Put differently, this study extended the already existing knowledge to consider this possibility of examining the role of ICT and human development in economic growth. Therefore, the current study focuses on the investigation of the dynamic linkage between information and communication technology, human development index, and economic growth in developing Asian countries. It would help policymaker to understand better the role of ICT and human development index in economic growth for developing Asian countries.

The selection of developing Asian countries can be justified in several ways. First, the rapid advancement in the ICT sector contributes to economic growth through human development, both in developing and developed countries. In the late 1990s, the Asian economies have liberalized their policies in the telecom sector. With these arrangements, the respective countries received investments by providing voice transmission facilities all over the region. The development in ICT sector influences the norm and the living standards of the people, reduces distances, fastens the business and commercial dealings, provides investment opportunities, and opens new jobs. Due to the liberalization, the mobile phone users have rapidly increased, developed the ICT infrastructure, and received huge investment that strengthens the economy. Second, the current situation of economy and human development in Asian countries is vulnerable. Since the 2000s, the Asian economies have experienced faster economic growth. Nevertheless, the accomplished economic growth neither is sufficient nor faces several challenges within the region. Third, most of the populace in the developing countries particularly in developing Asian countries live below or just above the poverty line (Mohammed and Sulong 2017), although the high rate of economic growth and the trend of ICT development have increased rapidly across Asian countries. It needs not to be emphasized that Asian countries are not poor in its resources, but poor and improper utilization of human resources has made it so. Thereby, the situation of economic growth in developing Asian countries is still worse, which needs to be controlled. Besides, the role of ICT and human development in economic growth in Asian countries is ignored.

This report is unique in presenting the relationship between ICT, economic growth, and human development index. First, this focuses on exploring the significant role of ICT and human development in economic growth in developing Asian economies, since till now, none of the studies refer to the role of human development and ICT in economic growth in the developing Asian countries. Second, more precisely, the study inspects whether enhancing ICT measured by the Internet and mobile phone users promotes economic growth in countries with better human development index. Third, we use the longest available dataset (1990–2016). Finally, the study uses

Table 2 The variables name, description, data source, and descriptive statistics

Variables	Descriptions	Obs.	Mean	St. dev.	Source
Economic growth	GDP per capita (Constant 2010 USD)	135	2.9416	0.2506	WDI
Internet	Internet use penetration (users per 100 people). It refers to people those who use the Internet via a computer, mobile phone, personal digital assistant, games machine, or digital TV in the last 12 months (Donou-Adonsou 2018).	135	0.20602	1.3067	WDI
Mobile	Mobile penetration (users per 100 people). This means that put differently, individuals those subscribe for mobile phones utilize the Internet for video calls, doing research, looking at the map, just to mention a few (Donou-Adonsou 2018).	135	0.3297	1.4204	WDI
Human development index	The index, of life expectancy, education and living slandered of people (Wang et al. 2018a)	135	0.5324	0.1035	Human development report
Trade openness	It is the sum of export (% of GDP) and import (% of GDP)	135	− 0.3130	0.6283	WDI
Foreign direct investment	Inflow (% of GDP)	135	1.6071	0.1683	WDI

Driscoll-Kraay standard error, mean group (MG) fully modified ordinary least square (FMOLS), and dynamic ordinary least square (MG-DOLS) panel data regression techniques, which produce more robust estimates.

The remaining study is divided into different sections, as next section is about "Data, model specification, and methods" explains the methodology and data source. Further, "Empirical results and discussion" describes the results and discussion. Finally, "Conclusion" concludes the study.

Data, model specification, and methods

Data

In this study, we used panel data for sample of selected 29 developing Asian countries for a time spanning from 1990 to 2016; the choice of this period is justified by the data available for these selected 29 Asian economies. Economic growth is measured through GDP per capita constant 2010 US dollar (Danish et al. 2017, 2018c; Xu et al. 2018). ICT is measured through mobile phone and Internet penetration. Hence, the Internet penetration rate (per 100 people) and the mobile phone penetration rate (per 100 people) are used as ICT related variables. The selection and measurement of ICT variables are based on recent literature (Asongu et al. 2017; Danish et al. 2018a; Park et al. 2018; Asongu and Odhiambo 2019). Human development refers to three principal dimensions, notably health, level of education, and living standard (Wang et al. 2018a). Moreover, ICT × HDI is the interaction between information and technology and human development index. TR is the trade rations the sum of export (% of GDP) and import (% of GDP) (Baloch et al. 2018). Finally, FDI is inflow % of GDP. Table 2 shows the variable description and summary statistic.

Model Specification

The study extended the relationship between ICT and economic growth by including the human development index and the interaction between the human development index and ICT, which can be expressed as follows:

$$\begin{aligned} &\mathrm{LOGGDP}_{it} \\ &= \alpha_0 + \alpha_1(\mathrm{ICT})_{it} + \alpha_2(\mathrm{HDI})_{it} + \alpha_3(\mathrm{ICT}\times\mathrm{HDI})_{it} + \alpha_4(\mathrm{TR})_{it} + \\ &\qquad \alpha_5(\mathrm{FDI})_{it} + \mu_{it} \end{aligned} \quad (1)$$

where GDP per capita refers to gross domestic, $i = 1, 2, \ldots, N$ refers to a number of countries, and $t = 1, 2, \ldots, T$ is time used in the study. ICT indicates for information and communication technology. We have used mobile and Internet penetration (per 100 people) for measuring ICT. Finally, TR refers to trade ration, and FDI mean foreign direct investment. Finally u is error term.

The human development index (HDI) is a broad index, which shows the level of human development made by a country in different sectors, like health, life expectancy, education, and income per capita (Hopkins 1991). The HDI shows that human development index based on a combination of three indicators such as life expectancy, education, and living standard used to rank countries into four tiers of human development (Khan et al. 2018). The HDI varies from country to country and so makes the productivity differences across countries. According to Martin et al. (2013), growth and advancement are different balanced conditions in technological change, although Qiu et al. (2018) concluded that long-term concept of production process depends on human capital (i.e. education) and technological advancement (Lee et al. 2017; Biggeri and Mauro 2018). The country's HDI is

considered higher with the higher survival birth rate, with a longer period of education and higher income per capita (Chikalipah and Makina 2019).

Econometric methodology

Driscoll-Kraay (DK) standard error regression approach

This study employs Driscoll-Kraay (DK) standard error approach suggested by Driscoll and Kraay (1998) since estimators obtained from DK model allow dependencies across countries. Moreover, DK standard error technique is recommended in case the model is autocorrelated, heteroscedastic, and cross-sectional dependent (Hoechle 2007). This method consists of a non-parametric approach based on the large time dimension and free from any restriction, due to its characteristics being robust against cross-sectional dependence as it takes averages of the multiplication of independent variables and residuals and using the obtained values from the calculation in a weighted HAC estimator to generate standard errors (Jalil 2014). The DK regression method counters heteroscedasticity, spatial, and serial dependency in the data (Ozokcu 2017; Sarkodie and Strezov 2019). This non-parametric regression algorithm is flexible without any assumption and more effective in the case of the large time dimension. Also, Driscoll-Kraay covariance method can give parameter estimates both in balanced and unbalance panel data and more effective if missing values present in the data (Baloch et al. 2019b). Due to abovementioned characteristics, the DK regression selection is a better choice for pooled ordinary least squares (OLS) estimation by considering a linear model.

MG-FMOLS and MG-DOLS

Since the study was based on panel data for selected 29 Asian developing countries, the possibility of heterogeneity cannot be ignored. Keeping this in view, together with DK regression method, this study also used MG-FMOLS and MG-DOLS; those are capable of countering heterogeneity, and serial correlation is present in the data (Danish et al. 2019b). This study preferred to FMOLS and DOLS panel data estimation methods due to some of their characteristics. Both FMOLS and DOLS help to get rid of the issue of endogeneity among regressor and autocorrelation in the error terms. The FMOLS uses a non-parametric approach for the elimination of endogeneity and serial correlation, whereas DOLS get rid of these difficulties through a parametric approach and lags and leads of the explanatory variables. DOLS is most effective to accommodate serious panel data problems such as endogeneity among regressors and autocorrelation using parametric approach and lags and leads. Further, DOLS is considered the most effective and give a reliable estimate in the case of small samples. Most importantly, the DOLS is best in handling CD and heterogeneity (Dogan and Seker 2016).

Empirical results and discussion

Cross-sectional dependence and panel unit root test

Recently, the investigation of panel unit root test becomes important in economic literature; it is due to the reason that existence of dependencies across countries produces unreliable and inconsistent estimates (Baloch et al. 2019a; Danish et al. 2019a). To this end, in line with recent literature (Danish and Wang 2019a), the study prefers cross-sectional dependence (CD) test proposed by Pesaran (2004). The results of the CD test are illustrated in Table 2, and from the result, it can be inferred that the null hypothesis of no cross-sectional dependence is rejected. In other words, there exist cross-sectional dependence and shock in one country; its spillover effect can be seen in other sample countries.

Recalling CD issue, so the second-generation panel unit root test would be a better choice as it is more effective and produces unbiased results (Wang et al. 2018b; Danish and Wang 2018). Based on the CD result, we have chosen the CIPS panel unit root proposed by Pesaran (2007). This panel unit root test is considered best if the CD exists in the data and frequently used in the literature. The CIPS is computed from cross-sectional ADF (CADF). The CIPS results are presented at the bottom of Table 3 recommending that the series is not stationary at level but first difference and rejecting null hypothesis at 1% significance level.

The results of the regression with Driscoll-Kraay standard errors and MG-FMOLS and MG-DOLS models are summarized in Table 4. The results reported in Table 4 can be categorized into two groups. We have applied DK regression, MG-FMOLS, and MG-DOLS to estimate the model with Internet usage (see columns 1, 3, and 5) and then applied the three methods to estimate the model with mobile phone usage (see columns 2, 4, and 6).

The result reported in Table 2 showed insignificant relationships exist between Internet usage and economic growth in case of all the three methods. Also, the impact of interaction between the Internet and human development on economic growth is insignificant (refer to columns 1, 3, and 5). For both Internet and interaction between the Internet and human development index, the results display that the Internet does not contribute to economic growth in countries with better human development. This could be attributed to weak Internet infrastructure in developing Asian countries; there is limited access to the Internet, which in turn is not beneficial for economic growth. The insignificant effect of Internet usage could be attributed with low penetration of the technology, insufficient skill of Internet users, inadequate or lack of local content on

Table 3 Cross-sectional dependence and CIPS panel unit root results

	Ln GDP	Ln HDI	Ln FDI	Ln TR	Ln Internet	Ln (Internet × HDI)	Ln mobile	Ln (mobile*HDI)
CD test	54.89* [0.000]	84.36* [0.000]	12.70* [0.000]	6.11* [0.000]	49.47* [0.000]	55.71*[0.000]	82.28* [0.000]	80.45* [0.000]
Panel unit root tests								
CIPS at level	− 1.830	− 2.067	− 3.300	− 2.128	− 1.594	− 1.489	− 0.901	− 1.214
CIPS at first difference	− 3.764*	− 3.770*	− 5.532*	− 4.505*	− 3.410*	− 3.375*	− 3.805*	− 3.744*

For more detail on the critical value of CIPS test, refer to Pesaran (2007)

Internet × *HDI* interaction between Internet usage and human development index; *Mobile* × *HDI* interaction between mobile phone usage and human development index

*Rejection level of the null hypothesis at 1%

the global network, and the comparatively immature state of the technology in study's sample countries. The result corresponds to Salahuddin and Alam (2015). For the role of ICT in economic growth, the results are consistent with Ravinesh et al. (2016).

Furthermore, the impact of mobile usage has positive and significant impact on economic growth (see columns 2, 4, and 6) in developing Asia countries and recommends that mobile phone usage contributes to economic growth. Also, the interaction between mobile phone usage and human development has a positive and significant effect on economic growth. In other words, with better human development, the mobile phone does contribute to economic growth. The selected developing Asian economies are now going uplift with rapid and successful diffusion of ICT. Mobile phones usage improves human development by offering advancement to society. It may facilitate health treatment practices, whereas a healthy society can change the economic structure of the country. This finding of the study is in line with Pradhan et al. (2015) who found that ICT accelerates human development, which further accelerates economic growth. Further similar result is found by Anthony Ilegbinosa et al. (2015), who argued that a productive utilization of ICT infrastructure reduces production cost and enlarge the choice of buying by expanding the market scope. Furthermore, prior studies like Latif et al. (2018) confirmed the positive relationship between mobile phone use and economic growth for developing and developed countries and Nath and Liu (2017), who stated that ICT positively influences the emerging economies.

Furthermore, Table 2 presents that human development has a positive and significant impact on economic growth in all the three models used in this study. Human development is a combination of better health, education, and living standard of people. It is attributed to that human development enables society to access a modern way of education and receive awareness about healthy living. The healthy and educated

Table 4 DK regression, MG-FMOLS, and MG-DOLS results

	MG-FMOLS		MG-DOLS		DK regression	
Variables	(1) Internet use Coefficient [prob]	(2) Mobile phone Coefficient [prob]	(3) Internet use Coefficient [prob]	(4) Mobile phone Coefficient [prob]	(5) Internet use Coefficient [prob]	(6) Mobile phone Coefficient [prob]
HDI	169.4* [0.000]	− 60.06* [0.000]	15.16* [0.000]	2.114* [0.000]	19.60** [0.019]	8.394** [0.015]
FDI	2.855* [0.000]	− 0.836* [0.000]	− 3.852* [0.000]	0.095* [0.000]	1.407* [0.000]	− 0.779* [0.003]
TR	4.575* [0.000]	4.037* [0.007]	38.87* [0.000]	− 0.595* [0.000]	0.907* [0.000]	0.469* [0.000]
Internet	0.254 [0.998]	–	− 1.354 [0.127]	–	1.791 [0.229]	–
Internet × HDI	2.436 [0.462]	–	− 1.866 [0.702]	–	1.37 [0.162]	–
Mobile	–	2.452* [0.000]	–	− 0.495* [0.000]	–	15.76* [0.000]
Mobile × HDI	–	− 0.589* [0.000]	–	0.493* [0.000]	–	14.70* [0.000]
F-statistic						
N	755	755	755	755	755	755
Groups	29	29	29	29	29	29

RMSE root mean square error

*1%; **5% significance levels

society recognized as human capital, whereas human capital is the primary driver of economic growth. For the effect of control variables, both FDI and trade have a significant and positive impact on economic growth, implying that FDI and trade both are contributing to economic growth.

To summarize, the interaction between mobile usage and human development promote economic growth, contrary to this interaction between Internet usage and human development, does not have an impact on economic growth. This refers to the crucial role of human development for mobile users to foster economic growth. Human development, thus, seems a priori irrelevant for Internet usage. Because the developing Asian economies have experienced a rapid increase in mobile phone and mobile cellular companies' infrastructure, the use of the smartphone has been observed in the last decade. Moreover, developing Asian economics populace with low purchasing power has limited access to smartphones and the Internet due to higher prices of smartphones. Also, most of the population in these countries living in rural areas due to other social problems, they have no awareness of the Internet and smartphone. Besides, people using a mobile phone are only interested in using mobile for voice calls that can be fulfilled by a simple GSM phone. Those few people who are using a smartphone, they use the Internet mainly for surfing, chatting, and other social websites like Facebook for entertainment purposes. These are the reasons that mobile phone users contribute positively to economic growth as compared to Internet users. However, due to large mobile usage, this brings investment in cellular companies that are highly contributing to the Asian countries. Spontaneously, people are not literate more to the Internet use directly via a computer, mobile phone, personal digital assistant, games machine, or digital TV, which seems to be the case in developing Asian countries.

Conclusion

This study examines whether human development influences the relationship between ICT and economic growth in Asian economies. ICT is measured through the Internet and mobile phones usage. For empirical estimation, the study uses the Driscoll-Kraay standard error, MG-FMOLS, and MG-DOLS. The results summarized that countries with better human development index, the mobile phone uses promote economic growth, although Internet use does not seem to do so. These results suggest that higher human development index is crucial for the mobile phone to promote economic growth; however, it looks inappropriate for Internet usage.

Based on the key findings, important policy recommendations are suggested. The governments should take the initiative to encourage foreign and local investor for the expansion of the Internet. The populace in the study's sample countries uses mobile phones to talk or just redundant things such as Facebook and WhatsApp. Awareness should be given to the people regarding the use of Internet through mobile usage for business, marketing, advertisement, and online shopping; few are listed here. Moreover, these measures would motivate investors to strengthen the standard of ICT tools, particularly data tools. Apart from it, human development would be helpful to promote economic growth. However, the current situation of human development needs improvement for its further contribution to economic growth. The government needs to allocate more budgets to education and health sector that would increase the life expectancy and living standard of the people, which, in turn, make it able the populace to contribute more to economic growth.

The study can be further extended by considering the role of interaction of ICT and human development for environmental sustainability because development in ICT penetration may or may not contribute to environmental sustainability (Asongu et al. 2018) and technology transfer in shape of FDI and trade worsen environmental quality (Danish et al. 2018b). Future studies can build to assess a similar model within country-specific settings and homogenous groups (e.g., income levels and legal origins). This would be necessary for more targeted policy implications.

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Nomenclature ICT, information and communication technology; SSA, sub-Saharan African; R&D, research and development; MG, mean group; FMOLS, fully modified ordinary least square; DOLS, dynamic ordinary least square; GMM, generalized method of moment; ARDL, autoregressive distributive lag; VAR, vector autoregressive; PMG, pooled mean group; FE, fixed effect; RE, random effect; OLS, ordinary least square; GDP, gross domestic product; HDI, human development index; DK, Driscoll-Kraay; CD, cross-sectional dependence

References

Anthony Ilegbinosa I, Micheal A, Ipalibo Watson S (2015) Domestic investment and economic growth in Nigeria from 1970-2013: an econometric analysis. Can Soc Sci 11:70–79. https://doi.org/10.3968/7009

Asongu SA, Le Roux S (2017) Enhancing ICT for inclusive human development in sub-Saharan Africa. Technol Forecast Soc Change 118:44–54. https://doi.org/10.1016/j.techfore.2017.01.026

Asongu SA, Nwachukwu JC (2018) Educational quality thresholds in the diffusion of knowledge with mobile phones for inclusive human development in sub-Saharan Africa. Technol Forecast Soc Change 129:164–172. https://doi.org/10.1016/j.techfore.2018.01.004

Asongu SA, Odhiambo NM (2019) Environmental degradation and inclusive human development in sub-Saharan Africa. Sustain Dev 27: 25–34. https://doi.org/10.1002/sd.1858

Asongu SA, Le Roux S, Biekpe N (2017) Environmental degradation, ICT and inclusive development in sub-Saharan Africa. Energy Policy 111:353–361. https://doi.org/10.1016/j.enpol.2017.09.049

Asongu SA, Le Roux S, Biekpe N (2018) Enhancing ICT for environmental sustainability in sub-Saharan Africa. Technol Forecast Soc Change 127: 209–216. https://doi.org/10.1016/j.techfore.2017.09.022

Baloch MA, Danish MF et al (2018) Financial instability and CO2 emissions: the case of Saudi Arabia. Environ Sci Pollut Res 25:26030–26045. https://doi.org/10.1007/s11356-018-2654-2

Baloch MA, Danish, Meng F (2019a) Modeling the non-linear relationship between financial development and energy consumption: statistical experience from OECD countries. Environ Sci Pollut Res 26: 8838–8846. https://doi.org/10.1007/s11356-019-04317-9

Baloch MA, Zhang J, Iqbal K, Iqbal Z (2019b) The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. Environ Sci Pollut Res 26:6199–6208. https://doi.org/10.1007/s11356-018-3992-9

Biggeri M, Mauro V (2018) Towards a more 'sustainable' human development index: integrating the environment and freedom. Ecol Indic 91:220–231. https://doi.org/10.1016/j.ecolind.2018.03.045

Chakraborty C, Nandi B (2011) 'Mainline' telecommunications infrastructure , levels of development and economic growth: evidence from a panel of developing countries. Telecommun Policy 35:441–449. https://doi.org/10.1016/j.telpol.2011.03.004

Chikalipah S, Makina D (2019) Economic growth and human development: evidence from Zambia. Sustain Dev sd 1953. https://doi.org/10.1002/sd.1953

Danish, Wang Z (2018) Dynamic relationship between tourism, economic growth, and environmental quality. J Sustain Tour 26:1928–1943. https://doi.org/10.1080/09669582.2018.1526293

Danish, Wang Z (2019a) Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. Sci Total Environ 670. https://doi.org/10.1016/j.scitotenv.2019.03.268

Danish, Wang Z (2019b) Investigation of the ecological footprint's driving factors: What we learn from the experience of emerging economies. Sustain Cities Soc 49:101626. https://doi.org/10.1016/j.scs.2019.101626

Danish, Zhang B, Wang B, Wang Z (2017) Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. J Clean Prod 156:855–864. https://doi.org/10.1016/j.jclepro.2017.03.203

Danish, Khan N, Baloch MA et al (2018a) The effect of ICT on CO2emissions in emerging economies: does the level of income matters? Environ Sci Pollut Res 25:22850–22860. https://doi.org/10.1007/s11356-018-2379-2

Danish, Wang B, Wang Z (2018b) Imported technology and CO 2 emission in China: collecting evidence through bound testing and VECM approach. Renew Sust Energ Rev 82:4204–4214. https://doi.org/10.1016/j.rser.2017.11.002

Danish, Zhang B, Wang Z, Wang B (2018c) Energy production, economic growth, and CO2emission: evidence from Pakistan. Nat Hazards 90:27–50. https://doi.org/10.1007/s11069-017-3031-z

Danish, Baloch MA, Mahmood N, Zhang JW (2019a) Effect of natural resources, renewable energy and economic development on CO2 emissions in BRICS countries. Sci Total Environ 678:632–638. https://doi.org/10.1016/j.scitotenv.2019.05.028

Danish, Hassan ST, Iqbal K, Zhang JW (2019b) Toward achieving environmental sustainability target in Organization for Economic Cooperation and Development countries: The role of real income, research and development, and transport infrastructure. Sustain Dev 1–8. https://doi.org/10.1002/sd.1973

Dogan E, Seker F (2016) Determinants of CO2emissions in the European Union: the role of renewable and non-renewable energy. Renew Energy 94:429–439. https://doi.org/10.1016/j.renene.2016.03.078

Donou-Adonsou F (2018) Technology, education, and economic growth in sub-Saharan Africa. Telecommun Policy 43:0–1. https://doi.org/10.1016/j.telpol.2018.08.005

Driscoll JC, Kraay AC (1998) Consistent covariance matrix estimation with spatially dependent panel data. Rev Econ Stat 80:549–560. https://doi.org/10.1162/003465398557825

Farhadi M, Ismail R, Fooladi M (2012) Information and communication technology use and economic growth. PLoS One 7:e48903. https://doi.org/10.1371/journal.pone.0048903

Ford GS (2018) Is faster better? Quantifying the relationship between broadband speed and economic growth. Telecommun Policy 42: 766–777. https://doi.org/10.1016/j.telpol.2018.05.006

Ghosh S (2017) Broadband penetration and economic growth: do policies. Telemat Informatics 34:676–693. https://doi.org/10.1016/j.tele.2016.12.007

Haftu GG (2018) Information communications technology and economic growth in sub-Saharan Africa: a panel data approach. Telecommun Policy 43:1–13. https://doi.org/10.1016/j.telpol.2018.03.010

Hoechle D (2007) Robust standard errors for panel regressions with cross-sectional dependence. Stata J Promot Commun Stat Stata 7: 281–312. https://doi.org/10.1177/1536867X0700700301

Hopkins M (1991) Human development revisited: a new UNDP report. World Dev 19:1469–1473. https://doi.org/10.1016/0305-750X(91)90089-Z

Ishida H (2014) The effect of ICT development on economic growth and energy consumption in Japan. Telemat Informatics 32:79–88. https://doi.org/10.1016/j.tele.2014.04.003

ITU (2015) Global cybersecurity & cyberwelness profiles. https://www.itu.int/dms_pub/itu-d/opb/str/D-STR-SECU-2015-PDF-E.pdf

Jalil A (2014) Energy-growth conundrum in energy exporting and importing countries: evidence from heterogeneous panel methods robust to cross-sectional dependence. Energy Econ 44:314–324. https://doi.org/10.1016/j.eneco.2014.04.015

Jin S, Moon C (2015) Is ICT a new essential for national economic growth in an information society? Gov Inf Q 32:253–260. https://doi.org/10.1016/j.giq.2015.04.007

Khan NH, Ju Y, Hassan ST (2018) Modeling the impact of economic growth and terrorism on the human development index: collecting evidence from Pakistan. Environ Sci Pollut Res 25:34661–34673

Kumar RR (2014) Exploring the role of technology, tourism and financial development: an empirical study of Vietnam. 2881–2898. https://doi.org/10.1007/s11135-013-9930-5

Kumar RR, Singh M (2014) Role of health expenditure and ICT in a small island economy: a study of Fiji. Qual Quant 48:2295–2311. https://doi.org/10.1007/s11135-013-9892-7

Lam PL, Shiu A (2010) Economic growth, telecommunications development and productivity growth of the telecommunications sector: evidence around the world. Telecommun Policy 34:185–199. https://doi.org/10.1016/j.telpol.2009.12.001

Latif Z, Mengke Y, Danish et al (2018) The dynamics of ICT, foreign direct investment, globalization and economic growth: panel estimation robust to heterogeneity and cross-sectional dependence. Telemat Informatics 35:318–328. https://doi.org/10.1016/j.tele.2017.12.006

Lee SO, Hong A, Hwang J (2017) ICT diffusion as a determinant of human progress. Inf Technol Dev 23:687–705. https://doi.org/10.1080/02681102.2017.1383874

Martin FM, Ciovica L, Cristescu MP (2013) Implication of human capital in the development of SMEs through the ICT adoption. Procedia Econ Financ 6:748–753. https://doi.org/10.1016/S2212-5671(13)00198-6

Masoud MA, Zunaidah S (2017) The linear and non-linear impacts of ICT on economic growth, of disaggregate income groups within

SSA region. Telecommun Policy 41(7–8):555–572. https://doi.org/10.1016/j.telpol.2017.07.007

Mishra S, Nathan HSK (2014) Measuring HDI–The Old, the New and the Elegant: Implications for multidimensional development and social inclusiveness, Working Paper. https://doi.org/10.1007/s13398-014-0173-7.2

Mohammed M, Sulong Z, Albiman MM, Sulong Z (2017) The linear and non-linear impacts of ICT on economic growth, of disaggregate income groups within SSA region. Telecommun Policy 41:555–572. https://doi.org/10.1016/j.telpol.2017.07.007

Nath HK, Liu L (2017) Information and communications technology (ICT) and services trade. Inf Econ Policy 41:81–87. https://doi.org/10.1016/j.infoecopol.2017.06.003

Niebel T (2018) ICT and economic growth – comparing developing, emerging and developed countries. World Dev 104:197–211. https://doi.org/10.1016/j.worlddev.2017.11.024

Njoh AJ (2018) The relationship between modern information and communications technologies (ICTs) and development in Africa. Util Policy 50:83–90. https://doi.org/10.1016/j.jup.2017.10.005

Ogundari K, Awokuse T (2018) Human capital contribution to economic growth in sub-Saharan Africa: does health status matter more than education? Econ Anal Policy 58:131–140. https://doi.org/10.1016/j.eap.2018.02.001

Ozokcu SOO (2017) Regression with Driscoll-Kraay standard errors.pdf. Renew Sust Energ Rev 72:639–647 www.elsevier.com/locate/rser

Park Y, Meng F, Baloch MA (2018) The effect of ICT, financial development, growth, and trade openness on CO2 emissions: an empirical analysis. Environ Sci Pollut Res 25:30708–30719. https://doi.org/10.1007/s11356-018-3108-6

Pesaran MH (2004) General Diagnostic Tests for Cross Section Dependence in Panels General Diagnostic Tests for Cross Section Dependence in Panels. Univ. Cambridge. https://www.repository.cam.ac.uk/bitstream/handle/1810/446/cwpe0435.pdf?sequence=1&isAllowed=y

Pesaran MH (2007) Intertemporal consumption choices, transaction costs and limited participation to financial markets: reconciling data and theory. J Appl Econ 343:322–343. https://doi.org/10.1002/jae

Pradhan RP, Arvin MB, Norman NR, Bele SK (2014) Economic growth and the development of telecommunications infrastructure in the G-20 countries: a panel-VAR approach. Telecommun Policy 38:634–649. https://doi.org/10.1016/j.telpol.2014.03.001

Pradhan RP, Arvin MB, Norman NR (2015) The dynamics of information and communications technologies infrastructure, economic growth, and financial development: evidence from Asian countries. Technol Soc 42:135–149. https://doi.org/10.1016/j.techsoc.2015.04.002

Pradhan RP, Arvin MB, Hall JH (2016) Economic growth, development of telecommunications infrastructure, and financial development in Asia, 1991-2012. Q Rev Econ Financ 59:25–38. https://doi.org/10.1016/j.qref.2015.06.008

Pradhan RP, Mallik G, Bagchi TP (2018) Information communication technology (ICT) infrastructure and economic growth: a causality evinced by cross-country panel data. IIMB Manag Rev 30:91–31. https://doi.org/10.1016/j.iimb.2018.01.001

Qiu Q, Sung J, Davis W, Tchernis R (2018) Using spatial factor analysis to measure human development. J Dev Econ 132:130–149. https://doi.org/10.1016/j.jdeveco.2017.12.007

Qureshi S, Najjar L (2017) Information and communications technology use and income growth: evidence of the multiplier effect in very small island states. Inf Technol Dev 23:212–234. https://doi.org/10.1080/02681102.2016.1173634

Ravinesh R, Devi R, Patel A (2015) Accounting for telecommunications contribution to economic growth: a study of Small Pacific Island States. Telecommun Policy 39:284–295. https://doi.org/10.1016/j.telpol.2014.08.005

Ravinesh R, Josef P, Samitas A (2016) The effects of ICT n on output per worker: a study of the Chinese economy. Telecommun Policy 40:102–115. https://doi.org/10.1016/j.telpol.2015.06.004

Salahuddin M, Alam K (2015) Internet usage, electricity consumption and economic growth in Australia: a time series evidence. Telemat Informatics 32:862–878. https://doi.org/10.1016/j.tele.2015.04.011

Salahuddin M, Alam K (2016) Information and communication technology, electricity consumption and economic growth in OECD countries: a panel data analysis. Int J Electr Power Energy Syst 76:185–193. https://doi.org/10.1016/j.ijepes.2015.11.005

Salahuddin M, Gow J (2016) The effects of Internet usage, financial development and trade openness on economic growth in South Africa: a time series analysis. Telemat Informatics 33:1141–1154. https://doi.org/10.1016/j.tele.2015.11.006

Sarkodie SA, Strezov V (2019) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871. https://doi.org/10.1016/j.scitotenv.2018.07.365

Sassi S, Goaied M (2013) Financial development, ICT diffusion and economic growth: lessons from MENA region. Telecommun Policy 37:252–261. https://doi.org/10.1016/j.telpol.2012.12.004

Sepehrdoust H (2018) Impact of information and communication technology and financial development on economic growth of OPEC developing economies. Kasetsart J Soc Sci:6–11. https://doi.org/10.1016/j.kjss.2018.01.008

Shi Y, Guo S, Sun P (2017) The role of infrastructure in China's regional economic growth. J Asian Econ 49:26–41. https://doi.org/10.1016/j.asieco.2017.02.004

Vu KM (2011) ICT as a source of economic growth in the information age: empirical evidence from the 19962005 period. Telecommun Policy 35:357–372. https://doi.org/10.1016/j.telpol.2011.02.008

Vu KM (2013) Information and communication technology (ICT) and Singapore's economic growth. Inf Econ Policy 25:284–300. https://doi.org/10.1016/j.infoecopol.2013.08.002

Wang Z, Danish, Zhang B, Wang B (2018a) Renewable energy consumption, economic growth and human development index in Pakistan: evidence form simultaneous equation model. J Clean Prod 184:1081–1090. https://doi.org/10.1016/j.jclepro.2018.02.260

Wang Z, Danish, Zhang B, Wang B (2018b) The moderating role of corruption between economic growth and CO2 emissions: evidence from BRICS economies. Energy 148:506–513. https://doi.org/10.1016/j.energy.2018.01.167

Ward MR, Zheng S (2016) Mobile telecommunications service and economic growth: evidence from China. Telecommun Policy 40:89–101. https://doi.org/10.1016/j.telpol.2015.06.005

Xu Z, Baloch MA, Danish et al (2018) Nexus between financial development and CO2emissions in Saudi Arabia: analyzing the role of globalization. Environ Sci Pollut Res 25:28378–28390. https://doi.org/10.1007/s11356-018-2876-3

Yakunina RP, Bychkov GA (2015) Correlation analysis of the components of the human development index across countries. Procedia Econ Financ 24:766–771. https://doi.org/10.1016/S2212-5671(15)00692-9