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ICT Leapfrogging and Economic Growth Among SAARC Economies: Evidence From Method of Moments Quantile Regression

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ABSTRACT

ICT "leapfrogging" is when developing economies adopt the use of technology to jump-start their development agenda. This study positions the 2030 United Nations Sustainable Development Goal 8 to test the leapfrogging hypothesis on eight SAARC economies (Afghanistan, Bhutan, Bangladesh, India, Maldives, Nepal, Pakistan, and Sri Lanka) from 2000 to 2020. We examine if the hypothesis holds using an unbalanced panel data on real per capita GDP and four ICT indicators (mobile phones, fixed telephones, fixed broadband, and Internet users). We deploy panel spatial correlation consistent (PSCC) and method of moments quantile regression (MM-QR) techniques. The MM-QR offers more reliable results than PSCC because it takes into account the conditional heterogeneity issues that are understated. The general consensus indicates that ICT (individual indicators and composite index) exerts a statistically significant positive effect on economic growth mostly at the 1% level. However, the MM-QR reveals that: (1) the leapfrogging hypothesis holds for mobile phones and composite index models; (2) the hypothesis holds only at the lower quantiles of fixed broadband model; and (3) mobile phones show the largest increasing leapfrogging effect of 0.034%, 0.052%, 0.082%, and 0.099%, respectively. Policy recommendations are discussed.

KEYWORDS

ICT; economic growth; leapfrog; SAARC

Introduction

Information and communication technology (ICT) is an integral part of development strategies for developing and developed countries. Recent developments in ICT have introduced a plethora of opportunities for development in every conceivable area because of the potentials to spur economic growth and the development of rural/urban markets. ICT as development-enabler has broken all bounds of cost, distance and time. It is latent to achieving desired social transformations by enhancing access to people, services, information and other technologies (Adegboye et al., 2022; Fong, 2009; Okafor, Adeleye, & Adusei, 2021; Papaioannou & Dimelis, 2007; Steinmueller, 2001; Stiroh, 2002; Third & Kao, 2007). The uneven pace of socio-economic development across Asia spurs the motivation to investigate factors that may have contributed to such huge disparities. Compared to Central, South and Western Asia, East Asian economies show more remarkable progress. However, within its sub-region, countries like China, Singapore, and South Korea display superior advancement, which may be connected to their abilities to harness the gains from ICT. In contrast, most South Asian

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countries lag behind which brings to our research question: *can South Asian Association for Regional Cooperation (SAARC) economies (Iran excluded) catch-up to more developed economies by leapfrogging traditional expensive developmental stages of ICT in order to stay competitive?"*

The concept of technology "leapfrogging" remains controversial and has been used in different context. For instance, Steinmueller (2001, p. 194) explained it as "bypassing some of the processes of accumulation of human capabilities and fixed investment in order to narrow the gaps in productivity and output that separate industrialized and developing countries." On the other hand, technology leapfrogging is defined as the "adoption of advanced or state-of-the-art technology in an application area where immediate prior technology has not been adopted" (Fong, 2009, p. 1). Following Niebel (2018), this study aligns with the definition of Fong (2009) to argue that technology "leapfrogging" is when technology adoption is used to "move forward" areas that are retrogressively developed. In order words, technology creates the path for developing economies to jump-start their development agenda. A good example is the effect of mobile phones in developing economies (Adegboye, Ojeka, Tolase, Omoremi, & Jude-Okeke, 2021; Baro & Endouware, 2013; Ejemeyovwi & Osabuohien, 2020; Kim, Park, & Komarek, 2021). Given its portability and accessibility, the use of mobile phones implies that government does not need to spend money developing infrastructures for landlines and as such can focus on other development goals. The literature on technology leapfrogging emerged in the 1990s (Lamberton, 1994; Mody & Dahlman, 1992) and recent studies have encapsulated its narrative (Chen, Farinelli, & Johansson, 2004; Gray & Sanzogni, 2004; Karlsson & Liljevern, 2017; Luo & Bu, 2016; Third & Kao, 2007; World Bank, 2017). Empirically, some studies confirm that the "leapfrogging" effect holds given the positive significance of the coefficient of ICT on economic growth (Adeleye & Eboagu, 2019; Hussain, Batool, Akbar, & Nazir, 2021; Niebel, 2018; Olurinola et al., 2021).

The literature is replete with studies on developed economies but this study expands the discourse on Palvia, Jacks, Ghosh, Licker, and Serenko (2017) to cover developing non-Western economies. Hence, the focus on SAARC economies is germane. The eight countries (Afghanistan, Bhutan, Bangladesh, India, Maldives, Nepal, Pakistan, and Sri Lanka) are excellent examples of developing economies where ICT leapfrogging may be relevant to stay competitive with more developed countries. This statement is supported using data from World Bank (2022) to show that ICT usage among SAARC economies is below the global average. Restricting to 2000–2020, the world average for mobile cellular subscriptions (per 100 people) is 67.09, fixed broadband subscriptions (per 100 people) 7.87, fixed telephone subscriptions (per 100 people) 16.24, and individuals using the Internet (% of the population) is 26.68. Compared to SAARC economies, the statistics displayed in Figure 1 indicates

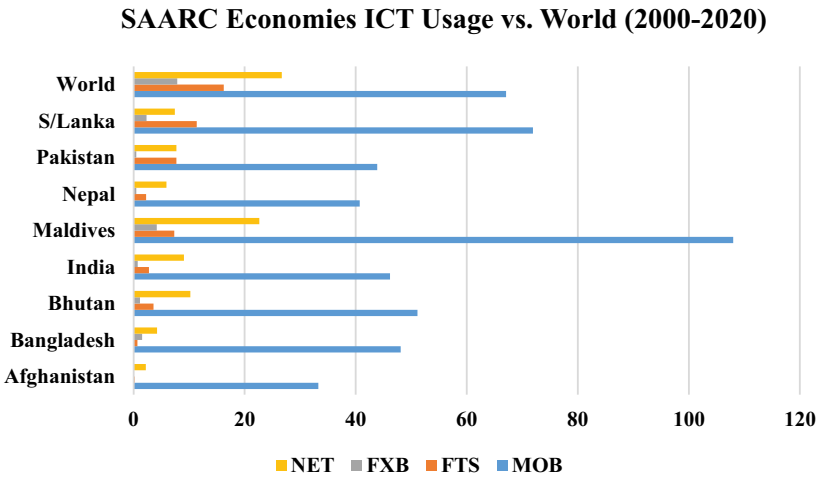


Figure 1. Comparative average ICT usage in SAARC vs. world.
Note: NET: Internet users; FXB: Fixed broadband users; FTS: Fixed telephone users; MOB: Mobile cellular users

that Maldives shows more ICT penetration with mobile phones 9107.98), Internet users (22,64) and fixed broadband usage (4.18). The countries with the least ICT penetration are Afghanistan, Nepal, and Pakistan.

Source: Authors' Compilations from World Bank (2022) World Development Indicators

The vast deviation from the global average justifies the need to further examine the peculiarities of South Asian economies vis-à-vis their ICT usage. Importantly, it highlights the potentials of ICT to economic growth. Moreso, the low-income countries (Afghanistan and Nepal) within the union may find ICT beneficial in catching up with the developmental progress of the rest of its members and the world at large.

This study has two objectives: (1) to elucidate if the leapfrogging proposition holds. In essence, for the hypothesis to hold, it is expected that the increasing effect of each ICT variable is positive. (2) Assess which ICT indicator has the most *leapfrogging* potentials to enable SAARC economies skip preliminary developmental stages. That is, to identify the output elasticity that is largest among the four indicators (mobile cellular subscriptions (per 100 people), fixed broadband subscriptions (per 100 people), fixed telephone subscriptions (per 100 people), individuals using the Internet (% of the population)). The findings of this study are expected to stimulate more policy discourse on the relevance of ICT regarding output growth, particularly in South Asia. It will also aid stakeholders in providing necessary enabling conditions such as infrastructural development for the realization of leapfrogging impact of ICT. Also, researchers with similar studies will find our results insightful and relate same with developing economies having semblances with SAARC economies. The rest of the study is structured as follows: Section 2 reviews the ICT-growth literature, Section 3 explains the data and econometric approach, Section 4 interprets the results, Section 5 discusses, Section 6 highlights the contributions, Section 7 details the limitations and areas for future research, and Section 8 concludes.

Literature Review

The ICT-growth nexus has received attention in development economics, however, there is a dearth of such specific studies on South Asia or SAARC member-countries. Some of the studies conducted on South Asia included Dhakal and Lim (2020), Tripathi and Inani (2020), Usman, Ozturk, Hassan, Maria Zafar, and Ullah (2021), and Hussain et al. (2021). Dhakal and Lim (2020) investigated the effect of ICT on economic growth among SAARC members from 2000 to 2017. Using mobile phone subscribers, fixed telephone users, fixed broadband subscribers and Internet users as ICT indicators, the study deployed the Bass, Gompertz, and logistic econometric diffusion models to conclude that the use of mobile phones is the most penetrated ICT in the region. Tripathi and Inani (2020) examined the ICT-economic growth in SAARC from 1990 to 2014. Using panel data techniques, the study concludes that ICT is growth-enhancing and that India showed the highest growth-elasticity followed by Sri Lanka, Bangladesh and Pakistan, respectively. Usman et al. (2021) analyzed the effect of ICT on energy use and economic growth in South Asia from 1990 to 2018. Using the bounds test and error correction model, the study concludes that a significant ICT-growth nexus exists in India only. Hussain et al. (2021) individually used three core ICT indicators (fixed-phone subscribers, mobile-phone subscribers, and Internet users) and constructed a composite index via Principal Component Analysis (PCA) to explore the ICT-growth dynamics in four South Asian economies (India, Pakistan, Bangladesh, and Sri Lanka) from 1995 to 2016. Using panel cointegration techniques and vector error correction model, the study finds that ICT penetration (individual and composite) exerts a positive effect on economic growth in the long-run which supports the leapfrogging hypothesis. Thus, given the dearth of studies on South Asia and SAARC economies, we extend the review to other regions where we explore both the direct and pass-through effects of ICT on economic growth as detailed in Table 1.

Principally, this current study differs from prior studies on SAARC/South Asia from two standpoints: (i) the extant literature examines only the linear effect of ICT on economic growth but this current study deviates by investigating the *increasing* quadratic effect of ICT on economic growth such that a consistent increasing effect confirms that the hypothesis holds; and (ii) we improve the

Table 1. Summary of reviewed literature on ICT and economic growth.

S/N	Author(s)	Scope	Techniques	Outcomes
		Direct Effect of ICT on Economic Growth		
1	Abdulqadir and Asongu (2022)	42 SSA countries, 2000–2018	DPT	Internet usage ↑ EG
2	Odhiambo (2022)	39 SSA countries, 2004–2014	GMM	ICT ↑ EG
3	Arvin, Pradhan, and Nair (2021)	G20 countries, 1961–2019	PGCM	ICT ↑ EG
4	Azu and Nwauko (2021)	15 ECOWAS, 1996–2018	Panel ARDL	Digitization ↑ Services Exports
5	Zhang, Meng, Sun, and Si (2021)	China, 2004–2006	FE	Enterprise ICT ↓ LF income and demand.
6	Appiah-Otoo and Song (2021)	122 countries, 2002–2017	IV-GMM	ICT ↑ EG in both rich and poor countries but ICT revolution ↑ EG in poor countries.
7	Kallal, Haddaji, and Ftiti (2021)	Tunisia, 1997–2015	PMG-ARDL	ICT ↑ EG
8	Kim et al. (2021)	22 countries, 2011–2016	POLS, FE	Mobile ICT ↑ NP in DCs; no impact of wired ICT for either DCs or LDCs.
9	Ofori and Asongu (2021)	40 SSA countries, 1980–2019	SGMM	ICT ↑ IG
10	Adeleye, Adedoyin, and Nathaniel (2021)	53 African countries, 2005–2015	BLSDV, DGMM	ICT ↑ EG and IG
11	Shahnazi (2021)	28 EU countries, 2007–2017	SDM	ICT spill-overs ↑ LFProd.
12	Ngoa and Song (2021)	48 African countries, 2001–2017	FE, SGMM	ICT ↑ female LFP
13	Koutroumpis, Leiponen, and Thomas (2020)	9,474 European firms, 2004–2013	GMM	R&D ICT ↑ TFP
14	Jung and Lopéz-Bazo (2020)	27 Brazilian states, 2007–2011	OLS, IV-FE	ICT ↑ EG
15	Ejemeyovwi and Osabuohien (2020)	West Africa, 2004–2014	SGMM	ICT ⚲ IG
16	Myovella, Karacuka, and Haucap (2020)	41 SSA, 33 OECD countries, 2006–2016	OLS, FE, GMM	ICT ↑ EG
17	Nguyen, Pham, and Tram (2020)	13 G20 countries, 2000–2014	FMOLS, QR	ICT ↑ EG
18	Gal, Nicoletti, Renault, Sorbe, and Timiliotis (2019)	20 OECD countries plus Turkey, 2010–2015	ECM	ICT ↑ TFP
19	Haftu (2019)	40 SSA countries, 2006–2015	SGMM	ICT ↑ EG
20	Adeleye and Eboagu (2019)	54 SSA Countries, 2005–2015	POLS, FE, RE, SGMM	ICT ↑ EG
21	Donou-Adonsou (2019)	45 SSA Countries, 1993–2015	FE; SGMM	Internet usage ↑ EG through education
22	Sepehrdoust and Ghorbanseresht (2019)	OPEC, 2002–2015	GMM	ICT ↑ EG
23	Chung (2018)	Korea, 1996–2015	DGEM	ICT ↑ growth
24	Tan, Ng, and Jiang (2018)	Azerbaijan	Thematic Study	ICT **leapfrog** ↑ EG
25	Niebel (2018)	59 countries, 1995–2010		Gains from ICT investments do not differ between developing, emerging and developed countries.
26	Pieri, Vecchi, and Venturini (2018)	OECD industries, 1973–2007	SFM	ICT ↓ PI
27	Edquist and Henrekson (2017)	50 Swedish industries; 1993–2013	OLS	ICT ⚲ TFP
28	Luo and Bu (2016)	6,236 from 27 EE, 2007	HLM	ICT ↑ productivity
29	Mitra, Sharma, and Véganzonès-Varoudakis (2016)	India, 1994–2010	FMOLS, PC, DPDM	ICT ↑ TFP

(*Continued*)

Table 1. (Continued).

S/N	Author(s)	Scope	Techniques	Outcomes
		Direct Effect of ICT on Economic Growth		
30	Strobel (2016)	Germany and the USA	OLS	ICT ↑ TFP
Pass-through Effect of ICT on Economic Growth				
31	Björkegren and Karaca (2022)	Rwanda, 2005–2009	Structural Model	Subsidized mobile phones ↑ rural well-being
32	Ofori et al. (2022)	42 SSA countries, 1980–2019	SGMM	ICT ↓ Income Inequality
33	Loaba (2021)	7 West African countries	ML&P	Mobile banking services ↑ savings behavior.
34	Gravina and Lanzafame (2021)	90 countries, 1970–2015	SGMM	Mobile cellular ↑ Gini Index
35	Zhu, Lyu, Long, and Wachenheim (2021)	6 China Provinces, 2016–2017	Binary Probit	Mobile phones ↑ financial access
36	Agyekum et al. (2021)	6,805 Firms in SEA	REPLM	ICT-based services ↑ credit access
37	Ahmed and Cowan (2021)	East Africa, 2013–2016	DiD	Mobile technology ↑ household healthcare access
38	Cho and Chen (2021)	34 Chinese banks, 2011–2017	DEA	Mobile device transactions ↑ banks' third-party payment transactions
39	Anser et al. (2021)	44 Asian countries, 2010–2019	PSCC-LSDV; MM-QR	ICT ↑ tourism
40	Ejemeyovwi et al. (2021)	7,634 households, Nigeria	Logit Regression	ICT ↑ household food security
41	Olurinola et al. (2021)	2,676, enterprises, Nigeria	Logit Regression; PSM	Digitization ↑ firms' performance
42	Haenssgen et al. (2021)	Survey data, 2141 Thai and Lao villagers	DS; MLRM	Mobile phone use ↑ access to formal healthcare
43	Phuc Nguyen et al. (2020)	109 economies, 1998–2017	PGCM; PMG-ARDL; DOLS; SGMM	Mobile phone usage ↑ overall FD; Internet access ↑ FM
44	Haile et al. (2019)	415 rural smallholders, Ethiopia	QML; PSM	Mobile phones usage ↓ farmers' price forecasting errors
45	Asongu and Nwachukwu (2018)	45 SSA Countries, 2000–2012	GMM	Mobile phone usage ↓ business start-up procedure
46	Islam et al. (2018)	200 respondents, Bangladesh,	Questionnaire	Mobile phone usage ↑ financial performance of microenterprises
47	Evans (2018)	44 African countries, 2000–2016	FMOLS, PCGM	Internet and mobile phones ↑ financial inclusion
48	Sam (2017)	Sierra Leone	ED; SEF	Mobile phones usage empowers marginalized young people
49	James (2015)	11 SSA countries	Survey Analysis	Mobile phone usage is mainly for safety-related purposes
50	Baro and Endouware (2013)	129 respondents, Niger Delta, Nigeria,	SSI; OEQ	Mobile phone ↑ socio- economic impact on the rural dwellers in the Niger Delta region

Notes: ↑: Increases/improves/stimulates/enhances; ↓: Reduces; ⚲: No effect; **ARDL**: Autoregressive distributed lag model; **BLSDV**: Bootstrapped least squares dummy variables; **DEA**: Data Envelopment Analysis; **DGEM**: Dynamic general equilibrium model; **DGMM**; Difference generalized method of moments; **DiD**: Difference-in-Difference; **DOLS**: Dynamic ordinary least squares; **DPDM**: Dynamic panel data model; **DPT**: Dynamic Panel Threshold; **DS**: Descriptive statistics; **ECM**: Error correction model; **ECOWAS**: Economic Community of West African States; **ED**: Ethnographic data; EE: Emerging Economies; **EG**: Economic growth; **EU**: European Union; **FD**: Financial development; **FE**; Fixed effects; **FM**: Financial market; **FMOLS**: Fully modified ordinary least squares; **GMM**: Generalized method of moments; HLM; Hierarchical linear modeling; ICT: Information and communication technology; IG: Inclusive growth; **IV-FE**: Instrumental variables-fixed effects; **IV-GMM**: Instrumental variables-generalized method of moments; **LFP**: labor force participation; **LFProd**: Labor force productivity; **LSDV**: Least squares dummy variables; **ML&P**: Multinomial Logit & Probit; **MLRM**: Multi-level regression models; **MM-QR**: Method of moments quantile regression; **NNM**: Nearest neighbor matching; **NP**: National productivity; **OECD**: Organization for Economic Cooperation and Development; **OEQ**: Open-ended questions; **OPEC**: Organization of Petroleum Exporting Countries; **PGCM**: Panel-Granger causality model; **PI**: Production inefficiency; **PMG**: Pooled mean group; **POLS**: Pooled ordinary least squares; **PSCC**: Panel-spatial correlation consistent; **PSM**: Propensity score matching; **QML**: Quasi-maximum likelihood; **USA**: United States of America; **R&D**: Research and Development; **RE**: Random effects; **REPLM**: Random-effect panel logistic regression model; **SEA**: South-East Asia; SEF: Synthesized empowerment framework; **SFM**: Stochastic Frontier Model; **SGMM**: System generalized method of moments; **SSA**: Sub-Saharan Africa; **SSI**: Semi-structured interview.
Source: Authors' Compilation

methodology to offer robustness to the analysis using the method of moments quantile regression technique developed by Machado and Santos (2019) to examine the impact of ICT on the conditional distribution of economic growth which differs from the conditional mean regressions carried out by prior studies. We conclude that the leapfrogging hypothesis holds if an increasing output elasticity is observed across the quantiles. To the best of our knowledge, this paper is the first to examine the ICT-growth dynamics and the leapfrogging supposition on SAARC economies using the quantile regression. These are gaps in the literature that this study sets out to fill.

Data and Model

The Variables

With a total of ten variables, this study uses an unbalanced panel data on eight SAARC economies (Afghanistan, Bhutan, Bangladesh, India, Maldives, Nepal, Pakistan, and Sri Lanka) from 2000 to 2020. The variables (see Table 2) are sourced from World Bank (2020a) World Development Indicators and World Bank (2020b) World Governance Indicators. The dependent variable is real GDP per capita (constant 2015 US$), which is a proxy for economic growth). Given the element of per capita income, this variable is also a measure of economic development. In line with the literature (Adeleye & Eboagu, 2019; Albiman & Sulong, 2016, 2017; Dhakal & Lim, 2020; Hussain et al., 2021; Pradhan, Arvin, Nair, Bennett, & Bahmani, 2017; Tripathi & Inani, 2020; Usman et al., 2021), the main regressors are five ICT indicators: mobile cellular subscriptions (per 100 people), fixed broadband subscriptions (per 100 people), fixed telephone subscriptions (per 100 people), individuals using the Internet (% of the population) and a composite ICT index developed via the Principal Component Analysis (PCA). The importance of ICT on output is explained in Sections 1 and 2. Thus, to avoid repetition, all ICT indicators are expected to have a positive impact on economic growth.

We offer some intuition on the ICT indicators. The mobile phone is quite popular among individuals and corporate organizations given its portability and light-weight. It is used by all age-groups regardless of income levels. With or without connectivity, the mobile phone is the fastest medium of communication and information dissemination. It is used to transact businesses via phone calls and text messages without the use of the Internet. With Internet connectivity, it enhances social media-business interactions on platforms like Facebook, LinkedIn, WhatsApp, Twitter, and Instagram. Not as popular, portable and easy to carry about like mobile phones, fixed telephones are common with corporate establishments solely for communications and disseminating information via landlines. If connected with a server or broadband, it can be used for Internet activities. In other words, the output elasticity and impact on growth is expected to differ significantly from that of mobile phones. The fixed broadband is an ultra-fast business Internet connection that beams through radio signals. It encompasses any high-speed data transmission to a residence or a business using a variety of technologies, including cable, fiber optics, and wireless.[1] The fixed broadband plays an important role in the communications networking and services industry and enabling business operations.[2] Also, it uses base stations to transfer the signal from building to building, like a satellite unlike the mobile broadband which is a high-speed Internet access delivered over a mobile phone network such as Code Division Multiple Access (CDMA), and Global System for Mobile (GSM) communications.[3] Lastly, the Internet can be accessed using a mobile phone and fixed telephone and its availability makes the world a global village. In essence, it makes the world "reachable." Internet access breaks international communication barriers such that contracts and business activities are executed at minimal cost.

There are four baseline control variables: (i) gross fixed capital formation (% of GDP) represents the absorptive capacity of firms to produce. It measures the net addition to physical assets within the measurement period. This variable is used because an increase in absorptive capacities will have a direct and positive impact on aggregate demand and output. Therefore, a positive coefficient is expected. (ii) Labor force participation rate, total (% of total population ages 15–64) is the share of the population aged 15 and older that is productively active. This variable is added because human capital

Table 2. Countries, variables description and signs.

Code	Description	Sign	Source	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	S/Lanka
PC	GDP per capita (constant 2015 US$)	N/A	WDI	490.92023	1038.697	2162.265	1286.114	8336.684	763.2336	1260.018	3032.262
MOB	Mobile cellular subscriptions (per 100 people)	+	WDI	33.265059	48.08714	51.11411	46.19741	107.9675	44.99522	43.87476	71.90889
FTS	Fixed telephone subscriptions (per 100 people)	+	WDI	0.2267348	0.679318	3.594431	2.766486	7.30888	2.49896	2.470796	11.38244
FXB	Fixed broadband subscriptions (per 100 people)	+	WDI	0.0164729	2.277296	1.847943	0.78098	4.622181	0.788631	0.650083	2.441329
NET	Individuals using the Internet (% of population)	+	WDI	3.0959201	4.438766	12.61255	9.509153	26.41778	6.897856	8.521586	10.8404
TR	Trade (% of GDP)	+	WDI		37.38482	95.42399	42.40934	147.9623	45.44739	30.238	60.69157
GFCF	Gross fixed capital formation (% of GDP)	+	WDI		27.32274	53.07447	30.79253	38.32144	24.0443	14.93516	25.16957
LAB	Labor force participation rate, total (% of total population ages 15–64) (modeled ILO estimate)	+	WDI	49.582	59.0795	70.3055	56.5285	62.6015	86.08	53.5155	59.423
ROL	Rule of Law Index (Ranges between −2.5 to +2.5)	+	WGI	−1.693476	0.31625	−0.82534	0.038673	−0.30202	−0.65264	−0.8211	0.044363

Note: WDI = World Development Indicators; WGI = World Governance Indicators
Source: Authors' Compilations

is a crucial production input in developing and emerging economies where the cost of technology acquisition is high. Hence, the importance of the variable is to capture the extent to which labor inputs affect output. A positive coefficient is expected. (iii) Trade (% of GDP) measures the degree of integration among countries with the rest of the world. It is likely that increased openness will have a positive effect on economic growth. (iv) Rule of law index reflects the extent to which the public have confidence in and abide by the rules of the society. The index ranges from −2.5 (weak institutions) and 2.5 (strong institutions). A positive coefficient is expected such that as institutions become effective, individuals and firms have renewed confidence in their government, enabling them to become more productive. To control for outliers and establish elasticity relationship, all variables except rule of law index are transformed into natural logarithms. The respective average values for each country are shown in Table 2.

The Model

To achieve the objectives of the study, the empirical procedure of Dhakal and Lim (2020), Hussain et al. (2021) and Adeleye and Eboagu (2019) is improved by specifying a quadratic model with the inclusion of the square of ICT as expressed in Equation (1):

$$\ln PC_{it} = \alpha + \omega \ln Z'_{it} + \varphi \ln ICT'_{it} + \gamma \ln\ ICT'sq_{it} + \omega_t + (\xi i + v_{it}) \tag{1}$$

Where $(\xi_i + v_{it}) = e_{it}$ the composite error term; $\ln PC_{it}$ is the natural logarithm of real per capita GDP; Z'_{it} is the vector of baseline regressors (gross fixed capital formation, labor participation rate, trade openness, and rule of law index); ICT'_{it} is the vector of ICT indicators (mobile phone subscription, fixed broadband subscription, fixed telephone subscription and Internet users); i is the number of countries $1, 2, \ldots, N$; t is the number of years $1, 2, \ldots, T$; ω_t = year dummies (which controls for common shock such as the global financial crises of 2007–2009); ξ_i indicates country-specific heterogeneity (country fixed effects): and v_{it} is the idiosyncratic error term that is independently and identically distributed (i.i.d). The two-way error component model is specified to recognize the distinct heterogeneities among the countries in the panel. Given that the level of economic development across these countries differ, it becomes imperative to control for the unobserved fixed affects. For robustness, Equation (1) is re-estimated using a composite ICT index. The conceptual framework is shown in Figure 1 where each ICT indicator and its composite ICT index have direct path to economic growth.

Note that the sign of the coefficient of the squared ICT indicator gives a clue on the direction of impact and shape of the polynomial. For instance, the first-order derivative of ICT on output which tests for marginal effect is given as:

$$\frac{\partial \ln PC}{\partial \ln ICT} = \varphi + 2\gamma \ln ICT \tag{2}$$

So, $\gamma > 0$ implies that increased ICT will have a positive impact on output, on average, *ceteris paribus*. Also, if $\gamma = 0$, then ICT has a constant impact, while $\gamma < 0$ provides evidence against the endogenous growth theory. In essence, an additional increase in ICT has a decreasing impact on output. $\varphi,\gamma > 0$ imply increasing relationship, if $\varphi,\gamma < 0$ decreasing relationship occurs, with φ,γ having opposite signs then the relationship is non-linear such that if $\varphi < 0$ and $\gamma > 0$ there is a U-shaped relationship and an inverted-U nexus occurs when $\varphi > 0$ and $\gamma < 0$.

Principal Component Analysis (PCA) for ICT Index

The justification for the PCA is strengthened when having many indicators of ICT and not knowing which best captures ICT or which is the most appropriate for an empirical analysis, coupled with the fact that there often exists a high correlation among them. From Table 3, in computing the ICT index, the first component has an eigenvalue (the variance of the component) of 2.715 (a value greater than 1 means that the component captures more variance than its nominal share of the total variance of the variables) and explains 67.9% of the common variance of the series while the second component has an eigenvalue of 1.017 and explains 25.4% of the variation. Only the first component is used in this case and the scree plot is shown in Figure 2. The Kaiser–Meyer–Olkin (KMO) index is the measure of sampling adequacy and it compares the partial correlations and correlations between variables. A value above 0.50 justifies the use of PCA (Creel, Hubert, & Labondance, 2014). Therefore, with a KMO of 0.6438, the use of PCA is validated. The top panel of Table 3 shows some salient features from the computation of ICT index, the middle panel indicates that the covariates are highly correlated, while the lowest panel displays the KMO index (Figure 3).

Summary Statistics, Pairwise Correlation and Cross-Sectional Dependence

The upper panel of Table 4 shows the preliminary analysis with regard to descriptive statistics using the untransformed values of the variables in order to retain their historical properties. The standard deviation of these variables indicates that the variables varied substantially within the study period. Of particular interest are the ICT variables with mobile usage having the largest disparity among other indicators in the region. Similarly, the standard deviation of real per capita GDP informs about the wide gap in economic development in the region. The middle panel of Table 4 details the pairwise correlations. All the variables with the exception to labor force indicate significant positive association with economic growth. The high collinearity among the ICT indicators is of less concern given that a stepwise analysis is adopted such that each ICT indicator is used in separate models. Lastly, the close proximities of these countries may cause the cross-sections to be dependent. Thus, the Pesaran (2015) cross-sectional dependence test is performed and the statistically significant results displayed in the lowest panel of Table 4 provide sufficient evidence on the presence of cross-sectional dependence in the data.

Table 3. ICT index, eigenvalues, correlation matrix and KMO.

Component		Eigenvalue	Difference	Proportion	Cumulative
Component 1		2.715	1.698	0.679	0.679
Component 2		1.017	0.851	0.254	0.933
Component 3		0.166	0.063	0.042	0.974
Component 4		0.103	-	0.026	1.000
Variables	ICT Index	MOB	FTS	FXB	NET
ICT Index	1.000				
MOB	0.922***	1.000			
FTS	0.294***	0.198**	1.000		
FXB	0.942***	0.805***	0.386***	1.000	
NET	0.944***	0.872***	0.420***	0.833***	1.000
Kaiser-Meyer-Olkin (KMO) Index = 0.6438					

Source: Authors' Computations

Table 4. Summary statistics, pairwise correlation, and cross-sectional dependence results.

Variable	PC	ICT Index	MOB	FTS	FXB	NET	GFCF	LAB	TR	ROL
Observations	166	104	166	161	131	142	133	160	133	160
Mean	2318.025	0	56.058	3.996	1.749	10.31	29.702	62.139	56.987	−0.487
Std. Dev.	2487.489	1.648	47.24	4.074	2.356	12.552	12.684	11.109	31.683	0.628
Minimum	332.767	−4.796	0	0.018	0.001	0.005	12.521	49.03	25.306	−1.897
Maximum	10207.491	2.603	181.329	17.689	11.782	63.186	69.673	88.13	165.979	0.628
Pairwise Correlation										
lnPC	1.000									
lnICT Index	0.608***	1.000								
lnMOB	0.489***	0.812***	1.000							
lnFTS	0.685***	0.368***	0.198**	1.000						
lnFXB	0.681***	0.795***	0.805***	0.386***	1.000					
lnNET	0.618***	0.764***	0.872***	0.420***	0.833***	1.000				
lnGFCF	0.349***	0.286**	0.241***	0.135	0.350***	0.163*	1.000			
lnLAB	0.061	0.053	−0.096	0.292***	0.331***	0.030	0.305***	1.000		
lnTR	0.651***	0.337**	0.268***	0.390***	0.282***	0.260***	0.700***	0.392***	1.000	
ROL	0.363***	0.123	0.022	0.397***	0.425***	0.080	−0.009	0.118	−0.191**	1.000
Cross-sectional Dependence										
Statistics	19.802***	−0.151	21.765***	5.735***	5.353***	11.445***	−0.191	23.661***	0.542	3.077***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; ln = Natural logarithm; GFCF = Gross fixed capital formation; LAB = Labor force participation; TR = Trade openness; ROL = Rule of law index; ICT Index = Information and communications technology; MOB = Mobile phones subscription per 100 people; FTS = Fixed telephones subscription per 100 people; F – XB = Fixed broadband subscription per 100 people; NET = Individuals using the Internet.

Source: Authors' Computations

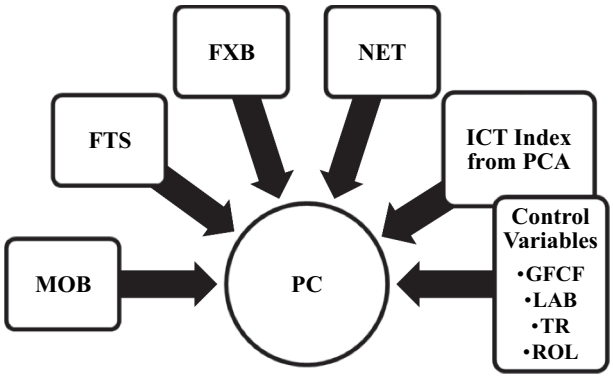


Figure 2. Research model on the ICT-economic growth dynamics.
Source: Authors'

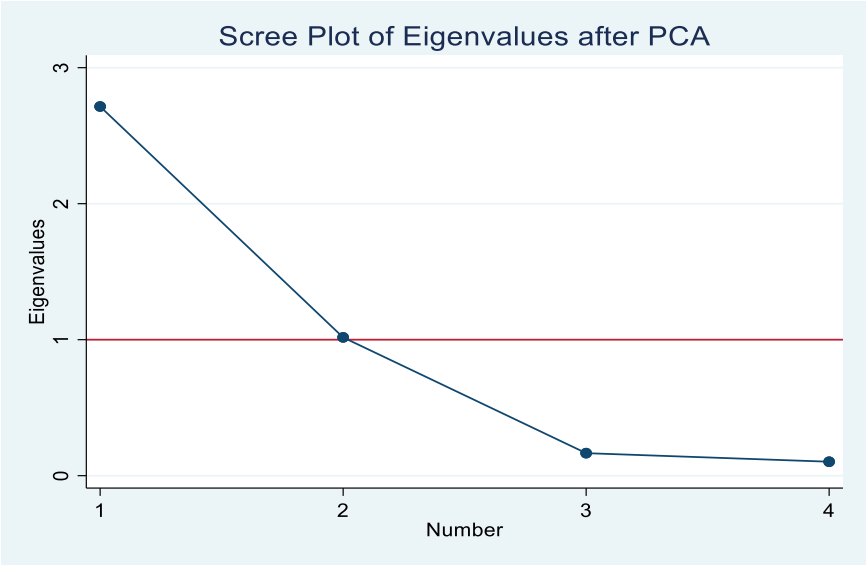


Figure 3. Scree plot of principal component of ICT index.
Source: Authors' Computations

Estimation Techniques

Panel Spatial Correlation Consistent (PSCC)

To account for the possibility of cross-sectional dependence which may occur given the close proximities of the countries and the sharing of common features, we use the Driscoll and Kraay (1998) panel spatial correlation consistent (PSCC)[4] method. This is because not accounting for the presence of cross-sectional dependence in the data may yield biased estimates (Pesaran, 2004). The PSCC method also controls for possible autocorrelation and heteroscedasticity (Cameron & Trivedi, 2005; Hoechle, 2006). First the model is estimated by the pooled ordinary least squares (OLS) version of the technique (PSCC-OLS) which does not recognize the differences among SAARC economies as it assumes the countries have the same characteristics and enabling conditions. Secondly, in the event that the respective unobserved differences correlate with variables, when $E\left(\xi_i \middle| Z'_{it}, ICT'_{it}\right) \neq 0$, and the errors also correlate over time, the OLS technique becomes inconsistent and Equation (1) yields biased

estimates, thus the PSCC-FE is deployed to address the unobserved heterogeneity (that is, fixed effects) in the data. In line with the suggestions of Lam and Shiu (2010), the PSCC approach includes lagged values of the regressors in the underlying algorithm to address the problem of endogeneity and reverse causality. We engage a step-wise estimation of Equation (1) as each ICT variable is included sequentially to show their distinct impact on economic growth.

Method of Moments Quantile Regression (MM-QR)

Recall that the PSCC approach is concerned about the linear relationship between ICT and economic growth. Taking a cue from Equation (1), a percentage change in ICT will result in Υ% change in PC, on average, *ceteris paribus* which does not *technically* capture the leapfrog potentials of ICT on PC. This is where the method of moments quantile regression (MM-QR) approach becomes appropriate. To show the leapfrog effect, the MM-QR technique developed by Machado and Santos (2019) allows for the estimation of the conditional distribution of the dependent variable. That is, it shows the impact of ICT at different points (quantiles) of economic growth. We consider five quantiles (10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th}) of economic growth and a leapfrog effect occurs if the coefficient of ICT is positive and increases at higher quantiles (levels) of growth. In other words, a surge in economic growth is indicative of a leapfrog effect. Also, a leapfrog effect occurs if at a lower quantile, the impact of ICT on economic growth is larger or largest than the rest of the quantiles. What this means is that if the impact of ICT at the 10^{th} quantile is 0.127 while at the 25^{th} it drops to 0.120 (see Table 6 for fixed telephones subscription), we infer that a leapfrog effect occurred at the 10^{th} quantile. Importantly, a negative coefficient does not support a leapfrog effect and neither does a *decreasing* positive coefficient along the distribution. Thus, modifying Equation (1) and following Machado and Santos (2019), and Anser, Adeleye, Tabash, and Tiwari (2021), the conditional quantile $Q_{PC}(\tau|X)$ estimation of the location-scale variant model takes the following general specification:

$$Q_{PC}(\tau|X_{it}) = (\alpha_i + \delta_i qi) + X_{it}^{'}\beta + R_{it}^{'}\gamma q(\tau) \tag{3}$$

Where, Equation (3) is assumed to be a linear model; $X_{it}^{'}$ is a vector of all explanatory variables used in the study; $Q_{PC}(\tau|X_{it})$ represents the quantile distribution of the dependent variable conditional on the location of explanatory variables; $\alpha_i(\tau) = \alpha_i + \delta_i q(\tau)$ is the scalar coefficient of the quantile-τ fixed effect for individual i, or the distributional effect at τ; $R^{'}$ is a k-vector of known differentiable (with probability 1) transformations of the components of X with element l where $l = 1, \ldots, k$; $q(\tau)$ is the $\tau -$ th quantile derived from the following optimization function:

$$\min_{q} \sum_{i} \sum_{t} \rho_{\tau}\left(\widehat{K}_{it} - \left(\widehat{\delta}_i + R_{it}^{'}\hat{\gamma}\right)q\right) \tag{4}$$

Such that, $\rho_{\tau}(A) = (\tau - 1)AI\{A \leq 0\} + \tau AI(\{A > 0\})$ represents the check-function.

Empirical Results

This section presents empirical findings on testing the leapfrogging hypothesis among SAARC economies by highlighting whether increasing ICT usage exerts a positive effect on economic growth and estimations begin with a stepwise analysis of the models using each ICT indicator. The second column of the Table of results presents outcomes from the PSCC-OLS technique followed by PSCC-FE and finally by MM-QR. Interpretations are taken in turns but restricted to the coefficient of the squared ICT indicator.

Table 5 displays the outcomes from the mobile phones model. The coefficient of the squared term is positive and statistically significant at the 1% level from the PSCC-OLS and PSCC-FE regressions but there are significant differences in estimates obtained using MM-QR which reveal relationships that are under-reported by OLS and FE. The OLS indicates a significant positive coefficient of 0.058 while that of FE is 0.009 indicating that the increasing effect on growth reduces when unobserved heterogeneity is accounted for. MM-QR, on the other hand, offers more robustness by demonstrating the

Table 5. Mobile phones subscriptions and economic growth.

	PSCC				MM-QR				
Variables	OLS	FE	Location	Scale	Q = 0.10	Q = 0.25	Q = 0.50	Q = 0.75	Q = 0.90
lnGFCF	−0.218	0.0941*	−0.218**	−0.0250	−0.182*	−0.195**	−0.212**	−0.242	−0.259
	(−1.561)	(1.998)	(−2.173)	(−0.338)	(−1.958)	(−2.430)	(−2.339)	(−1.588)	(−1.302)
lnLAB	−1.550***	−1.843***	−1.550***	0.276	−1.954***	−1.809***	−1.616***	−1.295***	−1.097**
	(−5.489)	(−7.511)	(−5.795)	(1.401)	(−7.814)	(−8.381)	(−6.613)	(−3.214)	(−2.083)
lnTR	1.002***	−0.0471	1.002***	−0.0741	1.110***	1.071***	1.020***	0.933***	0.880***
	(5.769)	(−1.400)	(7.663)	(−0.769)	(9.164)	(10.24)	(8.608)	(4.723)	(3.402)
ROL	−0.117	0.165*	−0.117*	0.0258	−0.155***	−0.142***	−0.124**	−0.0935	−0.0750
	(−1.847)	(2.433)	(−1.902)	(0.567)	(−2.718)	(−2.871)	(−2.215)	(−1.002)	(−0.614)
lnMOB	0.119	−0.0269**	0.119*	0.0173	0.0935	0.103*	0.115*	0.135	0.147
	(1.861)	(−2.703)	(1.722)	(0.339)	(1.467)	(1.863)	(1.840)	(1.290)	(1.075)
lnMOBSQ	0.0579***	0.00905***	0.0579***	0.0256**	0.0204	0.0339***	0.0517***	0.0815***	0.0998***
	(4.115)	(3.787)	(3.699)	(2.216)	(1.369)	(2.637)	(3.552)	(3.480)	(3.272)
Constant	0	0	105.2	63.44	12.34	45.69***	89.93***	163.7***	209.1***
					(1.107)	(6.243)	(12.36)	(15.59)	(13.75)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	122	122	122	122	122	122	122	122	122
R-squared	0.883								
Groups	7	7	7	7	7	7	7	7	7
F-Statistic	122.8***	796.2***							

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; *t*-statistics in parentheses for OLS and FE; *z*-statistics in parentheses for MM-QR; ln = Natural logarithm; GFCF = Gross fixed capital formation; LAB = Labor force participation; TR = Trade openness; ROL = Rule of law index; MOB = Mobile phones subscription per 100 people.
Source: Authors' Computations

Table 6. Fixed telephone subscriptions and economic growth.

	PSCC				MM-QR				
Variables	OLS	FE	Location	Scale	Q = 0.10	Q = 0.25	Q = 0.50	Q = 0.75	Q = 0.90
lnGFCF	−0.286**	−0.0119	−0.286***	−0.0793	−0.186***	−0.224***	−0.269***	−0.364***	−0.440**
	(−3.091)	(−0.222)	(−3.612)	(−1.436)	(−2.999)	(−3.801)	(−3.720)	(−2.945)	(−2.534)
lnLAB	−1.640***	−2.355***	−1.640***	0.0513	−1.705***	−1.680***	−1.651***	−1.589***	−1.540***
	(−12.64)	(−8.393)	(−12.72)	(0.572)	(−17.45)	(−17.58)	(−14.18)	(−7.957)	(−5.508)
lnTR	1.126***	0.133*	1.126***	0.114*	0.982***	1.037***	1.101***	1.237***	1.347***
	(7.491)	(2.047)	(12.77)	(1.850)	(13.96)	(15.77)	(13.60)	(8.966)	(6.912)
ROL	−0.0912**	0.273***	−0.0912*	0.0285	−0.127***	−0.114***	−0.0974**	−0.0634	−0.0359
	(−3.105)	(4.372)	(−1.755)	(0.786)	(−3.216)	(−2.946)	(−2.072)	(−0.786)	(−0.317)
lnFTS	0.00100	0.0536	0.00100	0.0277	−0.0342	−0.0208	−0.00508	0.0281	0.0549
	(0.0269)	(1.066)	(0.0240)	(0.952)	(−1.070)	(−0.668)	(−0.134)	(0.433)	(0.603)
lnFTSSQ	0.109***	0.0319**	0.109***	−0.0140	0.127***	0.120***	0.113***	0.0958***	0.0823**
	(7.016)	(2.682)	(6.548)	(−1.199)	(9.861)	(9.684)	(7.410)	(3.686)	(2.256)
Constant	0	0	−76.36	−1.544	−74.39***	−75.14***	−76.02***	−77.87***	−79.36***
					(−271.7)	(−441.8)	(−442.2)	(−335.2)	(−184.1)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	125	125	125	125	125	125	125	125	125
R-squared	0.938								
Groups	7	7	7	7	7	7	7	7	7
F-Statistic	144.2***	15345***							

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; *t*-statistics in parentheses for OLS and FE; *z*-statistics in parentheses for MM-QR; ln = Natural logarithm; GFCF = Gross fixed capital formation; LAB = Labor force participation; TR = Trade openness; ROL = Rule of law index; FTS = Fixed telephones subscription per 100 people.
Source: Authors' Computations

increasing pattern across the quantiles. Except at Q = 0.10, all the coefficients are positive and statistically significant at the 1% level with an increasing impact from Q = 0.25 (0.0339) to 0.90 (0.0998) which is higher than the OLS and FE coefficients.

From Table 6, the coefficient of fixed telephones indicates a significant positive effect across all model specifications. Similar to Table 5, the FE estimate (0.0319) is lower than the OLS (0.109) suggesting the effects of unobserved differences across the cross-sections. However, the contributory impact of fixed telephones to economic growth cannot be ignored. From MM-QR, we find that the coefficient is positive but declines across the quantiles from 0.127 at Q = 0.10 to 0.0823 at Q = 0.90.

Next, Table 7 displays the outcomes from fixed broadband usage. The coefficient of the squared term shows a significant positive sign from the OLS and FE estimates. Distinctively, the OLS coefficient (0.032) overshadows that of the FE estimate (0.006) when unobserved heterogeneity is accounted for. Across the conditional distribution, the MM-QR shows that the increasing effect is statistically significant and positive from Q = 0.10 to Q = 0.50 but the significance fizzles out at the upper quantiles.

The results from Internet usage are shown in Table 8. Similar to other ICT indicators, the coefficient of the OLS estimate (0.033) dwarfs that of the FE estimate (0.013) after accounting for fixed effects. From MM-QR, we observe a decreasing positive effect from 0.037 (Q = 0.10) to 0.033 (Q = 0.50) while effects at higher quantiles are also positive but statistically not significant. Knowing the importance of the Internet, we find this outcome puzzling. The only plausible reasoning may be the high cost of accessing the Internet in this region may be linked to this outcome.

Finally, we use a composite ICT index to test the overall robustness of our models. The results displayed in Table 9 strike a semblance with that of mobile phones model and offer some re-assuring outcomes. We observe that the coefficient of the squared term is positive and statistically significant at the 1% level from OLS (0.177) but its value decreased with its statistical significance in the FE model (0.023). As observed from previous results, the MM-QR offers more robustness and discloses relationships that are understated by OLS and FE.

Discussions

While the OLS and FE do not vividly show the leapfrogging potentials of mobile phones, the MM-QR shows that at higher levels of mobile phones usage, economic growth surges from 0.0339 to 0.0998. Also, a cursory look at the coefficients reveals the output elasticity is larger at the upper quantiles of economic growth which provides support that mobile phone usage exerts some leapfrogging potentials. Our results align with literature (Howard & Mazaheri, 2009; James, 2012; Paiano et al., 2013) on the growth-enhancing impact of mobile phones usage though these studies did not specifically test the leapfrogging hypothesis. The result from the mobile phone model is expected due to its commonness, popularity and portability among individuals and corporate organizations. In addition, the result supports the hedonistic aspect of cellular phones usage as individuals from all walks of life self-indulge in owning more than one cell phone and this goes without saying that the mobile phone is the most commonly used communication device. Also, the observed U-shaped relationship from the PSCC-FE technique suggests that at the onset mobile phones usage contributes to a drop in economic growth perhaps due to the high cost of obtaining a mobile cellular and other attendants' cost. However, innovations may cause massive production of mobile phones making it cheaper and more accessible, thus contributing to economic growth in the long-run (Asongu & Tchamyou, 2015). This outcome is therefore important for less developed countries to explore the opportunities inherent in mobile technology. The fixed telephones subscription results align with prior studies (Adeleye & Eboagu, 2019; Asongu & Nwachukwu, 2018; Dhakal & Lim, 2020; Odhiambo, 2022; Ofori, Osei, & Alagidede, 2022) and affirm the growth-enhancing effect of fixed telephones. Compared to mobile phones, fixed telephones usage indicates a retrogressive impact on economic growth. The results suggest that at lower usage of fixed telephones, economic growth increases on average by 0.13% but drops to about 0.08% when at its peak. This is an interesting outcome as we observe a leapfrogging effect of fixed telephones at the

Table 7. Fixed broadband subscriptions and economic growth.

	PSCC				MM-QR				
Variables	OLS	FE	Location	Scale	Q = 0.10	Q = 0.25	Q = 0.50	Q = 0.75	Q = 0.90
lnGFCF	−0.533***	0.0929	−0.533**	0.0385	−0.584***	−0.569***	−0.534**	−0.503	−0.460
	(−5.172)	(1.871)	(−2.086)	(0.156)	(−4.006)	(−5.069)	(−2.118)	(−1.154)	(−0.649)
lnLAB	−1.373***	−1.125***	−1.373***	−0.0270	−1.338***	−1.349***	−1.373***	−1.395**	−1.425
	(−6.530)	(−4.355)	(−3.484)	(−0.0711)	(−5.978)	(−7.792)	(−3.520)	(−2.067)	(−1.300)
lnTR	1.136***	−0.0693*	1.136***	−0.0817	1.242***	1.211***	1.137***	1.072***	0.979
	(8.930)	(−2.061)	(4.843)	(−0.361)	(9.135)	(11.78)	(4.978)	(2.716)	(1.528)
ROL	−0.133*	0.00821	−0.133	0.0244	−0.164*	−0.155**	−0.133	−0.113	−0.0858
	(−2.232)	(0.113)	(−0.792)	(0.151)	(−1.726)	(−2.109)	(−0.803)	(−0.397)	(−0.185)
lnFXB	0.328***	0.0159	0.328***	0.0761	0.228***	0.258***	0.327***	0.387**	0.473
	(6.114)	(1.340)	(2.838)	(0.683)	(3.244)	(5.099)	(3.002)	(2.063)	(1.555)
lnFXBSQ	0.0318***	0.00600***	0.0318*	0.00634	0.0236**	0.0260***	0.0318*	0.0368	0.0440
	(4.738)	(4.438)	(1.886)	(0.389)	(2.399)	(3.520)	(1.939)	(1.300)	(0.957)
Constant	0	0	70.21	52.75	1.411	21.91***	69.60***	111.6***	171.3***
					(0.0874)	(2.981)	(3.988)	(3.752)	(3.707)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	97	97	97	97	97	97	97	97	97
R-squared	0.893								
Groups	7	7	7	7	7	7	7	7	7
F-Statistic	216.7***	8210***							

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; *t*-statistics in parentheses for OLS and FE; *z*-statistics in parentheses for MM-QR; ln = Natural logarithm; GFCF = Gross fixed capital formation; LAB = Labor force participation; TR = Trade openness; ROL = Rule of law index; FXB = Fixed broadband subscription per 100 people.
Source: Authors' Computations

Table 8. Individuals using the internet and economic growth.

	PSCC				MM-QR				
Variables	OLS	FE	Location	Scale	Q = 0.10	Q = 0.25	Q = 0.50	Q = 0.75	Q = 0.90
lnGFCF	−0.362**	−0.00268	−0.362***	−0.00238	−0.359***	−0.360***	−0.362***	−0.364***	−0.366**
	(−3.020)	(−0.0567)	(−4.152)	(−0.0361)	(−5.039)	(−5.747)	(−4.408)	(−2.735)	(−1.971)
lnLAB	−1.382***	−1.411***	−1.382***	0.133	−1.576***	−1.486***	−1.397***	−1.268***	−1.153**
	(−10.36)	(−5.804)	(−6.528)	(0.830)	(−9.042)	(−9.739)	(−7.002)	(−3.938)	(−2.559)
lnTR	1.086***	0.0183	1.086***	0.0127	1.067***	1.076***	1.084***	1.096***	1.108***
	(9.388)	(0.370)	(11.38)	(0.176)	(13.70)	(15.68)	(12.07)	(7.527)	(5.447)
ROL	0.101*	0.226***	0.101	0.0696	−0.000714	0.0465	0.0933	0.161	0.221
	(2.345)	(3.772)	(1.502)	(1.368)	(−0.0127)	(0.952)	(1.465)	(1.580)	(1.548)
lnNET	0.118***	0.0520**	0.118***	0.0240	0.0830***	0.0993***	0.115***	0.139**	0.160**
	(3.851)	(3.646)	(3.102)	(0.835)	(2.645)	(3.615)	(3.215)	(2.396)	(1.970)
lnNETSQ	0.0330***	0.0133***	0.0330**	−0.00278	0.0371***	0.0352***	0.0333***	0.0306	0.0282
	(6.591)	(3.870)	(2.448)	(−0.273)	(3.366)	(3.630)	(2.625)	(1.488)	(0.982)
Constant	0	0	4.155	−4.338	10.50***	7.564***	4.649***	0.437	−3.339***
					(12.41)	(15.28)	(8.270)	(0.521)	(−2.622)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	112	112	112	112	112	112	112	112	112
R-squared	0.899								
Groups	7	7	7	7	7	7	7	7	7
F-Statistic	155.0***	1536***							

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; *t*-statistics in parentheses for OLS and FE; *z*-statistics in parentheses for MM-QR; ln = Natural logarithm; GFCF = Gross fixed capital formation; LAB = Labor force participation; TR = Trade openness; ROL = Rule of law index; NET = Individuals using the Internet.
Source: Authors' Computations

Table 9. Composite ICT index and economic growth.

	PSCC				MM-QR				
Variables	OLS	FE	Location	Scale	Q = 0.10	Q = 0.25	Q = 0.50	Q = 0.75	Q = 0.90
lnGFCF	−0.661***	−0.109*	−0.661***	0.0999	−0.800***	−0.736***	−0.662***	−0.576***	−0.498*
	(−11.16)	(−2.302)	(−5.770)	(1.217)	(−7.091)	(−7.649)	(−5.771)	(−3.530)	(−1.935)
lnLAB	−1.490***	−0.536	−1.490***	−0.0263	−1.454***	−1.471***	−1.490***	−1.512***	−1.533***
	(−6.706)	(−1.220)	(−5.740)	(−0.141)	(−6.010)	(−6.847)	(−5.764)	(−4.065)	(−3.069)
lnTR	1.040***	−0.184*	1.040***	−0.147*	1.243***	1.149***	1.041***	0.915***	0.800***
	(9.079)	(−2.269)	(8.708)	(−1.719)	(10.09)	(11.31)	(8.647)	(5.394)	(2.670)
ROL	0.149**	0.0698	0.149*	−0.00553	0.157**	0.153**	0.149*	0.144	0.140
	(3.430)	(1.171)	(1.941)	(−0.101)	(2.191)	(2.411)	(1.950)	(1.312)	(0.949)
lnICT	0.696***	0.120**	0.696***	0.0712	0.598***	0.643***	0.695***	0.757***	0.812***
	(6.065)	(2.972)	(6.336)	(0.905)	(5.667)	(7.022)	(6.333)	(4.816)	(3.524)
lnICTSQ	0.177***	0.0234**	0.177***	0.00675	0.168***	0.172***	0.177***	0.183***	0.188***
	(6.238)	(2.603)	(6.474)	(0.344)	(6.557)	(7.597)	(6.497)	(4.666)	(3.530)
Constant	0	0	54.22	39.70	−0.746	24.74***	53.78***	87.94***	119.1***
					(−0.0584)	(3.657)	(7.221)	(9.087)	(2.935)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	52	52	52	52	52	52	52	52	52
R-squared	0.951								
Groups	7	7	7	7	7	7	7	7	7
F-Statistic	1596***	31285***							

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; *t*-statistics in parentheses for OLS and FE; *z*-statistics in parentheses for MM-QR; ln = Natural logarithm; GFCF = Gross fixed capital formation; LAB = Labor force participation; TR = Trade openness; ROL = Rule of law index; ICT = Information and communications technology.
Source: Authors' Computations

10^{th} quantile but this effect dissipates along the distribution. Perhaps, the result from fixed telephone is a reflection of its restricted usage to corporate organizations. Similar to prior studies (Anser et al., 2021; Chavula, 2013; Huang, Li, Guo, & Hall, 2021; Jung & Lopéz-Bazo, 2020; Liao, Wang, Li, & Weyman-Jones, 2016; Xing, 2018) we submit that fixed broadband usage significantly contributes to economic growth from 0.024% to 0.032%. A critical look at the upper quantiles of Q = 0.75 and 0.90 indicate larger but statistically insignificant effects. We offer some perspectives to these outcomes. Given that it requires a huge capital outlay, most SAARC economies may not have the enabling infrastructure required to deliver the fixed wireless broadband. Also, on the flip-side, fixed broadband comes with high monthly fee compared to dialup Internet access. It also entails a higher security risk than dialup connection and a personal firewall is needed to protect one's computer which may be some of the reasons why the mobile broadband is preferred. On the flipside, the statistically insignificant coefficients of broadband relative to mobile cellular may proffer additional support for the leapfrogging potentials of mobiles since there will be less need for fixed broadband when cellular phones infrastructure is in place. Nevertheless, from the results, we conclude that fixed broadband has minimal leapfrogging effect on growth. The growth enabling properties of Internet usage align with previous studies (Freund & Weinhold, 2004; Ma, Buhalis, Song, & Baro, 2003; Madon, 2000; Najarzadeh, Rahimzadeh, & Reed, 2014; Salahuddin & Gow, 2016; Visser, 2019; Vu, 2019) but similar to the fixed telephones model, we find a leapfrogging effect at the 10^{th} quantile. The *reducing* positive effect across the quantiles may be connected with the high cost of connecting to the Internet. Finally, the results from the composite index support the leapfrogging potentials of ICT on economic growth. Similar to Hussain et al. (2021) who used a composite ICT index to investigate the ICT-growth nexus, we find that ICT is a positive predictor of economic growth and a springboard to launch developmental progress. Across all quantiles, an *increasing* positive effect is observed from 0.168 at Q = 0.10 to 0.188 at Q = 0.90. Given this, we conclude that the leapfrogging hypothesis holds. For the most part, these results (particularly mobile phones usage and the ICT composite index) support the leapfrogging hypothesis. We find evidence from that data and are able to show that real per capita GDP surges from an increasing usage of ICT.

Contributions

Contributions to Research

In testing the leapfrogging hypothesis, the literature often uses a conditional mean approach to establish a significant positive linear relationship between ICT and economic growth. However, this study deploys a novel methodology that examines the conditional distribution across five quantiles to expand the literature. It further expands the literature to address the ICT leapfrog effect in a non-Western context contrary to Palvia et al. (2017) and provokes a new discourse that an *increasing* effect of ICT on economic growth best provides support that the leapfrogging hypothesis holds. We have contributed to research by showing that a surge in economic growth is suggestive of a leapfrog effect. Notably, a negative ICT impact on growth does not support a leapfrog effect. Also, a leapfrog effect does not hold the economic growth *reduces* along its distribution. In other words, it provides sufficient evidence that increasing the usage and deployment of ICT devices may trigger the developmental agenda of developing economies like those of SAARC economies.

Contributions to Practice

For the most part, the consistency of the results provides sufficient evidence that ICT indicators are essential drivers of growth among SAARC economies. Specifically, since mobile phone usage has shown the most potentials, it becomes essential for government and stakeholders in SAARC economies to provide the enabling environment that will increase the usage of mobile phones, in particular, such that

domestic and international businesses can be transacted within the comfort of homes and offices cutting down traveling time and expenses. More so, investing in cellular phone infrastructures, like the 5 G towers, will have far-reaching long-run outcomes on the living and economic conditions of the population due to higher capacity and increased mobile bandwidths. Similarly, reducing access and connectivity costs will enhance the growth potentials of a fixed broadband subscription, fixed telephone usage, and the number of Internet users. This is because ICT applications can boost the well-being of SAARC economies, especially the poor, by providing opportunities via access to markets, health, and education. Furthermore, ICT can empower the poor by expanding the use of government services and reduce risks by widening access to microfinance. The use of ICT for development is actively promoted, for economic development, job creation, rural development and poverty alleviation. Failure to heed to these recommendations may stall the economic advancement of SAARC economies.

Limitations and Future Research

We identify three limitations to this study. The first is the use of eight SAARC economies (excluding Iran), though Afghanistan shows extreme loss of data on some essential variables but we do not expect this to bias the outcomes. An avenue for future research may be to engage a comparative study with Western developed economies or other economies with similar characteristics with SAARC to observe if the same outcomes will occur. The second is the use of only four ICT variables, perhaps future studies may incorporate other proxies to capture the ICT phenomenon. The third limitation is that though proving that leapfrogging is advantageous for less developed countries is somewhat difficult and there are no guarantees that leapfrogging will automatically lead to greater economic growth. Thus, future research may devote more sophisticated analytical method to unravel this. To widen future discourse on the ICT leapfrogging-economic growth dynamics, we propose the following study areas, subject to data availability: (i) evaluate the role of institutional quality; and (ii) examine the impact of the nexus on income inequality.

Conclusion

This study uses the Driscoll and Kraay (1998) pooled OLS (PSCC-OLS), fixed effects (PSCC-FE) and Machado and Santos (2019) method of moments quantile regression (MM-QR) techniques to test the ICT leapfrogging-economic growth dynamics on eight SAARC member-states (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka) from 2000 to 2020. The empirical results show that ICT (individual indicators and the composite index) wields positive and statistically significant effect on economic growth. Specifically, the MM-QR provides evidence that the leapfrogging hypothesis holds (i) from the mobile phones model; (ii) from the composite index model; and (iii) from the lower quantiles of fixed telephones and Internet users' model. Also, among the four ICT indicators, mobile phones exert the largest output elasticity across the quantiles. Our findings support the conjecture that ICT usage can help less developed economies stay competitive with their more developed counterparts.

Notes

1. https://www.upwardbroadband.com/is-fixed-wireless-Internet-good-the-pros-and-cons/
2. https://www.lightreading.com/partner-perspectives-(sponsored-content)/why-fixed-broadband-is-more-important-than-ever/a/d-id/754798
3. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/ICCP/CISP(2013)8/FINAL&docLanguage=En
4. We use the *xtscc* routine in Stata16.

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Data Availability

The data that support the findings of this study are available from the corresponding author, [BNA], upon reasonable request.

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