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Information and Communication Technology (ICT) and Economic Growth Nexus: A Comparative Global Analysis

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Abstract

This paper analyzes the impact of diverse ICT indicators on economic growth at both global and regional levels. The analysis is based on a sample of 149 counties over the period 1980-2015. The empirical exercise is based on Ordinary Least Squares (OLS), Pooled OLS, Two Stage Least Squares **(**2SLS) and Generalized Method of Moments (GMM) techniques. The results show that all indicators of ICT accelerate both global and regional economic growth. However, some indicators such as online service, telecommunication infrastructure and e-government are comparatively more conducive in enhancing economic growth. The analysis for the subsamples of developed, emerging and developing countries reveal that emerging and developing countries are gaining more form ICT than developed countries, validating the argument that these economies are 'leapfrogging' through ICT. Moreover, the Principal Component Analysis (PCA) of ICT indicators also confirms the results. Findings of the study are shown to be robust to different specifications, to alternative econometric techniques, to different control variables, and to regional sub-samples. This study contributes to the economic growth-ICT nexus by introducing the novel measures of ICT infrastructure such as telecommunication, online service and e-government index unlike previous literature that mainly emphasized the importance of fixed telephone and broadband subscriptions. Findings of the study imply that investment in ICT infrastructure is essential to take the maximum benefit from the knowledge economy of 21st century.

Keywords: telecommunication infrastructure, e-government index, ICT Index, research and development, ICT infrastructure, SAARC, BRICS.

1. Introduction.

The investigation of different determinants of economic growth has been an active area of research in macroeconomics since 17th century. It is a symbol of development and vital for economic density. Economic growth is an important factor for welfare of a society. It has prevalent impacts on well-being of masses. People of different countries have

different experiences regarding their living standards because of divergence in growth rates and growth patterns which differ to a great extent over time among economies.

There are some enormously prosperous countries such as U.S, U.K and Japan in the world. In contrast, there are many countries where major segment of population is living nearer to the subsistence level due to low economic growth. These differences in growth are not any coincidence rather a result of a number of factors. In this connection, the variation in economic growth invites scholars to explore the factors of economic growth and their significance in growth process.

Different theories of economic growth are developed to explore the factors of economic growth. The old economic growth theories, such as classical and neoclassical theories, are based on prevailing circumstances at that time and considered labor, land, physical capital as primary determinants of economic growth. Later, economists such as Romer (1986) and Lucas (1990) have brought new breakthroughs in growth theories by incorporating the role of human capital in growth models. These theories are referred as endogenous growth theories. Endogenous growth theory predicts that economic growth depends on endogenous factors rather than exogenous factors. The endogenous factors such as human capital, innovation, and knowledge are significant contributors to economic growth.

There is huge literature presented on socio-economic factors of economic growth but an equal amount of attention is not paid to the links of ICT with economic growth. Modern economic growth theories primarily focus on the contribution of technology, research and development (R&D) and knowledge innovations to induce growth. These new theories also suggest that economic growth mainly depends on ICT investments. However, the full and authentic empirical verification of this hypothesis is an open task that has captured the attention of many policy makers in the recent years. According to a report by World Bank (2016), digital technologies overcome information barriers, augment factors through automation and coordination, and transform products through scale economies and platforms. Consequently, digital technologies increase inclusiveness, efficiency and innovations in a knowledge economy.

Similarly, economic network theory is also an emerging field of research that applies scientific models to the analysis of economic phenomenon. Emanuel Castells is the pioneer of network theory who illustrates in his book “The rise of network society” that the changes in this world are coming from the advent of new information technology. Furthermore, innovations and connectivity alter the dynamic economic system and a number of major economic, social, cultural and technological transformations come together to present a new form of society (Castells, 2000).

ICT is the combination and integration of computer work stations, telecommunications, electronics, networks and information media that affect individuals, firm and economy as a whole. The larger utilization of ICT has reduced the communication costs which ultimately facilitated the flow of knowledge and information. ICT is the contemporary symbol of technological revolution and key factor of economic growth especially in industrial economies (Farhadi et al., 2012). From the last few decades, the penetration of internet and mobile phones has accelerated the diffusion of ICT technology. The rise in ICT has networked economies globally. Its institutional superstructure and technological infrastructure are increasingly integrated into dense, multimodal network from the

individuals' micro level organization to global level through global supply chain and global cities. Now economies are interconnected to the global cities in this 21st century because ICT enabled network organizations are thriving and emerging in these economies.

For most authors, promotion of ICT is essential, for better living conditions, innovations, stimulating entrepreneurship and economic growth. ICT can play role in trade facilitation and regional integration. It also facilitates sharing of information and knowledge, cross border communication and financial transactions. ICT also produces favorable outcomes for R&D, trade and financial development and also strengthens efficiency and skills of labor that indirectly affect economic growth. Similarly, ICT also contributes in other important sectors of economy such as e-commerce, e-business, e-trading and e-banking. E-commerce is reducing travel administration, market search and communication costs and also tackles many limitations of exporters/ producers by maximizing access to information, managing potential market isolation and by reducing high entry costs (Xing, 2018). ICT has also become the center of banking system in recent years because it improves the cost efficiencies of commercial banks that enhance firm's value of stocks in the market (Lin and Lin, 2007).

Similarly, ICT influences trade in many ways. For example, internet technologies create the basis of new markets, new business and new goods and services in this digital economy that, in turn, enhance the e-commerce development and economic growth. ICT is a milestone for e-trading by unlocking potentials and enhancing bilateral trade that, in turn, accelerate economic growth (Were, 2015; Xing, 2018). Modern infrastructure of telecommunication also leads to increase in GDP through smoothness of foreign investment and positive value of exports (Majeed and Ahmad, 2006; Zahra et al., 2008).

An extensive work has been produced on ICT and economic growth linkages. The studies mostly consider the common measures of ICT such as internet users, fixed telephone and broadband subscriptions (Waverman et al., 2005; Sridhar et al., 2007; Zahra et al., 2008; Rapson and Schiraldi, 2013; Kaur and Malhotra, 2014; Jin and Cho, 2015; Aghaei and Rezagholizadeh, 2017). However, these studies ignore the other important measures of ICT such as e-government index, online service index, telecommunication infrastructure, and Principal Component Analysis (PCA) of ICT measures.

This study contributes in ICT-growth nexus through a number of ways. First, this study uses novel measures of ICT, including conventional measures of ICT. Second, this study uses a large sample of 149 economies unlike previous studies which are narrow in their scope as they cover only a country or a region or a small sample size (Colecchia and Schreyer, 2001; Jalava and Pohjola, 2008; Lovric, 2012; Salimifar and Behname, 2013; Duner, 2015; Niebel, 2018). Third, this study also addresses the issue of endogeneity using novel and valid instruments of ICT. Finally, this study provides a comprehensive regional analysis as well.

This study also conducts a comparative analysis of developed, developing and other regional blocks. The impact of ICT on growth can vary depending upon the level of development and regional classification of countries under investigation. Theory suggests that, on the one hand, developing countries may gain less from investment in ICT because they lack complimentary requirements for ICT. For example, lower absorptive

capacity or lack of investment in human capital and research and development. On the other hand, Steinmueller (2001) purposes the theory that developing economies can leapfrog the conventional methods of productivity. The additional gains from increased productivity can be triggered by "'ICT-related spillovers or network effects Stiroh (2002)" because ICT lowers transaction costs and speeds up the process of knowledge creation. When firms use similar levels or types of ICT then network effects become more pronounced.

The broader objectives of present research include how different indicators of ICT affect economic growth, whether the ICT impacts are same for both global and regional levels, whether overall effects of ICT variables on economic growth are consistent with individual impact. This study highlights the significance of other important factors of ICT such as e-government index, online service index, telecommunication infrastructure and ICT PCA in determining economic growth at both global and regional levels that have been long ignored in previous literature. This research also explores, whether results are robust to the use of different data sets, alternative estimation methods and different control variables. The major implication of this study is that ICT exerts beneficial impacts on both global and regional economic growth. The research suggests that policies aimed to promote more ICT technologies especially online services, and e-government to enhance more global and regional economic growth.

Rest of the study is organized in the following manner. Section 2 reviews the past studies which analyses the impact of ICT on economic growth. Section 3 discusses variables and model used in this study. Section 4 presents construction of variables and data description. The discussion on results and estimation techniques is provided in Section 5, while Section 6 concludes the study with policy recommendations.

2. Literature Review

The macroeconomic empirical studies on ICT and growth are generally based on growth accounting and econometric studies. Earlier literature generally focused on developed economies. Many empirical studies showed positive contribution of ICT capital to economic growth after the mid-1990s in advanced economies. For example, Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) focused on the productivity effect of ICT in the US and confirmed positive contribution of ICT for growth of US economy. Using the data from 1979 to 2000, Inklaar et al., (2005) compared ICT contribution for the US with European countries and showed that ICT contribution is higher in the US than Europe. Jalava and Pohjola (2008) study the repercussions of ICT and electricity on economic growth in Finland by utilizing cross section and panel regressions for the time period 1990-2004. Results indicate that ICT role is three times more in GDP growth as compared to electricity.

The theoretical literature generally predicts favorable effects of ICT on economic growth of developing and developed economies. Levine (1997) argues that ICT helps to relax barriers to information access and increases investment and growth. Quah (2002) argues that the ICT revolution is improving broad based education, labor skills and consumer sophistication. The increasing use of technology improves labor productivity and as a result economic growth increases.

Mahyideen et al. (2012) examine the advantageous outcomes of ICT for economic growth through two channels. First conventional channel proposes that ICT infrastructure

raises the private inputs productivity and reduces cost of production. Second channel shows that ICT is important to save the time cost of people and enhances their efficiency.

In the same way, some researchers find useful contribution of broadband and internet in economic growth through the channel of fall in market friction and falling permanent information cost of entering in market (Koutroumpis, 2009; Choi and Yi, 2009; Zahra et al., 2008; Rapson and Schiraldi, 2013; Kaur & Malhotra, 2014). Jin and Cho (2015) find that internet, telecom profit, mobile adoption and ICT investment significantly affect the economic growth.

Later on, studies by Saglam (2018) and Edquist and Henrekson (2017) also explore the positive role of internet, ICT investments, mobile phones and R&D for economic growth. Their results indicate that diffusion in ICT also enhances the share of R&D and human capital formation that indirectly cause positive impact on economic growth. Saidi and Mongi (2018) analyze the casual relationship between ICT, education, R&D and economic growth by utilizing panel data set. They found the bidirectional causality between ICT and R&D in the short run while causality between education and ICT in the long run. Empirical results of their study showed the strong impacts of ICT and R&D on economic growth. Majeed and Khan (2018) found empirical evidence that ICT improves population health outcomes. Accordingly, healthy population contributes more to growth.

One strand of the literature explores that how the benefits of ICT led innovations and developments can be maximize to attain rapid and sustained levels of economic growth. Many studies are conducted for this purpose. For instance, Roller and Waverman (2001) argue that advancements in telecommunication contribute more to foster economic growth through FDI inflows and network externalities. Vu (2004) argues that more ICT benefits can be captured through improvement in English fluency and educational reforms and quality of institutions.

Similarly, appropriate outcomes of landline and mobile phones for economic growth are noticed in poor and developing countries through more spread of telecom by reduction in digital divide and empowering people and through regulatory policies (Waverman et al., 2005; Sridhar et al., 2007). Kozma (2005) discusses the relationship between ICT based educational reforms and socioeconomic growth. Kozma (2005) asserts that there is a prevalent optimism regarding ICT that it can play an important part in economic growth, development, poverty alleviation, organizational restructuring and productivity. Becchetti and Adriani (2005) claimed that ICT is a key factor to demonstrate the conditional convergence in growth rates as well as in growth levels.

One strand of the literature focused only on communication technology (CT). Roller and Waverman (2001) showed, in a sample of 21 OECD countries, that wireline telecommunications cause a positive effect on the GDP of 21 OECD countries. Czernich et al. (2011) also found similar results. Using a panel data of 20 OECD countries, they showed that increasing penetration of broadband led to increase in growth rate of GDP per capita. Recently, Bertschek et al. (2015) conducted a literature survey and confirmed a positive effect of broadband internet on economic growth.

In contrast, another strand of the literature finds negative effects of ICT on economic growth. For example, using US manufacturing industries data from 1984 to 1999, Stiroh (2002) found a negative output elasticity of ICT. Similarly, O'Mahony and Vecchi (2005)

found the negative impact of ICT on output growth for industries in U.K due to lack of skill and paucity of ICT investment but found positive impact in U.S. Lee et al. (2005) observed ICT impacts on economic development through different channels such as FDI and spillover effects. The results showed that developing countries do not get benefits from ICT investments because of low productivity improvements in developing countries. According to Ishida (2014), ICT caused lower energy consumption moderately but it did not contribute in economic growth of Japan. Hofman et al. (2016) examined the contribution of ICT to productivity and economic growth of Latin America. Their results showed that the contribution of ICT to economic growth is low.

Another strand of the literature debates the relative contribution of ICT in developing, emerging and developed countries. Does ICT contribute more to economic growth in emerging and developing countries? The theoretical literature predicts mixed answers to this question. Steinmueller (2001) argues that ''ICTs have the potential to support the development strategy of 'leapfrogging', i.e. 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." Thus, the 'leapfrogging' hypothesis implies that the impact of ICT on economic growth of emerging and developing economies is significantly larger than those of developed economies. However, 'leapfrogging' crucially depends on the 'absorptive capacity' of emerging and developing countries. The absorptive capacity is defined as "the ability and effort of workers and managers to apply new technology" (Kneller, 2005).

Now question arises as to why ICT may have a stronger impact on growth of emerging and developing economies. A report by the United Nations (2011) provides different links of ICT with economic performance of emerging and developing economies. First, ICT investment can decrease the administrative costs of firms as a result of e-government adoption. Second, ICT can facilitate training and advisory services. Third, ICT enhances access to relevant information. Fourth, ICT serves as a tool to reduce travel and transaction costs. These services are not specific to emerging and developing economics, however, these economies often provide services that were previously missing in non-digital or digital economy.

Stanley et al. (2018) conduct the meta-analysis for the ICT and economic growth relationship for developed and developing countries. They discovered positive impacts of cell technologies, internet and landline on economic growth. Niebel (2018) and Aghaei and Rezagholizadeh (2017) also found that ICT contributes to economic growth in OIC, developed as well as emerging and developing countries. Niebel (2018) did not confirm leapfrogging argument using a sample of 59 countries from 1995-2010.

E-government is another form of ICT applications. E-government is referred to the use of Information and Communication Technology (ICT) by government for "delivering and sharing" of information and better services to the people. E-government increases economic growth of the economy through combating the corruption, increasing the trade, and strengthening the financial development by supervising the administration reforms and lowering the transaction costs Majeed and Malik, 2016a, 2016b). The literature suggests that there should be an improvement in e-government, broadband infrastructures, education system, e-commerce and internet enabled services to enhance future economic growth (Ma et al., 2005; Vu, 2011, Majeed and Malik, 2016c).

The above literature review shows some gaps in the existing literature on ICT and growth. First, the empirical studies generally focus on ICT-growth nexus only for developed economies (Jorgenson and Stiroh, 2000; Oliner and Sichel, 2000; Inklaar et al., 2005; Jalava and Pohjola, 2008). Some studies question the positive contribution of ICT to growth (Stiroh, 2002; O'Mahony and Vecchi, 2005; Hofman *et al.* 2016). Third, the extant literature on developing economies provides mixed evidence on 'leapfrogging' argument (Steinmueller, 2001; Niebel, 2018; Aghaei and Rezagholizadeh, 2017). Fourth, many studies have been incorporated for small number of countries and limited time span (Colecchia and Schreyer, 2001; Duner, 2015; Jalava and Pohjola, 2008; Lovric, 2012; Salimifar and Behname, 2013). Fifth, previous literature mainly emphasized the importance of few ICT indicators such as, internet, ICT investments, fixed telephone and broadband subscriptions. Sixth, most of the studies are country or region specific (Waverman et al., 2005; Sridhar et al., 2007; Niebel, 2018; Stanley et al., 2018). Seventh, many studies do not address the issue of endogeneity.

Nevertheless, this study adds to the existing literature by using different measures of ICT to assess their relative strengths in influencing economic growth and also incorporates broader view of ICT and economic growth. This research does not rely on limited time span and also provides a regional and global picture of analysis using large number of countries. This study conducts a rigorous analysis to assess the validity of leapfrogging hypothesis. Moreover, this study takes care of the issue of endogeneity using novel and valid instruments of ICT.

3. Methodology

Economic growth is an imperative economic objective in 21st century. It plays an important role in determining welfare and wellbeing of the people in knowledge-based economy. More economic growth means more material ability and availability to address the economic issues. The role of new advancements in technology, knowledge and innovations is growing rapidly. Economic growth is progressively depending on the capability to obtain new information and knowledge and apply it in all aspects of life in knowledge-based economy. However, long run economic growth is a fundamental factor to measure how consistently an economy is growing. Given the significance of economic growth, understanding of the key factors of growth remains a foremost concern of social scientists and economists. In this connection many scholars have considered the importance of economic growth by taking different variables that affect growth in one way or another.

It is not possible to bring all factors of growth in a single research because of complexities of estimation. Accordingly, present study mainly focuses on the impact of ICT on economic growth. The functional form of the model of present study can written as,

$$Y_{it}=A_{it}f\left(K_{it},\ H_{it},L_{it},ICT_{it}\right) \qquad (3.1)$$

Where, i = 1,2,3,…….n; t = 1,2,3,…… T

Y_{it} is GDP per capita, K represents gross fixed capital formation (which is used as a proxy of physical capital), H stands for human capital, L denotes labor force. ICT represents eight different measures of ICT including mobile-cellular subscriptions, internet users, fixed telephone subscriptions, fixed broadband subscriptions,

telecommunication infrastructure index, online service index, e-government index and ICT PCA. Empirical model of present study is evolved by the Cobb-Douglas production function given by Mankiw et al. (1992).

$$Y_{it} = A_{it}K_{it}^{\alpha}H_{it}^{\beta}L_{it}^{1-\alpha-\beta} \quad (3.2)$$

By taking log of the equation (3.2) we get another equation,

$$LogY_{it} = LogA_{it} + \gamma_1 Log\,(K)_{it} + \gamma_2 H_{it} + \gamma_3 LogL_{it} \quad (3.3)$$

Let suppose technology is evolving over time is described below.

$$A_i = A\,(0)\, e^{\varphi it} \quad (3.4)$$

By taking log of equation (3.4) we get the following expression,

$$LogA_{it} = LogA_0 + \varphi_{it} \quad (3.5)$$

Where φ represents country's technological growth

Suppose investments in ICT boost the progress of technology through facilitating research and development (R&D), new innovations and knowledge then φ can be specified as following bellow.

$$\varphi_{it} = \beta_1 + \beta_2 ICT_{it} \quad (3.6)$$

By substituting equation (3.6) in equation (3.5) we get following expression,

$$LogA_{it} = \beta_0 + \beta_1 + \beta_2 ICT_{it} \quad (3.7)$$

Where $\beta_0 + \beta_1 = \beta$

$$LogA_{it} = \beta + \beta_1 ICT_{it} \quad (3.8)$$

By adding equation 3.8 into equation 3.3 we get the following expression,

$$LogY_{it} = \beta + \beta_1 ICT_{it} + \gamma_1 Log\,(K)_{it} + \gamma_2 (H)_{it} + \gamma_3 Log\,(L)_{it} + \epsilon_{it} \quad (3.9)$$

Present study is using inflation as a control variable to examine the robustness of the results for empirical analysis. So, (3.10) is the first final model of this study.

$$LogY_{it} = \beta + \beta_1 ICT_{it} + \gamma_1 Log\,(K)_{it} + \gamma_2 (H)_{it} + \gamma_3 Log\,(L)_{it} + \gamma_4 inf_{it} + \epsilon_{it} \quad (3.10)$$

According to the hypothesis (H_1) of this study the expected sign of β_1 is positive and significant because ICT accelerates economic growth (Koutroumpis, 2009; Zahra et al., 2008; Rapson and Schiraldi, 2013; Jin and Cho, 2015; Saidi and Mongi, 2018).

4. Data and Variable Description

The analysis covers 149 countries for the time period of 1980-2015. Economic growth is dependent while ICT is independent variable. Table 14 in appendix represents the summary statistics of cross sectional data that presents detailed review of data. It provides the information and maximum values on mean and standard deviation of ICT and economic growth. ICT levels show variation across countries. While economic growth is highest in United States with number 16.2619 whereas, Sao Tome and Principe reports poor performance on GDP growth as it secures lowest GDP value 5.89253. Table 1 gives brief description, sources and construction of variables utilized in analysis.

Table 1: Summary of Variables

Variables	Definition of Variables	Source
Dependent Variable		
Economic Growth	We have used real GDP as a measure of economic growth and dependent variable of present study. Real GDP per capita is measure of economic growth that is constructing at 2011 constant prices.	Feenstra *et al.*, (2015)
Independent Variables (Control Variables)		
Labor Force	People who ages 15 and more than 15 have included in labor force (employed and unemployed) that also supply labor to produce goods and services during a specified time period.	World Bank (2016)
Physical Capital	Gross fixed capital formation is utilized as a measure of physical capital. It includes machinery, land improvements, and constructions of railways, roads, industrial and commercial buildings.	World Bank (2016)
Human Capital	We have utilize human capital index as a measure of human Capital which consists of four components including tertiary, secondary and primary gross enrolment ratio, expected schooling years, average schooling year and adult literacy rate.	United Nations (2016)
Inflation Rate	Inflation rate shows the price change rate in economy as a whole. It is measured by GDP implicit deflator (GDP ratio in local current currency) at annual growth rate.	World Bank (2016)
Different Measures of Focused Variables (ICT)		
Mobile-cellular Telephone Subscriptions (per 100 people)	Mobile cellular telephone subscriptions are divided into the number of repaid active accounts (that have utilized during last three months) and number of postpaid subscriptions to a public telephone service	International Tele. Union (2016)
Internet Users (per 100 people)	Persons that are used internet (through any location) in last twelve months are called internet users.	World Bank (2016)
Fixed Telephone Subscriptions (per 100 people)	Fixed telephone subscriptions is the sum of fixed public payphone, fixed wireless local loop, voice over IP subscriptions and ISDN voice channel equivalents.	World Bank (2016)
Fixed Broadband Subscriptions (per 100 people)	Satellite broadband, DSL, cable modem and other broadband subscriptions are part of this variable. Organization subscriptions and residential subscriptions both are included in fixed broadband subscriptions.	World Bank (2016)
Telecommunication Infrastructure	This variable is an arithmetic mean of five (standardized) indicators including internet users, mobile subscriptions, fixed broadband subscriptions,	United Nations (2016)

Index	fixed telephone lines, and number of mobile subscriptions.	
Online Service Index	Online service index value to a given country that is equivalent to the score (actual total) less the lowest score (total) and divided with range of total score value for every country.	United Nations (2016)
E-Government Index	E-Government index is three normalized scores weighted average on three dimensions of e-government. The dimensions are telecommunication infrastructure (telecommunication infrastructure index), human capital index and quality and scope of online services (online service index).	United Nations (2016)
ICT PCA	We are developed PCA called ICT PCA that is composite of four proxies including fixed telephone subscriptions, fixed broadband subscriptions, internet users & mobile telephone subscriptions.	World Bank (2016) & ITU (2016)
Instrumental Variables		
Research and Development Expenditure	R&D covers experimental development, basic and applied research. R&D expenditures are capital and current expenditure including both private and public on the creative work to promote knowledge.	World Bank (2016)
Energy Use	Energy use refers to use of primary energy before transformation to other end-use fuels.	World Bank (2016)

5. Results and Discussion

The cross sectional and panel data estimation techniques are used to examine the impact of ICT on economic growth.

5.1. Cross Sectional Results

In estimation present study utilizes the different important proxies of ICT with fixed control variable in each regression. Table 2 shows the OLS results of ICT and economic growth indicators for 149 cross sections averaged over 1980-2015. Column 1 shows that there exists a positive and highly significant relationship between economic growth and ICT. The co-efficient of mobile-cellular telephone subscriptions (Mob-Tele-Subs) shows that one unit increase in mobile-cellular telephone subscriptions leads to 0.02 units increase in GDP per capita. It is because mobile phones improve the use of information, encourage access to information, reduce research costs and enhance market efficiency, thereby increasing economic growth. This result is consistent with the theoretical argument that is mobile phones are much accessible as compared to other alternatives in term of geographic coverage, cost and the ease of use (Aker and Mbiti 2010). The results are consistent with Saidi and Mongi (2018).

Table 2: OLS Results of Economic Growth and ICT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.995***	0.977***	0.962***	0.961***	0.957***	0.870***	0.906***	0.996***
	(0.0290)	(0.0302)	(0.0313)	(0.0330)	(0.0300)	(0.0347)	(0.0314)	(0.0291)
Physical Capital	0.346*	0.369*	0.391*	0.357	0.341*	0.279	0.366*	0.365*
	(0.193)	(0.200)	(0.209)	(0.222)	(0.200)	(0.207)	(0.202)	(0.197)
Human Capital	2.004***	2.491***	2.844***	3.303***	2.414***	2.667***	1.190**	2.026***
	(0.388)	(0.393)	(0.398)	(0.411)	(0.399)	(0.415)	(0.552)	(0.391)
Inflation	-0.00021	-0.00012	-0.0004	-0.0005	-0.00009	-0.0004	-0.0002	-0.0002
	(0.00045)	(0.00048)	(0.0005)	(0.0005)	(0.00048)	(0.0004)	(0.0004)	(0.0004)
Mob-Tele-Subs	0.0199***							
	(0.00232)							
Internet Users		0.0351***						
		(0.00492)						
Fix-Tele-Subs			0.0271***					
			(0.00452)					
Fix-Broad-Subs				0.0464***				
				(0.0105)				
Tele-Infra-Index					2.449***			
					(0.340)			
Online-Ser-Index						2.301***		
						(0.378)		
E-Gov-Index							3.710***	
							(0.534)	
ICT PCA								0.666***
								(0.0779)
Constant	-7.785***	-7.339***	-7.238***	-7.319***	-6.900***	-5.812***	-6.355***	-6.669***
	(0.750)	(0.793)	(0.828)	(0.891)	(0.798)	(0.878)	(0.821)	(0.781)
Observations	150	151	151	150	151	151	151	149
R-squared	0.913	0.904	0.896	0.885	0.904	0.897	0.903	0.912

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Column 2 shows the positive and significant relationship between internet users and economic growth. The coefficient on internet shows that one unit increase in internet causes 0.0351 units increase in economic growth. Persons that are used internet (through any location) in last twelve months are called internet users. Internet enhances the economic growth through fall in market friction and falling permanent information cost

of entering in market (Choi and Yi, 2009; Rapson & Schiraldi, 2013). The studies of Jin and Cho (2015) and Saidi and Mongi (2018) are consistent with our result.

Column 3 depicts the positive and highly significant relationship between economic growth and fixed telephone subscriptions (Fix-Tele-Subs), implying that one unit increase in fixed telephone subscriptions leads to 0.0271 units increase in GDP per capita. Our finding is consistent with the study of Tripathi and Inani (2015).

Column 4 shows the positive and highly significant relationship between fixed broadband subscriptions (Fix-Broad-Subs) and economic growth, implying that one unit increase in e-government index leads to 3.71 units increase in GDP per capita. E-government increases economic growth of the economy through combating the corruption, increasing the trade, and strengthening the financial development by supervising the administration reforms and lowering the transaction costs (Ma et al., 2005; Majeed and Malik, 2016a).

Column 8 shows the positive and highly significant relationship between ICT PCA and economic growth, implying that one unit increase in ICT PCA leads to 0.67 units increase in GDP per capita. It confirms the beneficial impacts of ICT on economic growth because development in ICT opens the avenues of opportunities and greater benefits for economies. ICT can play an important part in economic growth, development, poverty alleviation, organizational restructuring and productivity (Kozma, 2005; Jin and Cho, 2015).

The results of control variables are consistent with the findings of previous studies. In all eight equations, labor force has positive and significant impacts on economic growth with coefficients 0.961, 0.957, 0.870, 0.906 and 0.996, respectively. These results are consistent with Mankiw et al. (1992) who believe that a rise in labor force increases the physical capital marginal productivity that enhances economic growth.

Physical capital also has positive and significant impacts on GDP with coefficients 0.346, 0.369, 0.391, 0.357, 0.341, 0.279, 0.366 and 0.365, respectively. Physical capital is a key determinant of economic growth in the long run. This finding is consistent with Siddique and Majeed (2015), Majeed (2017) and Aghaei and Rezagholizadeh (2017).

Human capital has also positive and highly significant impacts on economic growth. the coefficient on human capital implies that one unit increase in human capital increases GDP per capita by 2.01, 2.49, 2.84, 3.31, 2.41, 2.67, 1.19 and 2.036. Investment in human capital and expenditures on education (primary and secondary) are fundamental for economic growth and economic progress. Our finding is consistent with the study of Pelinescue (2015), Siddiqui and Rehman (2017), Majeed (2017) and Aghaei and Rezagholizadeh (2017). Inflation rate has negative but insignificant impact on GDP.

There are studies that show economic growth of a country also affects adoption of ICT. For instance, literature presents that U.S (high income economy) gained more benefit in terms of productivity and economic growth by investing in ICT technology.

Endogeneity issue needs to be addressed because OLS estimates become biased and inefficient in the presence of endogeneity problem. The Two Stage Least Squares (2SLS) method is more reasonable and efficient to tackle the problem of endogeneity. The study applies the 2SLS technique on the cross sectional data to address the above issue. Test of over identified restrictions is also employed to check the validity of instruments. P-values of Sargan test and Basmann accept null hypothesis indicating that instruments are valid.

Table 3 is based on the 2SLS estimated regression results for GDP and ICT indicators. All endogenous variables are regressed on exogenous variables that are initial values and exogenous instrument. These 2SLS results are consistent with our OLS findings. In column 1 the coefficient of mobile-cellular telephone subscriptions (Mob-Tele-Subs) is highly significant and sufficiently large indicating the strong positive relationship between economic growth and ICT. One percent increase in mobile telephone subscriptions leads to 0.0215 units increase in GDP per capita.

Column 2 shows the positive relationship between ICT and internet users. While, column 3 shows the positive and highly significant relationship between GDP and fixed telephone subscriptions (Fix-Tele-Subs), implying that one unit increase in fixed telephone subscriptions leads to 0.02 unit increase GDP per capita. This finding is similar with previous research. Column 5 shows the positive and highly significant relationship between economic growth and telecommunication infrastructure index (Tele-Infra-Index) implying that one unit increase in telecommunication infrastructure index causes 2.07 unit increases in GDP per capita.

Table 3: 2SLS Results of Economic Growth and ICT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	1.000***	0.983***	0.976***	0.961***	0.970***	0.889***	0.919***	1.000***
	(0.0340)	(0.0428)	(0.0384)	(0.0465)	(0.0369)	(0.0468)	(0.0390)	(0.0340)
Physical Capital	0.750***	0.712**	0.720***	0.538	0.673***	0.581**	0.702***	0.750***
	(0.225)	(0.284)	(0.256)	(0.337)	(0.245)	(0.260)	(0.250)	(0.225)
Human Capital	1.764***	3.214**	3.082***	4.904***	2.718***	3.186***	1.821***	1.764***
	(0.576)	(1.278)	(0.472)	(1.649)	(0.469)	(0.539)	(0.691)	(0.576)
Inflation	-0.0002	-0.0007	-0.0007	-0.00158	-0.00048	-0.00082	-0.00057	-0.00026
	(0.0004)	(0.0007)	(0.0005)	(0.0011)	(0.0005)	(0.00055)	(0.00053)	(0.00048)
Mob-Tele-Subs	0.0215***							
	(0.00412)							
Internet Users		0.0215						
		(0.0225)						
Fix-Tele-Subs			0.0229***					
			(0.0057)					
Fix-Broad-Subs				-0.0210				
				(0.0650)				
Tele-Infra-Index					2.077***			
					(0.416)			
Online-Ser-Index						1.645***		
						(0.562)		
E-Gov-Index							3.023***	
							(0.712)	
ICT PCA								0.723***
								(0.138)
Constant	-9.031***	-8.77***	-8.56***	-8.63***	-8.23***	-7.189***	-7.742***	-7.724***
	(0.921)	(1.074)	(1.068)	(1.285)	(1.031)	(1.192)	(1.063)	(0.945)
Observations	92	94	94	94	94	94	94	92
R-squared	0.925	0.902	0.899	0.857	0.906	0.894	0.903	0.925
Sargan chi2	P= 0.371	p = 0.553	p = 0.856	p = 0.756	p = 0.786	p = 0.482	p = 0.538	p = 0.371
Basmann chi2	P= 0.396	p = 0.578	p = 0.867	p = 0.773	p = 0.801	p = 0.508	p = 0.563	p = 0.395

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Column 6 shows the positive and significant relationship between online service index (Online-Ser-Index) and economic growth implying that one unit increase in online service index increases GDP per capita by 1.645 units. Column 7 presents the positive and significant relationship between economic growth and E-government index (E-gov-index) implying that one unit increase in e-government index increase GDP per capita by 3.023 units. A positive and highly significant relationship between ICT PCA and economic growth is illustrated in column 8 where, one unit increase in ICT PCA

increases GDP per capita by 0.723 units. The results of control variables remain same as in OLS.

5.2 Panel Regression Analysis

Panel data has more degree of freedom and sample variability and also has capability to incorporate complexity of human behavior as compared to cross sectional data. Panel data gives more accurate predictions for outcomes by pooling the data (Hsiao, 2007). Accordingly, we also pooled panel for the validity and accuracy of our results. The results of pooled panel, fixed and random effects models are consistent with the findings of OLS and 2SLS as illustrated in Tables 4-6.

Table 4: Pooled OLS Results of Economic Growth and ICT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.972***	0.965***	0.970***	0.963***	0.962***	0.886***	0.908***	0.959***
	(0.0144)	(0.0125)	(0.0130)	(0.0141)	(0.0120)	(0.0142)	(0.0127)	(0.0145)
Physical Capital	0.247***	0.385***	0.384***	0.367***	0.372***	0.335***	0.341***	0.329***
	(0.0702)	(0.0599)	(0.0623)	(0.0765)	(0.0576)	(0.0627)	(0.0590)	(0.0799)
Human Capital	3.121***	2.568***	2.223***	3.090***	2.339***	2.691***	1.201***	2.528***
	(0.140)	(0.126)	(0.152)	(0.146)	(0.124)	(0.134)	(0.168)	(0.171)
Inflation	0.00339	0.0100***	0.0044*	0.00257	0.0118***	0.0054**	0.0115***	0.011***
	(0.0027)	(0.0025)	(0.0026)	(0.0030)	(0.0024)	(0.0026)	(0.0025)	(0.003)
Mob-Tele-Subs	0.0088***							
	(0.000627)							
Internet Users		0.0194***						
		(0.000956)						
Fix-Tele-Subs			0.0293***					
			(0.00172)					
Fix-Broad-Subs				0.0348***				
				(0.00275)				
Tele-Infra-Index					2.461***			
					(0.109)			
Online-Ser-Index						1.985***		
						(0.119)		
E-Gov-Index							3.612***	
							(0.172)	
ICT PCA								0.512***
								(0.0318)
Constant	-7.190***	-7.079***	-6.851***	-6.966***	-6.891***	-5.980***	-6.156***	-6.16***
	(0.319)	(0.278)	(0.293)	(0.341)	(0.267)	(0.306)	(0.281)	(0.359)
Observations	853	980	989	880	994	994	994	732
R-squared	0.873	0.891	0.879	0.867	0.898	0.879	0.893	0.882

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1***)

Table 5: Fixed Effects Results of Economic Growth and ICT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.638***	0.948***	1.277***	0.897***	1.046***	1.216***	1.061***	0.612***
	(0.0504)	(0.0466)	(0.0427)	(0.0451)	(0.0442)	(0.0448)	(0.0447)	(0.0543)
Physical Capital	0.0586***	0.150***	0.0930***	0.226***	0.130***	0.107***	0.120***	0.209***
	(0.0179)	(0.0194)	(0.0209)	(0.0221)	(0.0198)	(0.0211)	(0.0200)	(0.0214)
Human Capital	0.112*	-0.0687	-0.419***	-0.377***	0.0777	-0.161**	-0.284***	-0.117
	(0.0663)	(0.0661)	(0.0766)	(0.0709)	(0.0701)	(0.0715)	(0.0672)	(0.0790)
Inflation	0.000409	-0.000755	-0.000749	-0.000822	-0.000127	-0.00094	-0.000588	-0.00014
	(0.000525)	(0.00058)	(0.00063)	(0.00063)	(0.00060)	(0.00064)	(0.00061)	(0.00059)
Mob-Tele-Subs	0.00298***							
	(0.000145)							
Internet Users		0.0044***						
		(0.00037)						
Fix-Tele-Subs			0.0064***					
			(0.00123)					
Fix-Broad-Subs				0.0069***				
				(0.000686)				
Tele-Infra-Index					0.674***			
					(0.0543)			
Online-Ser-Index						0.209***		
						(0.0395)		
E-Gov-Index							0.830***	
							(0.0719)	
ICT PCA								0.151***
								(0.0103)
Constant	1.204	-3.574***	-8.140***	-2.569***	-5.172***	-7.406***	-5.301***	1.706**
	(0.758)	(0.697)	(0.661)	(0.687)	(0.661)	(0.680)	(0.671)	(0.820)
Observations	853	980	989	880	994	994	994	732
R-squared	0.722	0.668	0.609	0.637	0.655	0.605	0.648	0.667
Number of id	149	150	150	148	150	150	150	147

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1***

Table 6: Random Effects Results of Economic Growth and ICT

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.853***	0.932***	1.087***	0.933***	0.962***	1.025***	0.959***	0.840***
	(0.0300)	(0.0281)	(0.0287)	(0.0300)	(0.0269)	(0.0294)	(0.0277)	(0.0315)
Physical Capital	0.0532***	0.160***	0.117***	0.228***	0.149***	0.136***	0.138***	0.185***
	(0.0205)	(0.0212)	(0.0233)	(0.0241)	(0.0214)	(0.0235)	(0.0218)	(0.0240)
Human Capital	0.345***	0.214***	-0.291***	-0.112	0.393***	0.0875	-0.0922	0.191**
	(0.0745)	(0.0716)	(0.0834)	(0.0764)	(0.0737)	(0.0778)	(0.0717)	(0.0880)
Inflation	0.000348	-0.000844	-0.0016**	-0.00119*	-0.000146	-0.0016**	-0.000854	-0.000238
	(0.000607)	(0.000654)	(0.00072)	(0.000711)	(0.00067)	(0.00072)	(0.00068)	(0.00069)
Mob-Tele-Subs	0.0026***							
	(0.000138)							
Internet Users		0.0054***						
		(0.000362)						
Fix-Tele-Subs			0.0113***					
			(0.00131)					
Fix-Broad-Subs				0.0081***				
				(0.000733)				
Tele-Infra-Index					0.917***			
					(0.0533)			
Online-Ser-Index						0.367***		
						(0.0429)		
E-Gov-Index							1.132***	
							(0.0727)	
ICT PCA								0.140***
								(0.00993)
Constant	-2.232***	-3.623***	-5.516***	-3.458***	-4.265***	-4.845***	-4.107***	-2.079***
	(0.461)	(0.430)	(0.454)	(0.466)	(0.414)	(0.455)	(0.426)	(0.487)
Observations	853	980	989	880	994	994	994	732
Number of id	149	150	150	148	150	150	150	147

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1***)

There is possibility of reverse causality between economic growth and ICT. Countries with high levels of GDP per capita are more capable to invest in new technologies than low income countries. For instance, a study by Stanley *et al.* (2018) showed higher ICT effects and benefits on economic growth in high income countries. Secondly, our panel data has heterogeneity issue. To tackle these issues, the study uses the instrumental variable technique namely Generalized Method of Moment (GMM). The GMM method gives more efficient and reasonable results even in the presence of endogeneity and heterogeneity. We have used research and development expenditure (R&D) and energy

use as exogenous instruments along with own lags as an internal instrument. R&D is the key determinant of ICT because ICT technology is boost up through research and development (R&D), new innovations and knowledge. For instance, Investment in R&D positively affects the ICT such as broadband penetration (Koutroumpis, 2009). While, Energy use is also highly correlated with ICT measures because both the ICT production and utilization of ICT devices require energy use. Moreover, the increasing use of energy affects economic growth through the expansion of ICT setup. Therefore, we employ R&D and energy use as exogenous instruments of ICT to assess the robustness of empirical findings.

The results for GMM are reported in Table 7. The results indicate the strong linkage between ICT and economic growth as all proxies of ICT are causing positive and significant impact oneconomic growth (Zahra *et al.*, 2008; Aker and Mbiti, 2012; Rapson and Schiraldi, 2013; Kaur and Malhotra, 2014; Tripathi and Inani, 2015; Ji and Cho, 2015, Aghaei and Rezagholizadeh, 2017; Saidi and Mongi, 2018). The overall results based on empirical findings of cross-sectional and panel data confirm that ICT is a tool that enhances economic growth. Broadband infrastructure, internet use, advancements in telecommunication, e- government, e-commerce and online services all are very important to enhance the economic growth. We also apply test of over identifying restriction to check the validity of instruments. The empirical estimates are sound and robust to the result of diagnostic tests.

Table 7: GMM Results of Economic Growth and ICT using Energy Use as Instrument

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.969***	0.979***	0.976***	0.970***	0.986***	0.828***	0.893***	0.967***
	(0.0233)	(0.0251)	(0.0245)	(0.0248)	(0.0229)	(0.0308)	(0.0235)	(0.0214)
Physical Capital	-0.498***	-0.150	-0.388**	-0.846**	-0.383**	-0.389*	-0.473***	-0.510*
	(0.173)	(0.228)	(0.191)	(0.345)	(0.184)	(0.208)	(0.176)	(0.262)
Human Capital	0.316	0.449***	0.392	1.640**	0.0276	0.349*	-1.432***	-0.206
	(0.291)	(0.159)	(0.286)	(0.755)	(0.162)	(0.182)	(0.321)	(0.492)
Inflation	0.00124	0.0107	-0.00098	-0.0152*	0.0066	-0.00084	0.011	0.0130
	(0.0084)	(0.0084)	(0.00823)	(0.0089)	(0.0072)	(0.0102)	(0.0086)	(0.0095)
Mob-Tele-Subs	0.0187***							
	(0.0015)							
Internet Users		0.0234***						
		(0.0018)						
Fix-Tele-Subs			0.0317***					
			(0.00257)					
Fix-Broad-Subs				0.0520***				
				(0.00904)				
Tele-Infra-Index					2.614***			
					(0.192)			
Online-Ser-Index						2.630***		
						(0.247)		
E-Gov-Index							4.519***	
							(0.356)	
ICT PCA								0.769***
								(0.0833)
Constant	-2.758***	-3.780***	-3.135***	-1.912	-2.868***	-1.146	-1.639**	-1.142
	(0.777)	(0.867)	(0.837)	(1.482)	(0.746)	(0.806)	(0.706)	(0.952)
Observations	128	121	128	112	129	129	129	116
R-squared	0.920	0.915	0.917	0.912	0.922	0.887	0.920	0.921
Hansen's J chi2	P= 0.01	P= 0.002	P= 0.001	P= 0.001	P= 0.03	P= 0.01	P= 0.014	P= 0.48

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1***)

5.3 Sensitivity Analysis

Our study conducts sensitivity analysis to check the robustness of results. In sensitivity analysis, we have introduced additional control variables that are life expectancy, current account balance, terms of trade and fertility rate to check whether our findings regarding the positive impact of ICT on economic growth are robust.

Table 8: Sensitivity Analysis of Variables

Variables	Life Expectancy	Current Account Balance	Terms of Trade	Fertility Rate
	Dependent Variable: Economic Growth			
Mobile telephone subscriptions **R-Squared**	0.0110*** 0.9445	0.0157*** 0.9275	0.0190*** 0.9185	0.0174*** 0.9145
Internet users **R-Squared**	0.0128*** 0.9390	0.0167*** 0.9165	0.0208*** 0.9066	0.0202*** 0.9161
Fixed telephone subscriptions **R-Squared**	0.0190*** 0.9362	0.0280*** 0.9223	0.0342*** 0.9114	0.0289*** 0.9080
Fixed broadband subscriptions **R-Squared**	0.0331*** 0.9442	0.0260*** 0.9239	0.0430*** 0.9100	0.0634*** 0.9089
Telecommunication infrastructure **R-Squared**	1.393*** 0.9404	1.945*** 0.9209	2.329*** 0.9081	2.212*** 0.9184
Online service index **R-Squared**	1.088*** 0.9344	1.811*** 0.9076	2.425*** 0.8896	1.983*** 0.8968
E-government index **R-Squared**	2.467*** 0.9419	3.495*** 0.9217	4.228*** 0.9112	3.676*** 0.9160
ICT PCA **R-Squared**	0.555*** 0.9391	0.715*** 0.9141	0.801*** 0.9091	0.679*** 0.9176

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 8 shows the estimation results of independent variables after adding additional control variables. The impact of ICT on economic growth remains same, highly significant and positive across all sensitivity variables. Similarly, mobile telephone subscriptions are still increasing economic growth significantly. The variables internet users, fixed telephone subscriptions, telecommunication infrastructure index, online service index, e-government index and ICT PCA remain positive and highly significant. The results of sensitivity analysis suggest that the variables of study are robust and not sensitive to additional variables included in econometric analysis.

5.4 Regional Analyses

This section presents the regional analysis of the relationship between ICT and economic growth by utilizing regional sub-samples. The results are obtained from panel data to examine the connection of ICT and growth among different regions of the world (Developed, Developing, European, BRICs, and SAARC countries). The results of regional analysis are reported in Tables 9-13, respectively.

Table 9: Results of Economic Growth and ICT in Developed Countries

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	LGDP	LGDP	LGDP	LGDP	LGDP	LGDP	LGDP	LGDP
Labor Force	1.086***	1.077***	1.080***	1.075***	1.062***	1.050***	1.042***	1.079***
	(0.0165)	(0.0148)	(0.0150)	(0.0151)	(0.0140)	(0.0170)	(0.0154)	(0.0153)
Physical Capital	-0.234*	-0.0364	0.00708	-0.0301	-0.0105	-0.105	-0.0814	-0.219*
	(0.135)	(0.118)	(0.121)	(0.122)	(0.110)	(0.121)	(0.114)	(0.128)
Human Capital	-1.671***	-1.564***	-2.225***	-1.397***	-1.895***	-1.418***	-2.255***	-2.720***
	(0.459)	(0.355)	(0.413)	(0.360)	(0.334)	(0.361)	(0.367)	(0.459)
Inflation	0.0212***	0.0344***	0.0295***	0.0333***	0.0423***	0.0266***	0.0356***	0.0302***
	(0.00621)	(0.00574)	(0.00568)	(0.00584)	(0.00544)	(0.00559)	(0.00551)	(0.00592)
Mob-Tele-Subs	0.0024***							
	(0.00085)							
Internet Users		0.0071***						
		(0.00126)						
Fix-Tele-Subs			0.0099***					
			(0.0021)					
Fix-Broad-Subs				0.0101***				
				(0.0023)				
Tele-Infra-Index					1.263***			
					(0.135)			
Online-Ser-Index						0.577***		
						(0.135)		
E-Gov-Index							1.678***	
							(0.226)	
ICT PCA								0.234***
								(0.0340)
Constant	-2.050***	-2.866***	-2.393***	-2.749***	-2.697***	-2.282***	-2.293***	-1.042*
	(0.583)	(0.473)	(0.482)	(0.476)	(0.437)	(0.490)	(0.459)	(0.547)
Observations	278	321	323	321	323	323	323	274
R-squared	0.944	0.948	0.946	0.946	0.954	0.945	0.950	0.952

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 9 presents the results for only developed countries. Columns (1-8) present the impact of eight ICT indicators on economic growth. All measures of ICT have positive and highly significant impact on economic growth with coefficients 0.0023 (mobile telephone), 0.007 (internet users), 0.0098 (fixed telephone subscriptions), 0.010 (fixed

broadband), 1.263 (telecommunication infrastructure), 0.577 (online services), 1.678 (e-government index) and 0.234 (PCA). The impact of e-government is the largest while the impact of mobile is the smallest. This finding implies that the developed economies need to focus on ICT implementation in public sector. The studies by Duner (2015) and Stanley et al. (2018) also highlight the positive impacts of cell technologies, internet and landline on economic growth of developed countries. Our results are also consistent with the findings of Niebel (2018) who found out that investments in ICT enhance economic growth in developed countries.

Table 10 reports the results for eight measures of ICT and economic growth for only developing countries. All measures of ICT have positive and significant impact on economic growth with coefficients 0.0064 (mobile telephone), 0.021 (internet users), 0.039 (fixed telephone subscriptions), 0.054 (fixed broadband), 3.152 (telecommunication infrastructure), 1.637 (online services), 3.219 (e-government index), 0.563 (PCA).

Earlier literature supports our results. For instance, appropriate outcomes of mobile phones, internet and landline for economic growth are noticed in poor and developing countries through reducing digital divide, empowering people and improving regulatory policies (Waverman et al., 2005; Sridhar et al., 2007) and Stanley et al., 2018).

A comparative analysis shows that the contribution of diverse ICT indicators to economic growth varies across developing and developed countries. All measures of ICT have relatively stronger impact on economic growth of developing countries. These findings confirm that leapfrogging hypothesis holds in developing countries. However, these results contradict with Niebel (2018) who did not confirm the presence of leapfrogging in emerging and developing countries. Niebel (2018) uses a small sample of 59 countries from 1995 to 2000 and this can be the likely reason of different findings. The present study uses a sample of 149 countries and finds robust findings across various groups of countries.

Table 10: Results of Economic Growth and ICT in Developing Countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.985***	0.973***	0.982***	0.985***	0.975***	0.923***	0.931***	0.973***
	(0.0165)	(0.0150)	(0.0151)	(0.0167)	(0.0145)	(0.0173)	(0.0161)	(0.0176)
Physical Capital	0.395***	0.454***	0.435***	0.454***	0.420***	0.466***	0.442***	0.457***
	(0.0692)	(0.0620)	(0.0625)	(0.0781)	(0.0599)	(0.0638)	(0.0624)	(0.0824)
Human Capital	2.549***	2.369***	1.812***	2.526***	2.207***	2.330***	1.247***	2.346***
	(0.145)	(0.133)	(0.160)	(0.157)	(0.129)	(0.141)	(0.192)	(0.175)
Inflation	0.0080***	0.0082***	0.0029	0.0042	0.0083***	0.0074***	0.0092***	0.0093***
	(0.00277)	(0.0026)	(0.0026)	(0.0030)	(0.0025)	(0.0027)	(0.0026)	(0.0031)
Mob-Tele-Subs	0.0063***							
	(0.0007)							
Internet Users		0.0211***						
		(0.00165)						
Fix-Tele-Subs			0.039***					
			(0.0033)					
Fix-Broad-Subs				0.054***				
				(0.0068)				
Tele-Infra-Index					3.152***			
					(0.220)			
Online-Ser-Index						1.637***		
						(0.165)		
E-Gov-Index							3.219***	
							(0.276)	
ICT PCA								0.563***
								(0.0592)
Constant	-7.547***	-7.366***	-7.081***	-7.396***	-7.268***	-6.757***	-6.783***	-6.715***
	(0.343)	(0.315)	(0.325)	(0.382)	(0.304)	(0.345)	(0.330)	(0.414)
Observations	575	659	666	559	671	671	671	458
R-squared	0.887	0.894	0.889	0.882	0.899	0.885	0.890	0.893

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 11 reports the results for European countries. The impact of all measures of ICT on economic growth is positive and significant. A comparative analysis of European and developing countries indicate that the impact of ICT measures is relatively stronger in developing economies, thereby confirming the presence of leapfrogging hypothesis in developing countries. Our findings are consistent with the study of Duner (2015) who also highlights the positive impact of ICT interments in Finland, Austria and United Kingdom.

Table 11: Results of Economic Growth and ICT in European Countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	1.148***	1.135***	1.085***	1.125***	1.104***	1.025***	1.049***	1.146***
	(0.0258)	(0.0168)	(0.0167)	(0.0191)	(0.0160)	(0.0218)	(0.0171)	(0.0185)
Physical Capital	0.121	0.446***	0.186*	0.383***	0.344***	0.109	0.102	0.477***
	(0.156)	(0.110)	(0.101)	(0.133)	(0.0981)	(0.123)	(0.101)	(0.129)
Human Capital	1.473***	0.954***	0.00154	1.024***	0.566**	1.057***	-0.346	0.357
	(0.445)	(0.286)	(0.297)	(0.331)	(0.273)	(0.341)	(0.300)	(0.335)
Inflation	-0.025***	-0.0084**	-0.015***	-0.018***	-0.0065**	-0.0155***	-0.0050	-0.0079**
	(0.0045)	(0.0034)	(0.0031)	(0.0036)	(0.0032)	(0.0039)	(0.0033)	(0.0036)
Mob-Tele-Subs	0.0073***							
	(0.0009)							
Internet Users		0.0188***						
		(0.0016)						
Fix-Tele-Subs			0.0300***					
			(0.0016)					
Fix-Broad-Subs				0.0339***				
				(0.0027)				
Tele-Infra-Index					2.202***			
					(0.113)			
Online-Ser-Index						2.012***		
						(0.160)		
E-Gov-Index							3.412***	
							(0.185)	
ICT PCA								0.521***
								(0.0327)
Constant	-7.799***	-8.423***	-6.100***	-7.641***	-7.332***	-5.885***	-6.073***	-7.533***
	(0.759)	(0.496)	(0.476)	(0.575)	(0.453)	(0.580)	(0.472)	(0.578)
Observations	187	213	218	208	219	219	219	174
R-squared	0.922	0.962	0.962	0.951	0.964	0.943	0.962	0.962

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 12: Results of Economic Growth and ICT in BRICs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.843***	0.732***	0.522***	0.679***	0.744***	0.659***	0.649***	0.704***
	(0.0425)	(0.0445)	(0.0896)	(0.0436)	(0.0452)	(0.0869)	(0.0568)	(0.0336)
Physical Capital	-0.0806	0.205	0.470	0.0825	0.190	0.538	0.644**	0.279*
	(0.166)	(0.189)	(0.294)	(0.185)	(0.192)	(0.386)	(0.248)	(0.140)
Human Capital	1.513***	0.691**	-1.783*	0.328	0.607*	1.170**	-0.476	0.940***
	(0.247)	(0.292)	(1.014)	(0.300)	(0.299)	(0.499)	(0.483)	(0.252)
Inflation	0.0227*	0.0181	0.00919	0.0234*	0.0177	0.0102	0.0223	0.0338***
	(0.0117)	(0.0139)	(0.0209)	(0.0137)	(0.0141)	(0.0246)	(0.0175)	(0.0105)
Mob-Tele-Subs	0.0056***							
	(0.0009)							
Internet Users		0.0135***						
		(0.0017)						
Fix-Tele-Subs			0.0441***					
			(0.0136)					
Fix-Broad-Subs				0.062***				
				(0.0082)				
Tele-Infra-Index					2.178***			
					(0.306)			
Online-Ser-Index						0.859		
						(0.590)		
E-Gov-Index							3.853***	
							(0.755)	
ICT PCA								0.343***
								(0.0484)
Constant	-2.443***	-0.545	4.162**	1.182*	-0.744	-0.705	-1.116	-0.152
	(0.536)	(0.582)	(1.643)	(0.602)	(0.592)	(1.051)	(0.740)	(0.481)
Observations	24	28	28	28	28	28	28	24
R-squared	0.990	0.983	0.962	0.984	0.983	0.948	0.974	0.992

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 12 reports the empirical results for BRICS countries. BRICS is the association of five major emerging economies: Brazil, Russia, India, China and South Africa. BRICS are considered as largest developing economies. It is argued that BRICS will obtain world's prospective economic growth in the next generations. By considering the abundance of human and natural resources and geographical advantages this study tests

the association between ICT and economic growth. Columns (1-8) of Table 12 show the positive and significant impacts of ICT on economic growth with 0.0067 (mobile telephone), 0.0135 (internet users), 0.0441 (fixed telephone subscriptions), 0.0614 (fixed broadband), 2.178 telecommunication infrastructure), 0.859 (online services), 3.853 (e-government index), 0.343 (PCA) coefficients. Empirical results indicate that the effects of telecommunication infrastructure and e-government are higher in emerging economies. Our findings are consistent with Amiri and Woodside (2017).

Table 13: Results of Economic Growth and ICT in SAARC Countries

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**	**LGDP**
Labor Force	0.935***	0.963***	0.980***	0.962***	0.945***	0.882***	0.880***	0.985***
	(0.0366)	(0.0320)	(0.0362)	(0.0335)	(0.0318)	(0.0405)	(0.0356)	(0.0389)
Physical Capital	-0.0189	-0.0966	0.0969	-0.306	0.0192	0.00882	-0.0201	-0.268
	(0.215)	(0.188)	(0.197)	(0.231)	(0.185)	(0.203)	(0.187)	(0.238)
Human Capital	1.617***	2.053***	0.337	1.938***	1.632***	1.312**	-0.564	2.283***
	(0.510)	(0.436)	(0.649)	(0.473)	(0.434)	(0.498)	(0.723)	(0.556)
Inflation	-0.00588	-0.00780	-0.0163	-0.0104	-0.000796	0.0183	0.0150	-0.0197
	(0.0215)	(0.0173)	(0.0200)	(0.0168)	(0.0171)	(0.0186)	(0.0171)	(0.0186)
Mob-Tele-Subs	0.0079**							
	(0.0032)							
Internet Users		0.0410***						
		(0.0097)						
Fix-Tele-Subs			0.0990***					
			(0.0284)					
Fix-Broad-Subs				0.342***				
				(0.110)				
Tele-Infra-Index					5.101***			
					(1.222)			
Online-Ser-Index						1.708***		
						(0.591)		
E-Gov-Index							5.409***	
							(1.337)	
ICT PCA								1.576***
								(0.519)
Constant	-4.635***	-5.090***	-5.095***	-4.156***	-4.995***	-4.125***	-4.071***	-3.186**
	(1.224)	(1.053)	(1.136)	(1.110)	(1.058)	(1.194)	(1.093)	(1.225)
Observations	39	45	45	34	45	45	45	28
R-squared	0.967	0.970	0.965	0.974	0.969	0.964	0.969	0.979

Standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Table 13 provides the results of ICT indicators and economic growth for South Asian Association for Regional Cooperation (SAARC) countries. Columns (1-8) indicate that there exists a positive and significant relationship between GDP and eight measures of

ICT. The co-efficient of mobile-cellular telephone subscriptions (Mob-Tele-Subs) in column 1 shows that one percent increase in mobile-cellular telephone subscriptions leads to increase in economic growth by 0.008 units. Columns 2-4 show the positive and highly significant impacts of internet users, fixed telephone and broadband subscriptions on GDP. The impact of telecommunication infrastructure is very high with coefficient of 5.1 in SAARC countries as demonstrated by column 5, a one unit increase in telecommunications leads to rise economic growth 5.1 units. Column 6 depicts the positive and significant relationship between online service index (Online-Ser-Index) and GDP per capita implying that one unit increase in online service index leads to 1.708 units increase in GDP per capita. Column 7 also gives the positive, highly significant and larger impacts of e-government index (E-Gov-Index) with one unit increase in e-government index GDP increases by 5.409 units. Finally, column 8 shows the positive and significant impact of ICT PCA on GDP per capita implying that one unit increase in ICT PCA increases GDP per capita by 1.576 units. Our results are consistent with the study of Tripathi and Inani (2015) they also find positive impacts of ICT in SAARC countries. The results of control variables are consistent with the findings of previous studies.

The results of regional analysis confirm the positive relationship between ICT and economic growth. However, a comparative analysis shows that the ICT has more strong impact on economic growth of developing countries as compared to developed countries. In particular, the groups of BRICS and SAARC countries are taking more advantage of ICT applications. This finding implies that other developing countries also need to increase adoption of ICT applications to enhance their economic performance. The regional analysis also reveals that ICT measure cause dissimilar effects on economic growth. The impact of telecommunication infrastructure is stronger in emerging and developing economies. In the case of developed economies e-government contributes more to growth.

6. Conclusion

The importance of ICT in enhancing economic growth is immensely discussed in theoretical literature. Generally, the literature suggests that ICT is positively associated with economic growth because it saves time cost, boosts labor skills, reduces production costs, raises productivity of inputs, combats corruption, and reduces market frictions.

Given the importance of ICT and growth linkages this study empirically analyzes the role of ICT in determining economic growth utilizing both cross sectional and panel data sets for 149 countries from 1980 to 2015. The estimations are based on following econometrics techniques: OLS, 2SLS, fixed effects, random effects and Generalized Method of Moments (GMM). All measures of ICT have significant and positive impact on economic growth. However, some indicators such as online service, telecommunication infrastructure and e-government are comparatively more conducive in enhancing economic growth. The empirical results remain consist to various robustness checks.

The regional analysis is also conducted for developed, developing, SAARC, BRICs and European region. All ICT measures for economic growth also confirm the positive and significant effects of ICT on economic growth among different regions around the world.

This study recommends utilization of ICT infrastructure at both public and private levels to sustain economic growth. Therefore, it seems necessary to increase online services, internet use, fixed and broadband subscriptions, e-government and telecommunication infrastructure in order to increase economic growth. The present research contributes to collective endeavor for the ICT benefits to enhance more economic growth at both global and regional levels.

7. Contribution of the Study

Previous studies mostly consider limited and common measures of ICT such as internet users, ICT investments, fixed and broadband subscriptions. Secondly, most of the studies are restricted to small number of countries. Thirdly, much of the work is conducted for one region or just for developed or developing countries. Considering these gaps in the literature this research paves the ways for the better understanding of ICT-growth nexus in following ways. First, present study uses various novel ICT measures. It also develops a PCA of ICT measures. Secondly, the study is not restricted to some countries specific analysis rather it gives the picture of analysis at global level using a large number of countries. Thirdly, to the best of our knowledge this is the first study which gives both global and regional (developed, developing, European, SAARC, BRICs) analysis in a single research. It also addresses the problem of endogeneity in model by utilizing instrumental variables techniques. Finally, this study also applies different important econometric techniques to explore better empirical results and utilizes robustness analysis to provide soundness of data, variables and robustness of empirical results.

8. Difference in ICT Role in Economic Growth

Along with global analysis this research also examines the ICT impacts on economic growth in different groups of countries that are developed, developing, European, SAARC and BRICs. We conduct regional analysis to discover the ICT role in different demographic and other economic conditions around the world.

The empirical results of regional analysis confirm the positive relationship between ICT and economic growth. Overall impacts of ICT are beneficial for all groups of countries but the contribution of telecommunication infrastructure, e-government and online services is much higher than other indicators. For instance, the role of telecommunication and e-government is much higher in SAARC countries implying that more benefits can be obtained through more investments in telecommunication and e-government in SAARC countries. After SAARC on the second number, the impacts of telecommunications, e-government and online services are more pronounced in other developing countries. Empirical results indicate that developing countries can get more economic growth through improving telecommunication infrastructure, and online services along with more human capital and labor force. While, our findings suggest that emerging economies (BRICs) can also get more strong economic position through investing more in telecommunications, online services and e-government along with other ICT advancements. Amiri and Woodside (2017) also find positive effects of ICT investment for BRICs.

9. Limitations of the Study

Present research has some limitations. First, the data set for all countries of the world was not available and therefore the sample of study is limited to 149 countries. Second, the empirical analysis is not performed exclusively for Pakistan because of the data

limitations. Third, panel time series analysis is not conducted because of the data limitations.

10. Theoretical/Policy Implications

Economists have developed various growth theories such as classical, neoclassical and endogenous growth theories to explore the determinants of economic growth. These theories suggest that growth is not only determined by labor, physical capital and human capital but also depends on other factors. The association between economic growth and ICT is scrutinized by wealth of studies began in 1990s. Findings of these studies indicate that ICT is an effective tool to enhance economic growth. An in-depth empirical analysis of this study implies that ICT-growth nexus depends on the measures of ICT and the groups of the countries. These are the developing economies in general and emerging economies are in particular which are taking more benefit from ICT investment.

This research invites policy makers to revise their economic policies that bring advancements for the better telecommunication infrastructure to achieve more economic growth. The present research contributes to collective endeavor for the ICT benefits to promote economic growth at both global and regional levels. To achieve more benefits from ICT and other technical advancements there is a need to introduce new comprehensive regulatory policies.

11. Instrumental Variables

To deal with the problem of endogeneity we have used two instrumental variables that are research and development expenditure and energy use.

11.1 Research and Development Expenditure

Research and Development (R&D) expenditures are capital and current expenditures including both private and public expenditures on the creative work to promote knowledge such as knowledge for new applications, humanity, culture and society. A large number of factors are responsible for fast growth of ICT. According to Saglam (2018), R&D activities are the most notable reason of the rapid expansion of ICT. ICT boosts the progress of technology through R&D, new innovations and knowledge. Investment in R&D positively affects the ICT such as broadband penetration (Koutroumpis, 2009). The R&D expenditures are highly correlated with ICT measures but uncorrelated with the error term and influence economic growth through ICT. Therefore, the issue of endogeneity is controlled using R&D expenditures as external instrument of ICT measures.

11.2 Energy Use

Energy use is highly correlated with ICT measures because both the production and use of ICT indicator require use of energy. Moreover, the increasing use of energy affects economic growth through the expansion of ICT setup. The study by Ishida (2014) also illustrates the positive connection between ICT and energy consumption. Therefore, we employ energy use as an alternative instrument of ICT to assess the robustness of empirical findings.

12. Directions for Future Research

There is a scope of extensive research based on present study. For instance, our work is based on secondary data the same work can be done with primary data by utilizing Logit Probit models. This research can be extended by considering other dimensions of ICT such as artificial intelligence and a robotic economy. Moreover, spillover effects of digital technologies can be estimated using spatial regression analysis.

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Appendix A

Table 14: Cross-Sectional Summary for Economic Growth and ICT

Variable	Obs	Mean	Std. Dev.	Min	Max
GDP	166	10.83253	2.110254	5.89253	16.2619
Labor Force	182	14.85991	1.838755	10.5471	20.4135
Physical Capital	186	3.09107	0.292075	1.93077	4.51967
Human Capital	181	0.723677	0.210178	0.0384	0.99355
Inflation	200	42.69766	143.7809	0.25361	1539.637
Mob-Tele-Subs	199	59.95462	33.76247	1.084046	153.993
Internet-Users	204	18.20681	15.66117	0	65.31271
Fix-Tele-Subs	205	17.01113	17.98483	0.009139	92.96263
Fix-Broad-Subs	201	6.860492	8.611276	0	50.8518
Tele-Infra-Index	181	0.241076	0.219632	0.003866	0.827224
Online-Ser-Index	181	0.341733	0.220898	0.021674	0.976364
E-Gov-Index	181	0.426855	0.201383	0.018087	0.886494

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