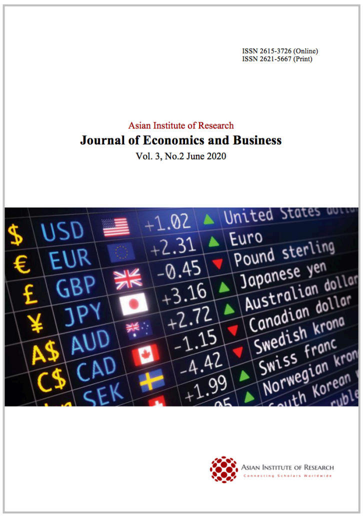

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ICT Diffusion and Economic Growth: A Comparative Study Across Economies

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Abstract
The development in information and communication technology (ICT) has opened up many endless opportunities, enabling broad communication and easy access to knowledge and information. This paper aims to offer a discussion regarding the economic impact of ICT on 89 countries divided into 7 low-, 20 lower middle-, 19 upper middle- and 43 high income economies. Accordingly, it studies the impact of investment growth in ICT and non ICT assets on economic growth for a period 1990 to 2018, thereafter, it examines the economic impact of using three ICT infrastructure indicators in order to tests the effective usage of ICT investment in those economies for the period 2000 to 2018. The methodology of this research follows a deductive approach and uses a panel data estimation. The results show that ICT capital still plays a major role in the richest countries in the world, while there is no significant impact of ICT in the Upper middle and low income economies and weak significant in lower middle income economies. Regarding the impact of using ICT, the results for four income groups, indicate that the level of the ICT infrastructure effect varies according to the indicator studied and middle income economies are gaining more from the use of ICT infrastructure than high income economies with a positive and strong effect on economic growth.

Keywords: ICT Capital, Non ICT Capital, ICT Infrastructure, Panel Data, Economic Growth

Introduction

Information and Communication Technology (ICT) is defined as an expansion of Information Technologies (IT). However, UNESCO (2002) presented a definition of ICT, stating that ICT is a mix of IT and related technologies, particularly communications. The World Bank (2014) reported that ICT includes networks, software, hardware, and media for gathering, storing, processing, transmitting, presenting information and associated services. Moreover, Pradhan et al. (2018) refers to the mobile telephone, digital phone network, servers and capabilities of the Internet and fixed broadband as ICT infrastructure.

Most economists argued that ICT gradually redefined and transformed economic landscapes from 1971 onwards after the technological (informational) revolution emerged (Dosi, 1982; Perez, 2009). This transformation leads to widespread acknowledge of the importance of information and communication technology for economic development. Dutta (2001) and Czernich et al. (2011) stated that Adopting ICT allows timely and easy access to information, which in turn enables the removal of an essential barrier to the effective functioning of the market: information asymmetries. Meijers (2014) explained that ICT enables widespread communication between companies so that reducing the cost of production and increasing productivity. Furthermore, ICT enables access to new markets, adopt e-business and e-commerce that reduce transaction costs and improve its efficiency and speed. Ding and Hynes (2006) claimed that the telecommunications sector works as a source of employment and revenue. It also has a role in encouraging domestic and foreign investment, which affect positively on economic growth.

Undeniably, ICT provide boundless opportunities on economic, institutional and social grounds. Nevertheless, the essential prerequisites to benefit from it are ICT infrastructure and access to it since technological advances will produce gains only when societies accept and adapt it. Dimelis and Papaioannou (2009) stated that technological advances are no more the same for all economies around the world. Each economy maintains different policies, conditions, and prerequisites to promote the implementation of new technology. Avgerou (2003) debates that ICT investment is successful only in those economies which have fundamentals for assets' efficient implementation and use. Therefore, developed countries have to possess better technologies according to their historical experience and existing infrastructure that is suitable for effective use.

Investments in ICT generally include: computers and their facilities, software as well as devices of telecommunications. Given the importance of ICT and the significant decline in the cost of computers and their other parts, and in the cost of communications networks and equipment over the last decades (Jorgenson, 2001), ICT become a dynamic area for investment and different economies have encouraged to get the benefit from the low cost of ICT infrastructure to do more investment in ICT in order to enhance their output and gain additional advantages from ICT. This raises many questions: How does investment in ICT assets, in comparison with investment in non-ICT assets affect economic growth? Which type of ICT infrastructure has the greatest impact on economic growth? Can ICT be a growth generator for the middle and low income economies?

In this regard, the aim of this paper is to explore the impact of the growth of ICT investment and non ICT investment on economic growth among different economies groups (high-, upper middle-, lower middle- and low-income economies). Furthermore, the paper examines the effective usage of ICT investment of those economies by studying the economic impact of using three ICT infrastructure indicators.
The rest of the paper is structured in the following manner. Section 2 discusses the main economic growth theories and explains the necessary factors for growth. Section 3 provides an overview of previous studies that empirically examine the economic importance of ICT. Section 4 discusses and analyzes the impact of ICT and non ICT investment growth on economic growth among different economies groups for a period 1990 to 2018. Section 5 examines the economic impact of using three ICT infrastructure indicators between the economies groups for a period 2000 to 2018. Last Section summarizes the study.

2. Technologies and Economic Growth: Theoretical Review

Theories of economic growth develop over time to explain differences in growth and to examine economic growth factors. The neoclassical theory of growth and endogenous theory of growth are the two dominant growth models. Robert Solow as the best known contributor to the neoclassical theory of growth used a neo-classical standard production function in his economic growth study, which showed that output (Y) depends on labor (N), capital (K) and the level of technology or productivity (A) which was assumed to be exogenous (Solow, 1956).

$$Y = AF(K, N) \qquad (1)$$

Solow argued that the capital has diminishing returns that is as capital increases output increases, but output increases less at high levels of capital than at low levels so that economy will reach to a steady-state and only technological change which has been assumed to be exogenous could achieve a permanent output growth rate.

Although Solow related the technological change to economic growth and believed that technological progress would be the determine of the long-term growth, neoclassical traditional growth theory had nothing to speak about the source of technological change and considered that knowledge itself as a residual that remained once the contribution of capital and labor was taken into account.

Therefore, Romer (1986) developed an endogenous growth theory that addresses problems with neoclassical theory. The theory incorporates the knowledge and technical progress into the production function as an endogenous input.

$$Y = F(A, K, N) \qquad (2)$$

This model addresses the importance of technological change and concludes that technical change is largely caused by intentional actions by people responding to incentives of the market (Romer, 1990). He claims that Investments not only produces new machines but also a new way of doing things. In this scenario, when a company raises its capital, the output of the business will increase, but also other companies will increase their productivity. That is why the endogenous growth model does not yield diminishing returns, contrary to the Solow growth model. In a later time Castellacci (2011) argued that technology and innovation will raise low-income countries' catch-up processes primarily through enabling improvement in education, knowledge dissemination, and labor productivity shifts. In this context, Technological progress plays an important role in economic development.

3. Previous Studies

In the last decades, several researchers who have used different timespans, data sources and various methodologies on one country or panel of countries level, have studied the effect of ICT. Some studies investigated the impact on the economic growth of ICT and conclude that ICT sector contributes significantly to the growth of economies. Another group of studies measured the ICT's impact by controlling other growth determinants and show that the ICT sector is one of the major drivers of economic growth. Additional studies designed for analyzing the causality between economic growth and ICT. Regarding the latter, some researchers found ICT causes economic growth, others showed that causality goes instead from economic growth to ICT, while most argued that ICT is both a cause and a result of economic development and few posited that there is no statistically significant causal or even negative effects between economic growth and ICT. However, with reference to the researches' target state, the research on ICT could be classified into three groups: The impact of ICT on global economies, on the developed economies, and on the developing economies.

Among the first group, where economists examine the ICT impact on global economies, Shiu and Lam (2008) used a sample of 105 countries, divided into different regions then into different income levels groups from 1980 to 2006. They found that the relationship between GDP and telecoms development is bidirectional in European countries and high income group, while a uni-directional relation existed from telecoms development to GDP in the Asia and Oceania countries, and from GDP to telecoms development in other income groups and other regions countries. Chakraborty and Nandi (2011) assessed the relationship between investment in telecom infrastructure and GDP in a panel sample of 93 countries classified to: developed, emerging and less developed countries over the period 1985 to 2007. They concluded that the relation between mainline teledensity and GDP is a bidirectional causal relationship for developing countries whereas for the more developed country the results showed weak evidence of the bidirectional relation. Yousefi (2011) examined the effect on the economic growth of ICT investment among four income groups for a sample of 62 countries from 2000 to 2006. The finding indicated that investment in ICT positively affect economic growth in high and upper middle income groups however in lower middle income and low income groups the effect was insignificant. Pradhan et al. (2013) studied 43 OECD countries from 1961 to 2011 to explore the relationship between the growth of economies and telecoms infrastructure. The results displayed a uni-directed causality running from GDP to telecoms infrastructure suggesting that the telecoms infrastructure in those OECD countries is not so helpful to improve economic growth. Niebel (2014) used a sample consist of 59 countries classified to developing, emerging and developed groups over the period 1995 to 2010 to study the economic impact of ICT investment. He revealed that the differences among the subgroups are small, also, ICT capital and GDP growth have a positive relationship. Pradhan et al. (2014) studied the G-20 countries by dividing it into developing, developed and total groups during 1991 and 2012. The results showed bi-direction causality between economic growth and telecoms infrastructure index in the three groups. Liljevern and Karlsson (2017) argued the effects of investments growth in ICT on economic growth across 101 countries classified in four income groups for the period 2000 to 2017. They concluded that non-ICT capital are still much more important than ICT capital. Furthermore, in the high income group, a significant contribution of ICT on output existed, while no contribution existed in low and middle income group. Majeed and Ayub (2018) used various indicators of ICT in order to analyze their effects on GDP in 149 countries divided into regional and global levels between 1980 and 2015. The results presented that all ICT indicators have a positive and significant impact on GDP in both global and regional levels, however, the benefit from ICT is more in emerging and developing countries than developed countries. Pradhan et al. (2018) focused on G-20 countries over the period 2001 to 2012 to study the nature and direction of the relation between GDP and ICT infrastructure represented by two indicators internet and broadband users. The results indicated a long-run equilibrium relationship and short-run causality from ICT infrastructure to GDP.

Economists among the second group explore ICT impact in developed economies and several have shown that ICT has a significant contribution to developed economies' economic growth. O'Mahony and Vecchi (2005) found that ICT investment in the UK industry has a negative economic growth impact while in the US industry it has a positive effect on growth over the period 1976 to 2000. However, Beil et al. (2005) studied the causality between the US's GDP and telecom investments for the period 1947 to 2011. The findings identified a uni-directional causality that telecoms investment is caused by economic growth. Ramlan and Ahmed (2009) examined the relation between investment in the telecoms and Malaysia's economic growth between 1965 and 2005. The results proved that in short-run, there is no causality between ICT and GDP, while in long-run, ICT has the same pattern as GDP which shows it to be a growth factor in economic development. Ishida (2014) investigated the ICT impact on japan economic growth and energy consumption from 1980 to 2010. He found that ICT has moderately caused lower energy use, but it has not contributed to Japan's economic growth since the result shows that it is insignificant in growth model, while it is negative and significant in energy demand function. Khalili et al. (2014) argued the long term and short term causal analysis between ICT and GDP across six EU top ranked ICT countries for a period 1990 to 2011. They did not find any causality between ICT and economic growth in the short term, while in the long term, they found a unidirectional causality from ICT to economic growth. On the other hand, Toader et al. (2018) examined four indicators of ICT to evaluate how ICT affects GDP for the period 2000 to 2017 in European Union countries. The findings showed a positive and important effect of the ICT and the highest impact on GDP was recorded for mobile subscriptions.

The last group focuses on economic growth and ICT in developing countries. Sassi and Goaied (2013) used 17 MENA countries to study the economic growth impact of financial development and ICT during 1960 – 2009. The findings showed that ICT has appositive effect while financial development has a negative effect on the growth of economies, furthermore, the interaction between them is significantly positive indicating that the economies of MENA regions can profit from financial development once ICT thresholds are reached. Mehmood and Siddiqui (2013) evaluated the relationship between GDP and investment in telecoms in a group of 23 Asian countries from 1990 to 2010. They found causality runs from telecommunications investments to GDP. Hodrab et al. (2016) used a sample of 18 Arab countries in order to study the effect of ICT on the growth of economies during 1995 – 2013. They measured the infodensity index as an indicator of ICT and found a positive influence of ICT on the selected Arab countries' economic growth. Pradhan et al. (2016) assessed relationships between development of telecom infrastructure, financial development and economic growth in 21 countries of Asia divided into sub regions over the period 1991 to 2012. The results showed that the development of financial sector and telecoms infrastructure has a significant impact on economy output and there is causality between the variables in short and long run. Bahrini and Qaffas (2018) used a panel of 45 countries: 14 in MENA and 31 in SSA over 2007- 2016. The results derived from the GMM model indicated that mobile adoption, internet, and broadband adoption are the key drivers of economic growth. In addition, the results confirmed that in the fields of internet use and broadband adoption MENA countries are superior to the SSA countries. Haftu (2018) investigated the economic impact of telecom infrastructure with a particular emphasis on internet and mobile penetration in a group of 40 countries in sub-Saharan Africa from 2006 to 2015. He concluded that the mobile phone penetration impacted the region's GDP with a 10% rise in it contributes to a 1.2% GDP per capita change, while Internet users did not contribute to GDP during the period of the study. Adeleye and Eboagu (2019) studied 54 African countries from 2005 to 2015 and applied different panel estimation to evaluate the ICT contribution to economic growth. The results demonstrated that the three ICT indicators have a positive significant economic impact, where the mobile subscriptions have the greatest elasticity across every specification and have the greatest potential for Africa to bypass conventional stages of development.

This study offers a global research image using a wide range of countries to examine the economic effect of ICT investment growth and to investigate the economic impact of using three ICT infrastructure indicators.

4. Impact of ICT Investment Growth on Economic Growth

In order to explore the impact of the growth of ICT investment and non ICT investment on economic growth among different economies groups. A sample of 89 countries is used for this aim and divided into four categories, which are classified as high-, upper middle-, lower middle- and low income economies by following the World Economic Situation and Prospects' country classification table, WESP (UN 2019), that depends on the per capita gross national income (GNI) of each country. Countries with GNI per capita below $1,025 are classified as low income economies, countries ranging from $1,026 to $4,035 are considered as lower middle income economies, on the other hand, from $4,036 to $12,475 are considered as upper middle income economies and high income economies for those with more than $12,475. Accordingly, the empirical part in this section is based on a panel dataset for 89 countries divided to 7 low income economies, 20 lower middle income economies, 19 upper middle income economies and 43 high income economies over 29 years from 1990 till 2018. Table A1 (Appendix A) presents the countries of this study.

4.1 Model Building of ICT Investments effects

Based on the existing theories which argued that labor, capital, and technological innovation are the essential drivers of sustainable growth economies, growth rate of GDP per capita is used as the dependent variable and the key explanatory variables represented by ICT capital services growth rates, non ICT capital services growth rates, employment growth rate and export growth rate are used as independent variables.

Table 1: Variables Descriptive and Data Sources of ICT Investments effects Model

Variables	Definitions	Measurement	Sources/Period 1990 - 2018
gGDPPC	Real GDP per capita growth rate expressed in 2016 PPP $.	Percentage	Conference Board Total Economy Database (TED)
gICT	ICT capital services growth rate, where ICT capital services are provided by assets as telecoms material, computer software and hardware	Percentage	Conference Board Total Economy Database (TED)
gNICT	Non-ICT capital services growth rate, where Non-ICT capital services provided by machinery, construction, transports, buildings, and other types of non-ICT assets	Percentage	Conference Board Total Economy Database (TED)
gEMPLOY	Employment growth rate that covers all people engaged in productive activity within the boundary of production of national accounting system (self-employed, employees, worker of unpaid family and military).	Percentage	Conference Board Total Economy Database (TED)
gEXPORT	Exports of services and goods growth rate. Exports of services and goods represent the value of every market service and good provided to the rest of the world.	Percentage	World Bank, World Development Indicators (WDI)

Source: authors' preparation based on empirical studies.

The following general model of linear regression is considered:

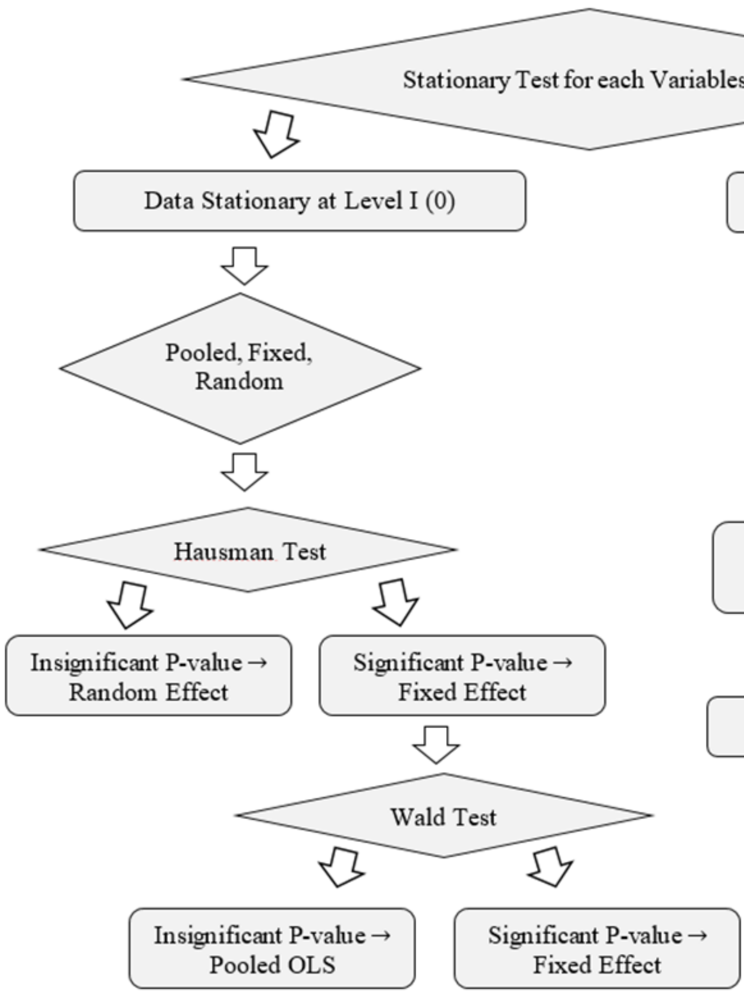
$$\text{gGDPPC}_{it} = \beta_0 + \beta_1 \text{ gICT}_{it} + \beta_2 \text{ gNICT}_{it} + \beta_3 \text{ gEMPLOY}_{it} + \beta_4 \text{ gExport}_{it} + \mu_{it} \quad (3)$$

Where, μ_{it} is the error term, *t* shows time effects and *i* shows individual effects. This model will apply to the four income groups of economies in order to compare ICT capital contribution to economic growth for each group. Both types of capital services are expected to be a contributor to the growth of GDP as theory suggested. However, due to diminishing returns law on investments (Solow, 1956), ICT services should have relatively more marginal effects in lower income groups. Furthermore, since better prerequisites are supposed in developed countries, they will usually also be perceived as more effective users and active in investing in new technology. Therefore, ICT may also have a significant impact on output in high income economies. In addition, employment levels are essential to the increase in output, and thus, in most income economies, a positive effect on GDP is anticipated (Solow, 1956; Romer, 1990). For the export and trade levels, a positive effect on GDP is also expected since they are considered as vital factors for the growth of GDP, as Awokuse (2008) says that export growth stimulates economic growth, by expanding the market size, leading to large economies of scale, growing capital formation rates and technical changes.

4.2 Methodology of Testing the Impact of ICT Investment Growth on Economic Growth

Panel data is used to analyze the relationship between investment in ICT and economic growth since it eliminates heteroscedasticity problems from potential differences across countries (Greene, 2003).

Summary Diagram: Panel Method Followed in the paper



Source: authors' preparation

4.2.1 Stationarity Tests

The data shall be stationary prior to modeling and analysis, in that case, a stationary test is the essential prerequisite test in many techniques. Fisher ADF, Fisher PP (1932), and Levin, Lin, Chu (LLC) (2002) tests are the basic tests for panel unit root. Under the null hypothesis a unit root is existed, while under the alternative hypothesis no unit root existed. Studying the AR (1) for panel data, analytically:

$$y_{it} = \rho_i y_{it-1} + X_{it}\delta_i + \epsilon_{it} \qquad (4)$$

Where I =1, 2… N is cross section series or units, observed over periods t = 1, 2… T. The exogenous variables represented by X_{it} in the model, ρ_i are the coefficients of the autoregressive coefficients, and ϵ_{it} is the errors and assumed to be independent. If $|\rho_i| < 1$ then it is said that y_{it} is stationary, while if $|\rho_i| = 1$ then y_{it} is not stationary.

4.2.2 Panel Models

Pooled OLS, Random Effect (REM), and Fixed Effect (FEM) are three panel data models that examine group effects, country specific effects or both. Pooled OLS Estimator ignores the panel structure of the data assuming that all individuals have homogenous effects:

$$Y_{it} = \alpha + \beta X_{it} + \varepsilon_{it} \quad (U_i = 0) \qquad (5)$$

Where Y is dependent variable, X is independent variable, α is intercept, β is slope coefficient, U_i is the individual effect, ε_{it} are error terms, t shows time effects and i shows individual effects.

Fixed and random effects models examine the effects of individuals or time to check the heterogeneity (individuality) of every individual (country). Dummy variables consider a key role in the difference between the both. In fixed effect models, a dummy variable parameter is in the part of intercept while in the random effect model a dummy variable parameter is in the part of an error component.

Random effect model: $Y_{it} = \alpha + \beta X_{it} + (\varepsilon_{it} + U_i)$ (6)

Fixed effect model: $Y_{it} = (\alpha + U_i) + \beta X_{it} + \varepsilon_{it}$ (7)

For the fixed effect model, the effect of individual is assumed to be correlated with the regressors while the effect of individual in the random effect model is assumed to be uncorrelated with the regressors.

4.2.3 Model Selection

In order to estimate the best-fitted model between Pooled OLS, REM, and FEM, Hausman test (1978) answers for best model by comparing the random effect and fixed effect model. The null and alternative hypotheses that:

H_0: U_i uncorrelated with other regressors (REM is the preferred)

H_1: U_i correlated with other regressors (FEM is the preferred)

After Hausman test, if the fixed effect model is the appropriate model then a further test - Wald test - has to be checked to determine the right model between the pooled OLS and fixed effect. The null and alternative hypotheses are:

H_0: all dummy parameters are zero (Pooled OLS model is the preferred)

H_1: at least one dummy parameter is not zero (FEM is the preferred)

4.3 Tests Results of ICT Investments effects Model

The results of econometric methods for the panel data employed are presented in this section.

4.3.1 Stationary Tests Results for the Variables of ICT Investments Effects Model

With respect to the group income economies, the results of Fisher ADF, PP and LLC tests presented in Appendix B, tables B1–B4. They prove that gGDPPC, gICT, gNICT, gEMPLOY, and gExports are stationary at level in the four groups since at least two tests out of three tests adopted show that p-value is less than 5 %.

4.3.2 Panel Data Regression

Tables C1–C4 (Appendix C) present the pooled, random effect and fixed effect models results of the four income groups of economies. However, the best fitted model is fixed effects model in all groups since the results of Hausamn and Wald tests show p-value < 0.05 (null hypothesis rejected) (See Appendix D, Tables D1–D2). Accordingly, the regression for each income group is estimated by using fixed effect specification with cross-section weights Panel Corrected Standard Errors (PCSE) as a coefficient covariance method, that the PCSE estimator generates accurate standard error estimates.

Table 2: Fixed Effect Models Estimation Results – for All Income Groups

Dependent Variable: gGDPPC								
Economies Groups	**High Income**		**Upper Middle Income**		**Lower Middle Income**		**Low Income**	
Variables	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
C	-1.0235	(0.0000)	-0.4627	(0.1650)	-0.091325	(0.7717)	-0.911854	(0.3524)
gICT	0.0530	(0.0000)	0.0192	(0.2268)	0.024382	(0.0498)	-0.030234	(0.1675)
gNICT	0.0806	(0.1781)	0.4452	(0.0000)	0.336007	(0.0000)	0.358686	(0.0001)
gEMPLOY	0.2429	(0.0001)	0.3078	(0.0000)	0.318194	(0.0000)	0.492159	(0.0694)
gEXPORT	0.2476	(0.0000)	0.1338	(0.0000)	0.075469	(0.0000)	0.047096	(0.0058)

Source: authors' calculation using Eviews

4.4 Analysis and Discussions of ICT Investments effects Model

Interesting results are achieved from the empirical part that are different according to income level of economies. In the high income economies, the significance level of ICT capital services is in line with growth theories and Niebel (2014) and Yousefi (2011); high income economies should have an enormous stock of ICT capital as well as historic experience with how these assets can be used efficiently. Moreover, these economies are expected to develop suitable infrastructure to support such assets. The insignificance level of Non ICT capital services, consistent with Solow model that the capital has diminishing returns that is as capital increases, output increases, but output increases less at high levels of capital than at low levels. Employment growth has a significant impact on GDP growth, consistent with Glaeser et. al (2004). The results show that 1% increase in the employment growth rate will increase the growth of GDP per capita by 0.24%. For the export growth rate, the results also show a bigger coefficients which indicating a stronger relationship between export growth rate and GDP.

The findings of the fixed-effect model in the upper middle income economies show that ICT capital services no longer contribute to economic growth. According to Waverman et al. (2005) who argue the reason why ICT capital services exhibit insignificant contributions in less developed countries, which could have been a result of the telecom income trap. This means that ICT costs are higher than productivity gains. Consistent with the neoclassical model the value non-ICT capital services demonstrate increasing importance in explaining economic growth in comparison with the economies of high income. The results also show that growth in employment and exports in this group have an extremely important impact on economic growth.

In lower middle income economies, the result of ICT capital services contribution does not resemble those of the upper middle income economies, it shows that ICT capital services has significant impact on economic growth but with lower contribution, in line with the Niebel (2014) if the lower middle income economies considered to be an emerging economy. The findings for non-ICT capital services indicate substantially less important in explaining GDP growth in comparison with the upper middle income economies, which is not compatible with the idea of capital diminishing return mentioned in the neoclassic model that states that higher elasticity is required in economies that have fewer capital stocks, but in comparison with the high-income group, the contribution to this group appears to be higher. The growth rate of employment and exports also has a significant effect on per capita GDP growth. A 1% rise in the employment growth levels, leads to a 0.32% rise in the GDP per capita growth.

In low income economies, ICT capital services have made no significant contribution to GDP growth with a negative sign and Non-ICT capital services tend to have increased importance on economic growth. This is in line with Liljevern and Karlsson (2017), who stressed that lower income levels might also influence the promotion of efficient telecommunications infrastructure. Furthermore, Wavermann et al. (2005) have pointed out that economies with low-income tend to be less likely to invest in new technologies infrastructure. The explanation is that these types of investments are not encouraged by country-specific characteristics and infrastructure. This might imply that countries with lower incomes generally have lower ICT contributions in respect of other forms of capital that meet more primary requirements. Relative to the other income group, employment growth in low income economies tends to be much greater importance. This can be explained in part by the lower stocks of capital making employment in production more essential. Moreover, export growth also impacts economic growth significantly.

Overall, the results show that ICT capital still plays a major role in the richest countries in the world, while there is no significant impact of ICT in the Upper middle and low income economies and weak significant in lower middle income economies.

5. Impact of Using ICT on Economic Growth

To evaluate the using of ICT capital and its effects on growth of economies this section takes the usage of three ICT infrastructure indicators as a proxy, trying to assess which one has the greatest impact on economic growth and how their effect level differs between the groups of economies. Therefore, the empirical part in this section is established on the same panel dataset of 89 countries but over the time span 2000-2018 that is because, the availability of ICT infrastructure data for some years and some variables was limited, so we ended up with a period 2000 to 2018.

5.1 Model Building of ICT Usage effects

A set of variables regarding the use and access to ICT are chosen to achieve the aim of this section. Accordingly, per capita GDP is used as the dependent variable, three different measures of ICT infrastructure are used as the main explanatory variables (fixed broadband subscriptions, % of persons using the Internet, and mobile-cellular subscriptions) and three macro-economic control variables are used as the second explanatory variables (participation rate of Labor force, Gross Fixed Capital Formation as % of GDP, and Trade Openness).

Table 3: Variables Descriptive and Data Sources of ICT Usage effects Models

Variables		Definition	Measurement	Sources/Period 2000 - 2018
GDPPC		GDP per Capita, which is real gross domestic product divided by the total population	in US dollars using 2016 PPP USD	Conference Board Total Economy Database (TED)
ICT Indicators	**FBS**	Fixed Internet broadband subscriptions per hundred inhabitants, refers to the number of fixed broadband Internet subscriptions in a country for every 100 people	Percentage	ITU
	IU	Internet users, refers to the proportion of individuals who have used Internet from anywhere in the past three months	Percentage	ITU
	MCS	Mobile cellular telephone subscriptions per hundred inhabitants, refers to the number of mobile cellular subscriptions in a country for every 100 people	Percentage	ITU
TO		Trade Openness, which is the summation of imports and exports of services and goods as percentage of GDP	Percentage	World Bank, World Development Indicators (WDI)

GFCF	Gross Domestic Fixed Capital Formation as percentage of GDP, which includes equipment purchases, plant, land improvements, machinery, railways, the construction of roads, and industrial buildings.	Percentage	World Bank, World Development Indicators (WDI)
LABOR	Labor force participation rate, which is the proportion of the economically active population aged 15 and older, it includes employed people, unemployed people seeking employment and first time jo bseekers.	Percentage	World Bank, World Development Indicators (WDI)

Source: authors' preparation based on empirical studies.

The following general model of linear regression is considered:

$$\text{GDPPC}_{it} = \beta_0 + \beta_1 \text{ ICTIndicator}_{it} + \beta_2 \text{ LABOR}_{it} + \beta_3 \text{ GFCF}_{it} + \beta_4 \text{ TO}_{it} + \mu_{it} \quad (8)$$

Based on the above model, three models are built, one for each ICT indicator. However, for the purpose of unity and linearity, variables are taken with log. Therefore, for the panel data models, the estimated three equations are:

Model I:

$$\text{logGDPPC}_{it} = \beta_0 + \beta_1 \text{ logFBS}_{it} + \beta_2 \text{ logLABOR}_{it} + \beta_3 \text{ logGFCF}_{it} + \beta_4 \text{ logTO}_{it} + \mu_{it} \quad (9)$$

Model II:

$$\text{logGDPPC}_{it} = \beta_0 + \beta_1 \text{ logIU}_{it} + \beta_2 \text{ logLABOR}_{it} + \beta_3 \text{ logGFCF}_{it} + \beta_4 \text{ logTO}_{it} + \mu_{it} \quad (10)$$

Model III:

$$\text{logGDPPC}_{it} = \beta_0 + \beta_1 \text{ logMCS}_{it} + \beta_2 \text{ logLABOR}_{it} + \beta_3 \text{ logGFCF}_{it} + \beta_4 \text{ logTO}_{it} + \mu_{it} \quad (11)$$

Each model will apply on the four income group of economies in order to compare the contribution of each ICT infrastructure usage to economic growth for each group.

Since many economists have stated that ICT infrastructure, directly and indirectly, impacts economic growth a strong and positive effect of ICT infrastructure on economic growth is expected in the four income groups of economies, but the impact will be varied according to the type of technology studied. Furthermore, in line with Mankiw et al. (1992) who state that a rise in the labor force will boost economic growth, a positive and significant coefficient of the labor force is predicted in the four income groups. In addition, gross fixed capital formation is considered a key factor for higher output (Haftu, 2018), thus a positive impact on GDP in most income groups is predicted. With regard to the degree of trade openness, it is predicted that this factor will impact positively and significantly on GDP per capita.

5.2 Methodology of Testing the Impact of Using ICT Investment on Economic Growth

The strategies followed in this sections are as follow:

5.2.1 Co-Integration Tests

Co-integration test is a statistical test to study the existence of long run association between the variables. It is based on an analysis with variables that are integrated with order one and the investigation of the spurious regression's residuals. Pedroni (1999), Kao (1999) and Fisher (1932) are three co-integration tests. The hypotheses are:

$$H_0\text{: the variables are not cointegrated}$$
$$H_1\text{: the variables are cointegrated}$$

5.2.2 Dynamic Ordinary Least Squares Estimator (DOLS)

DOLS is a simple and effective approach to estimate the co-integrating relationship coefficients. The Stock and Watson's DOLS (Dynamic Ordinary Least Squares) model can be used to estimate long-lasting relations between variables based on the presence of the co-integration relationship between them (Stock and Watson, 1993). For panel data, the extension of the Stock and Watson (1993) DOLS estimator is proposed by Kao and Chiang (2000).

In panel DOLS, the equation of panel co-integrating regression is augmented with cross-section specific leads and lags to reduce serial correlation, the asymptotic endogeneity and give better approach to normal distribution.

5.3 Tests Results of ICT Usage Models

The results of the tests applied are represented in this section.

5.3.1 Stationary Tests Results for the Variables of ICT Usage Effects Models

Tables B5–B8 (See Appendix B) present the results of Fisher ADF, PP and LLC tests. They reveal that, under a level of significance of 5%, Log_GDPPC, Log_FBS, Log_IU, Log_MCS, Log_GFCF, Log_TO, and Log_LABOR in the four income groups are not stationary, and their first differences are stationary. Accordingly, the integration order of the variables are d = 1.

5.3.2 Co-Integration Tests Results

The results of Kao, Pedroni, and Fisher test of model I, II and III, presented in Appendix E, tables E1–E3 shows that the long term relation existed between the variables for high, upper middle, lower middle and low income Economies.

5.3.3 DOLS Estimation Results

Twelves regressions estimated and presented in tables 4–6, for high income economies followed by the like for the upper middle, lower middle and low income economies.

Table 4: DOLS Estimation Results – Model I

Dependent Variable: Log_GDPPC								
Economies Groups	**High Income**		**Upper Middle Income**		**Lower Middle Income**		**Low Income**	
Variables	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
Log_FBS	0.036155	(0.0345)	0.0862	(0.0000)	0.098491	(0.0000)	0.022137	(0.4384)
Log _LABOR	2.107323	(0.0000)	1.5366	(0.0000)	1.482143	(0.0000)	0.54619	(0.0027)
Log _GFCF	0.27295	(0.0063)	0.7889	(0.0000)	0.880948	(0.0000)	0.873836	(0.0000)
Log _TO	0.22333	(0.0000)	0.1633	(0.0585)	-0.025723	(0.8185)	0.650308	(0.0000)

Source: authors' calculation using Eviews

Table 5: DOLS Estimation Results – Model II

Dependent Variable: Log_GDPPC								
Economies Groups	**High Income**		**Upper Middle Income**		**Lower Middle Income**		**Low Income**	
Variables	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
Log _IU	0.171294	(0.0002)	0.1747	(0.0000)	0.224698	(0.0000)	0.054793	(0.0837)
Log _LABOR	1.858708	(0.0000)	1.3754	(0.0000)	1.766614	(0.0000)	0.570296	(0.0010)
Log _GFCF	0.398944	(0.0001)	0.8484	(0.0000)	0.545266	(0.0026)	0.743671	(0.0000)
Log _TO	0.223016	(0.0000)	0.1696	(0.0228)	-0.203004	(0.0645)	0.678877	(0.0000)

Source: authors' calculation using Eviews

Table 6: DOLS Estimation Results – Model III

Dependent Variable: Log_GDPPC								
Economies Groups	**High Income**		**Upper Middle Income**		**Lower Middle Income**		**Low Income**	
Variables	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
Log _MCS	0.126255	(0.0635)	0.1985	(0.0000)	0.185173	(0.0006)	0.04919	(0.1081)
Log _LABOR	1.865013	(0.0000)	1.4009	(0.0000)	1.329972	(0.0000)	0.711453	(0.0001)
Log _GFCF	0.367448	(0.0020)	0.6920	(0.0000)	0.687048	(0.0016)	0.764929	(0.0000)
Log _TO	0.269481	(0.0000)	0.1772	(0.0387)	0.087354	(0.4933)	0.501979	(0.0022)

Source: authors' calculation using Eviews

According to the latest studies in econometrics especially for dynamic panel data models whereby dependent variable lag added to the formula, further stationarity tests for the residuals are conducted in order to check the robustness of the model. Therefore, the stationarity of residuals of these models is tested based on the ADF, PP, and Levine Lin & Chu. The results show that p-value of the three tests is <5 %, which prove that the residuals do not have a unit root and the models are not spurious for high, upper middle, lower middle and low income Economies (See Appendix B, Tables B9–B11).

5.4 Analysis and Discussions of ICT Usage effects Models

The empirical results produce interesting results that differ according to the level of income of the economies. In high income economies, a positive results appeared regarding the use of ICT infrastructure on economic growth impact, which are consistent with theories, literature review and ICT indicators expectations. This is explained by the adequate infrastructure that high-income economies built and the long history of experience that it had in how these assets should be used efficiently. The highest impact was recorded for the percentage of individuals using the Internet, suggesting that a 1% rise in the level of internet users would determine a rise in GDP about 0.17% across the high-income economies. Toader et al. (2018) argue the positive impact of technology and of Internet on the growth of economic of developed economies. Regarding the control variables, the results show a substantial impact on economic growth in all three models. The labor participation rate has a higher coefficient with a positive and significantly associated with economic growth, in line with the theoretical predictions that a rise in labor force raises physical capital's marginal output leading to a boost of economic growth. On the other hand, the results of gross fixed capital formation show that all estimated coefficients were positive and significant which is in line with the findings of Haftu (2018) and Pradhan et al. (2014). In addition a positive and closely related effect of trade openness on GDP per capita existed.

Results from the upper middle income economies confirm the positive impact that the three ICT infrastructures have on economic growth. The results show that the effect of mobile cellular subscriptions appears marginally greater than other ICT infrastructures for the time period covered. Mobile subscriptions yielded a 0.1985% rise in GDP per 1% rise in penetration, compared to 0.0862% for fixed broadband. This result implies that the upper-middle-income economies must concentrate on suitable ICT infrastructure to support the efficient use of it. The impact of macroeconomic control variables on economic growth has shown that in each of the three models they have a significant effect in line with economic theories, literature reviews and expectations for labor rate, gross fixed capital formation, and trade openness indicator.

For lower middle income economies, the findings also show a very optimistic and very important impact of the use of ICT infrastructure on economic growth. The comparative results show that in high and middle income economies the contribution of three ICT infrastructures to economic growth differs and a stronger effect of these infrastructures on economic growth appears in middle income economies indicating the efficiency of these economies' use of these assets. The outcomes in line with Majeed and Ayub (2018) who reported that the results for economic growth from internet, mobile telephones, and fixed broadband are noticed more in middle-income economies. In contrast, the results of the control variables' effects show that almost all have a positive impact on economic growth, except for trade openness. Additionally, the labor participation rate shows a bigger coefficient in comparison to other controlling variables with a positive and significant relationship with economic growth that as a 1% increase in the labor participation rate, the GDP level will increase between 1.32 and 1.77 %.

In low income economies, the results show that the two ICT indicators: fixed broadband and mobile cellular subscriptions have insignificant impact on economic growth while the level of internet users have a little impact on economic growth at 10% level that as the level of internet users increases by 1%, the GDP per capita level will increase by 0.05%. The reason behind this result is that high income economies are better able to invest in new technology and enhance the efficient use of it than low income economies that are less likely to invest in new technology and use the available one for a consumption purpose rather than productive purposes. Regarding the association between control variables and economic growth, the results show a positive and significant relationship in all three models. The impact of gross fixed capital formation is the largest with coefficients between 0.74 and 0.87.

Overall, the analysis for four income groups, high, upper middle, lower middle and low income economies show that the level of the ICT infrastructure effect varies according to the type of technology studied and middle income economies are gaining more form the use of ICT infrastructure than high income economies with positive and strongly effect on economic growth.

6. Conclusion

The ICT revolution has spread quickly across countries and transformed how people live, interact and work. The growth in pace, reach, intensive use and reliability of information access, knowledge sharing, and interaction across countries are at the core of this transformation. It is predicted that these strong impacts will translate into economic results.

This paper has aimed to offer a discussion regarding the economic impact of ICT on 89 countries classified according to their income level to 7 low income economies, 20 lower middle income economies, 19 upper middle income economies and 43 high income economies. Accordingly, the first approach is to determine the impact of investment in ICT and non ICT assets on economic growth for a period 1990 to 2018. A panel model of ICT capital services growth rates, non ICT capital services growth rates, employment growth rate, export growth rate and per capita GDP growth is constructed and applied for each group. By comparing between pooled OLS, Fixed and random effect, the results show that the preferred model is fixed effects model and reveal that the non ICI capital is still have a higher importance in comparison to ICT. ICT capital still plays a major role in the richest countries in the world, and a weak significant impact of ICT capital appears in lower middle income economies, while no significant impact of ICT capital in the upper middle and low income economies. There is thus no convincing statistical evidence that middle and low income economies benefit more than high income economies from investment in ICT for the time period covered and that middle and low income economies must concentrate on suitable investment of ICT infrastructure. The results also show that growth in employment and exports in the different groups have an extremely important impact on economic growth.

The second approach is to examine the economic impact of using various ICT infrastructure to evaluate which one has the greatest impact on economic growth and how their effect level differs between the groups of economies for a period 2000 to 2018. A three ICT indicators are used and three panel models were built one for each indicators, these indicators are: number of fixed broadband Internet subscribers in one country per 100 people, the percent of people who used the Internet from every place in the last three months and the number mobile cellular subscriptions per 100 inhabitants in a country. In addition, each model controlled with three variables: participation rate of labor force, trade openness and gross fixed capital formation. Co-integration tests and DOLS estimation applied. The empirical results show that middle-income economies are gaining more form the use of ICT infrastructure than high-income economies with positive and strongly effect on economic growth. The highest impact was recorded for the percentage of individuals using the Internet in high and upper middle income economies, while the effect of mobile cellular subscriptions appears marginally greater than other ICT infrastructures in upper middle for the time period covered. In low income economies only the level of internet users have a little impact on economic growth at 10% level. With regard to control variables in all models almost all, except for trade openness in middle economies, had significant impact on economic growth.

As the use of ICT infrastructures have positive and important economic development, the main focus of investments in middle and low income economies should be on suitable technologies to support the efficient use of it, in addition to the establishment of mechanisms and policies that improve the infrastructure of ICT, the use and the access to it. Moreover, as regards the negative coefficient of ICT capital variable in low income economies, the government should be proactive in reforming the ICT sector with major investments in order to make it a key engine that drives the economy towards a knowledge economy.

For future work, our modeling can be implemented at country level or at economy's lower parts, for example, companies that can contribute to deeper insight into the ICT productivity impacts in developing and emerging countries, on the other hand the work can be expanded by taking into account other ICT dimensions like artificial intelligence and the robotic economy. Nonetheless, one of the challenges is to collect and build time series or cross-section data series on the selected ICT indicator.

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Appendix

Appendix A: Countries List

Table A1: List of counties covered in this study

High Income		Upper Middle Income	Lower Middle Income	Low Income
Uruguay	Ireland	Turkey	Ukraine	Uganda
United States	Iceland	Thailand	Tunisia	Tanzania
United Kingdom	Hungary	Romania	Sudan	Tajikistan
United Arab Emirates	Hong Kong, China	Mexico	Sri Lanka	Niger
Switzerland	Greece	Malaysia	Philippines	Mozambique
Sweden	Germany	Kazakhstan	Pakistan	Mali
Spain	France	Jamaica	Morocco	Malawi
South Korea	Finland	Iran, Islamic Rep.	Moldova	
Slovenia	Estonia	Guatemala	Kyrgyzstan	
Singapore	Denmark	Ecuador	Kenya	
Saudi Arabia	Czech Republic	Dominican Republic	Indonesia	
Portugal	Cyprus	Costa Rica	India	
Poland	Croatia	Colombia	Ghana	
Norway	Chile	China	Egypt, Arab Rep.	
New Zealand	Canada	Bulgaria	Côte d'Ivoire	
Netherlands	Belgium	Brazil	Cameroon	
Malta	Barbados	Armenia	Cambodia	
Luxembourg	Bahrain	Algeria	Bolivia	
Kuwait	Austria	Albania	Bangladesh	
Japan	Australia		Vietnam	
Italy	Argentina			
Israel				

Source: United Nation (2019)

Appendix B: Stationary Tests Results

Table B1: Stationary Tests Results for the Variables of ICT Investments Effects Model - High Income Economies

Test Type		gGDPPC		gICT		gNICT		gEMPLOY		gExport	
		Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**
Levin, Lin&Chu	**At Level**	-16.5767	(0.0000)	-6.48425	(0.0000)	-7.99601	(0.0000)	-10.7796	(0.0000)	-15.9546	(0.0000)
ADF	**At Level**	434.015	(0.0000)	124.696	(0.0041)	159.193	(0.0000)	320.045	(0.0000)	421.61	(0.0000)
PP	**At Level**	437.068	0.0000)	125.394	(0.0036)	187.29	(0.0000)	307.18	(0.0000)	469.749	(0.0000)

Source: authors' calculation using Eviews

Table B2: Stationary Tests Results for the Variables of ICT Investments Effects Model - Upper Middle Income Economies

Test Type		gGDPPC		gICT		gNICT		gEMPLOY		gExport	
		Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**
Levin, Lin&Chu	**At Level**	-7.88129	(0.0000)	-4.80898	(0.0000)	-2.08316	(0.0186)	-8.17411	(0.0000)	-12.9567	(0.0000)
ADF	**At Level**	192.713	(0.0000)	71.4752	(0.0008)	67.7604	(0.0021)	175.174	(0.0000)	226.375	(0.0000)
PP	**At Level**	207.22	(0.0000)	64.9144	(0.0042)	53.9112	(0.0452)	235.78	(0.0000)	227.194	(0.0000)

Source: authors' calculation using Eviews

Table B3: Stationary Tests Results for the Variables of ICT Investments Effects Model - Lower Middle Income Economies

Test Type		gGDPPC		gICT		gNICT		gEMPLOY		gExport	
		Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**
Levin, Lin&Chu	**At Level**	-1.90918	(0.0281)	-4.3865	(0.0000)	-2.38652	(0.0085)	-5.04421	(0.0000)	-13.2775	(0.0000)
ADF	**At Level**	105.624	(0.0000)	72.9056	(0.0011)	57.9009	(0.0333)	110.66	(0.0000)	272.74	(0.0000)
PP	**At Level**	149.549	(0.0000)	71.2599	(0.0017)	37.2335	(0.5955)	221.563	(0.0000)	293.459	(0.0000)

Source: authors' calculation using Eviews

Table B4: Stationary Tests Results for the Variables of ICT Investments Effects Model - Low Income Economies

Test Type		gGDPPC		gICT		gNICT		gEMPLOY		gExport	
		Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**
Levin, Lin&Chu	**At Level**	-5.59715	(0.0000)	-3.98012	(0.0000)	-1.87686	(0.0303)	-2.74506	(0.0030)	-8.64134	(0.0000)
ADF	**At Level**	79.073	(0.0000)	38.8091	(0.0004)	25.6372	(0.0288)	40.0197	(0.0003)	95.1004	(0.0000)
PP	**At Level**	106.02	(0.0000)	39.8695	(0.0003)	19.9056	(0.1331)	40.7004	(0.0002)	95.3254	(0.0000)

Source: authors' calculation using Eviews

Table B5: Stationary Tests Results for the Variables of ICT Usage Effects Models - High Income Economies

	At Level						At First Difference					
Tests Type	**Levin, Lin &Chu**		**ADF**		**PP**		**Levin, Lin &Chu**		**ADF**		**PP**	
Variables	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****
Log_GDPPC	15.3552	(1.0000)	8.55363	(1.0000)	10.0369	(1.0000)	-12.8042	(0.0000)	324.768	(0.0000)	316.46	(0.0000)
Log_FBS	3.68141	(0.9999)	40.2091	(1.0000)	40.271	(1.0000)	-54.7947	(0.0000)	619.054	(0.0000)	646.822	(0.0000)
Log_IU	7.65031	(1.0000)	12.4085	(1.0000)	1.57373	(1.0000)	-22.7487	(0.0000)	493.358	(0.0000)	513.629	(0.0000)
Log_MCS	8.44949	(1.0000)	19.6975	(1.0000)	2.74652	(1.0000)	-20.7139	(0.0000)	502.94	(0.0000)	544.501	(0.0000)
Log_GFCF	-1.28835	(0.0988)	58.4527	(0.9900)	69.1981	(0.9072)	-21.6779	(0.0000)	569.142	(0.0000)	570.441	(0.0000)
Log_TO	3.65146	(0.9999)	26.6071	(1.0000)	25.6833	(1.0000)	-24.3111	(0.0000)	625.483	(0.0000)	650.109	(0.0000)
Log_LABOR	2.04646	(0.9796)	51.2365	(0.9989)	58.2896	(0.9904)	-18.6976	(0.0000)	497.178	(0.0000)	535.901	(0.0000)

Source: authors' calculation using Eviews

Table B6: Stationary Tests Results for the Variables of ICT Usage Effects Models - Upper Middle Income Economies

	At Level						At First Difference					
Tests Type	**Levin, Lin &Chu**		**ADF**		**PP**		**Levin, Lin &Chu**		**ADF**		**PP**	
Variables	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****
Log_GDPPC	10.8872	(1.0000)	2.45113	(1.0000)	1.24831	(1.0000)	-4.90417	(0.0000)	106.304	(0.0000)	112.459	(0.0000)
Log_FBS	-0.67623	(0.2494)	49.5107	(0.1000)	110.126	(0.0000)	-23.9331	(0.0000)	201.458	(0.0000)	197.233	(0.0000)
Log_IU	5.07278	(1.0000)	6.42885	(1.0000)	1.67912	(1.0000)	-11.2689	(0.0000)	160.599	(0.0000)	126.5	(0.0000)
Log_MCS	1.00184	(0.8418)	16.5985	(0.9990)	3.1776	(1.0000)	-14.0976	(0.0000)	188.732	(0.0000)	205.799	(0.0000)
Log_GFCF	1.21272	(0.8874)	19.9228	(0.9931)	21.8102	(0.9836)	-14.6238	(0.0000)	243.705	(0.0000)	253.102	(0.0000)
Log_TO	-0.44438	(0.3284)	29.1868	(0.8470)	33.6711	(0.6698)	-17.8793	(0.0000)	304.099	(0.0000)	311.248	(0.0000)
Log_LABOR	0.78607	(0.7841)	20.9532	(0.9887)	46.5624	(0.1606)	-8.75432	(0.0000)	245.89	(0.0000)	232.346	(0.0000)

Source: authors' calculation using Eviews

Table B7: Stationary Tests Results for the Variables of ICT Usage Effects Models - Lower Middle Income Economies

	At Level						At First Difference					
Tests Type	**Levin, Lin &Chu**		**ADF**		**PP**		**Levin, Lin &Chu**		**ADF**		**PP**	
Variables	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****
Log_GDPPC	22.5333	(1.0000)	1.75095	(1.0000)	0.35824	(1.0000)	-0.58632	(0.2788)	70.8971	(0.0019)	78.4345	(0.0003)
Log_FBS	-13.9597	(0.0000)	243.935	(0.0000)	239.527	(0.0000)	-11.8956	(0.0000)	212.05	(0.0000)	184.836	(0.0000)
Log_IU	2.61288	(0.9955)	11.51	(1.0000)	8.66758	(1.0000)	-11.8359	(0.0000)	159.508	(0.0000)	179.037	(0.0000)
Log_MCS	-1.65565	(0.0489)	29.6172	(0.8856)	5.99399	(1.0000)	-12.1207	(0.0000)	191.186	(0.0000)	179.448	(0.0000)
Log_GFCF	4.30632	(1.0000)	16.8062	(0.9995)	16.4046	(0.9997)	-15.3166	(0.0000)	270.742	(0.0000)	289.73	(0.0000)
Log_TO	0.00741	(0.5030)	31.2432	(0.8377)	43.7562	(0.3151)	-16.0148	(0.0000)	271.745	(0.0000)	298.127	(0.0000)
Log_LABOR	0.47799	(0.6837)	38.347	(0.5448)	31.4535	(0.8309)	-9.74701	(0.0000)	235.899	(0.0000)	230.139	(0.0000)

Source: authors' calculation using Eviews

Table B8: Stationary Tests Results for the Variables of ICT Usage Effects Models - Low Income Economies

	At Level						At First Difference					
Tests Type	**Levin, Lin &Chu**		**ADF**		**PP**		**Levin, Lin &Chu**		**ADF**		**PP**	
Variables	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****
Log_GDPPC	12.4823	(1.0000)	0.17972	(1.0000)	0.11237	(1.0000)	-4.18836	(0.0000)	50.9738	(0.0000)	65.9535	(0.0000)
Log_FBS	-2.63345	(0.0042)	19.3078	(0.1535)	17.4959	(0.2307)	-8.93119	(0.0000)	79.9183	(0.0000)	92.5504	(0.0000)
Log_IU	0.37999	(0.6480)	21.3147	(0.0938)	14.8024	(0.3918)	-5.06321	(0.0000)	47.0642	(0.0000)	56.4484	(0.0000)
Log_MCS	-0.5589	(0.2881)	10.1742	(0.7493)	6.07283	(0.9646)	-6.03204	(0.0000)	57.1756	(0.0000)	62.5884	(0.0000)
Log_GFCF	2.27047	(0.9884)	2.71739	(0.9995)	2.66998	(0.9995)	-9.16815	(0.0000)	91.2615	(0.0000)	103.519	(0.0000)
Log_TO	-0.15856	(0.4370)	12.8502	(0.5383)	12.8875	(0.5354)	-11.3318	(0.0000)	114.19	(0.0000)	109.495	(0.0000)
Log_LABOR	-0.31564	(0.3761)	13.1084	(0.5180)	27.9343	(0.0145)	-2.40323	(0.0081)	24.7825	(0.0368)	21.2629	(0.0951)

Source: authors' calculation using Eviews

Table B9: Stationary Tests Results for the Residual of ICT Usage effects Model I

		High Income		**Upper Middle Income**		**Lower Middle Income**		**Low Income**	
Test Type		**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****
Levin, Lin&Chu	At Level	-7.23776	(0.0000)	-6.57482	(0.0000)	-9.27297	(0.0000)	-2.93445	(0.0017)
ADF	At Level	197.134	(0.0000)	99.1242	(0.0000)	144.038	(0.0000)	26.7296	(0.0209)
PP	At Level	233.835	(0.0000)	110.322	(0.0000)	142.213	(0.0000)	74.1552	(0.0000)

Source: authors' calculation using Eviews

Table B10: Stationary Tests Results for the Residual of ICT Usage effects Model II

		High Income		**Upper Middle Income**		**Lower Middle Income**		**Low Income**	
Test Type		**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****	**Statistics**	**Prob.****
Levin, Lin&Chu	At Level	-7.92394	(0.0000)	-6.2026	(0.0000)	-12.7817	(0.0000)	-5.55558	(0.0000)
ADF	At Level	229.433	(0.0000)	98.436	(0.0000)	209.727	(0.0000)	65.7067	(0.0000)
PP	At Level	288.528	(0.0000)	129.748	(0.0000)	210.401	(0.0000)	62.1485	(0.0000)

Source: authors' calculation using Eviews

Table B11: Stationary Tests Results for the Residual of ICT Usage effects Model III

Test Type		High Income		Upper Middle Income		Lower Middle Income		Low Income	
		Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**	Statistics	Prob.**
Levin, Lin&Chu	At Level	-6.01384	(0.0000)	-6.18889	(0.0000)	-4.34112	(0.0000)	-2.4	(0.0082)
ADF	At Level	204.078	(0.0000)	98.3324	(0.0000)	72.231	(0.0013)	41.856	(0.0001)
PP	At Level	225.308	(0.0000)	105.857	(0.0000)	85.3509	(0.0000)	45.892	(0.0000)

Source: authors' calculation using Eviews

Appendix C: Panel Models Results

Table C1: Panel Models Estimation Results for ICT Investments effects Model - High Income Economies

Dependent Variable: gGDPPC						
Variable	**Pooled OLS**		**Fixed Effect**		**Random Effect**	
	Coefficients	**Prob.**	**Coefficients**	**Prob.**	**Coefficients**	**Prob.**
C	-1.080935	(0.0000)	-1.0235	(0.0000)	-1.078274	(0.0000)
gICT	0.069051	(0.0000)	0.0530	(0.0000)	0.064631	(0.0000)
gNICT	0.100505	(0.0024)	0.0806	(0.1781)	0.092982	(0.0089)
gEMPLOY	0.130462	(0.3641)	0.2429	(0.0001)	0.188058	(0.0098)
gEXPORT	0.252971	(0.0000)	0.2476	(0.0000)	0.251312	(0.0000)

Source: authors' calculation using Eviews

Table C2: Panel Models Estimation Results for ICT Investments effects Model - Upper Middle Income Economies

Dependent Variable: gGDPPC						
Variable	**Pooled OLS**		**Fixed Effect**		**Random Effect**	
	Coefficients	**Prob.**	**Coefficients**	**Prob.**	**Coefficients**	**Prob.**
C	-0.075819	(0.7994)	-0.4627	(0.1650)	-0.28536	(0.5281)
gICT	0.038975	(0.0043)	0.0192	(0.2268)	0.023565	(0.0584)
gNICT	0.300584	(0.0000)	0.4452	(0.0000)	0.403859	(0.0000)
gEMPLOY	0.18752	(0.1234)	0.3078	(0.0000)	0.264267	(0.0000)
gEXPORT	0.156066	(0.0000)	0.1338	(0.0000)	0.137883	(0.0000)

Source: authors' calculation using Eviews

Table C3: Panel Models Estimation Results for ICT Investments effects Model - Lower Middle Income Economies

Dependent Variable: gGDPPC						
	Pooled OLS		**Fixed Effect**		**Random Effect**	
Variable	**Coefficients**	**Prob.**	**Coefficients**	**Prob.**	**Coefficients**	**Prob.**
C	0.615258	(0.0224)	-0.091325	(0.7717)	0.356034	(0.2672)
gICT	0.027577	(0.0152)	0.024382	(0.0498)	0.027452	(0.0133)
gNICT	0.186128	(0.0000)	0.336007	(0.0000)	0.239097	(0.0000)
gEMPLOY	0.276317	(0.0003)	0.318194	(0.0000)	0.255951	(0.0000)
gEXPORT	0.08778	(0.0000)	0.075469	(0.0000)	0.079325	(0.0000)

Source: authors' calculation using Eviews

Table C4: Panel Models Estimation Results for ICT Investments effects Model - Low Income Economies

Dependent Variable: gGDPPC						
	Pooled OLS		**Fixed Effect**		**Random Effect**	
Variable	**Coefficients**	**Prob.**	**Coefficients**	**Prob.**	**Coefficients**	**Prob.**
C	0.717993	(0.3358)	-0.911854	(0.3524)	0.717993	(0.3178)
gICT	-0.019863	(0.2313)	-0.030234	(0.1675)	-0.019863	(0.2141)
gNICT	0.238222	(0.0020)	0.358686	(0.0001)	0.238222	(0.0014)
gEMPLOY	0.394082	(0.6064)	0.492159	(0.0694)	0.394082	(0.5928)
gEXPORT	0.047196	(0.0141)	0.047096	(0.0058)	0.047196	(0.0109)

Source: authors' calculation using Eviews

Appendix D: Model Selection Results

Table D1: Hausman Test results for ICT Investments effects Model - for All Income Groups

Economies Groups	Summary	Chi -Sq. Statistic	Chi -Sq. d.f.	Prob.	Result (preferred model)
High Income Economies	Cross section random	74.139705	4	(0.0000)	FEM
Upper Middle Income Economies	Cross section random	17.723141	4	(0.0014)	FEM
Lower Middle Income Economies	Cross section random	41.773539	4	(0.0000)	FEM
Low Income Economies	Cross section random	18.26366	4	(0.0011)	FEM

Source: authors' calculation using Eviews

Table D2: Wald Test results for ICT Investments effects Model - for All Income Groups

Economies Groups	Test Statistic	Value	df	Probability	Result (preferred model)
High Income Economies	F-statistic	5.04845	(42, 1125)	(0.0000)	FEM
	Chi-square	212.0349	42	(0.0000)	
Upper Middle Income Economies	F-statistic	10.1465	(18, 505)	(0.0000)	FEM
	Chi-square	182.637	18	(0.0000)	
Lower Middle Income Economies	F-statistic	7.147838	(19, 533)	(0.0000)	FEM
	Chi-square	135.8089	19	(0.0000)	
Low Income Economies	F-statistic	3.207285	(6, 165)	(0.0053)	FEM
	Chi-square	19.24371	6	(0.0038)	

Source: authors' calculation using Eviews

Appendix E: Co-integration Tests Results

Table E1: Co-integration Tests Results of ICT Usage effects Model I

		High Income		Upper Middle Income		Lower Middle Income		Low Income	
Pedroni Residual Co Integration Test		**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**
Within Dimention	V- Statistic	4.7766	(0.0000)	10.2740	(0.0000)	21.3231	(0.0000)	10.8787	(0.0000)
	Rho- Statistic	5.4396	(1.0000)	4.3498	(1.0000)	5.8932	(1.0000)	2.8514	(0.9978)
	PP- Statistic	0.9029	(0.8167)	1.5738	(0.9422)	0.5074	(0.6941)	-0.3032	(0.3809)
	ADF- Statistic	-2.3373	(0.0097)	-0.0923	(0.4632)	-1.0076	(0.1568)	-3.1273	(0.0009)
	V- Weighted Statistic	2.7540	(0.0029)	6.6576	(0.0000)	-3.7039	(0.9999)	4.0789	(0.0000)
	Rho- Weighted Statistic	4.6412	(1.0000)	3.9015	(1.0000)	6.9185	(1.0000)	2.5974	(0.9953)
	PP- Weighted Statistic	-2.5186	(0.0059)	0.2659	(0.6048)	-10.7175	(0.0000)	-3.2610	(0.0006)
	ADF- Weighted Statistic	-5.4115	(0.0000)	-1.1583	(0.1234)	-3.3460	(0.0004)	-4.1511	(0.0000)
Between Dimension	Group rho - Statistic	6.9878	(1.0000)	5.0712	(1.0000)	6.4161	(1.0000)	3.5869	(0.9998)
	Group PP- Statistic	-5.3187	(0.0000)	-3.7318	(0.0001)	-7.0059	(0.0000)	-4.6952	(0.0000)
	Group ADF- Statistic	-6.2411	(0.0000)	-2.1748	(0.0148)	-3.6025	(0.0002)	-4.6424	(0.0000)
Kao Residual Co-integration Test		**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**
	ADF	-2.3795	(0.0087)	-1.6516	(0.0493)	-1.6482	(0.0497)	-1.8165	(0.0346)
Fisher Residual Co-integration Test		**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**
	None	1858	(0.0000)	842.8	(0.0000)	839.9	(0.0000)	266.6	(0.0000)
	At most 1	1056	(0.0000)	491.4	(0.0000)	434.7	(0.0000)	132	(0.0000)
	At most 2	541.5	(0.0000)	243.9	(0.0000)	223.6	(0.0000)	86.23	(0.0000)
	At most 3	296.3	(0.0000)	118.3	(0.0000)	119.7	(0.0000)	61.9	(0.0000)
	At most 4	215.4	(0.0000)	69.33	(0.0000)	81.11	(0.0001)	46.98	(0.0000)
Results		Co-integrated		Co-integrated		Co-integrated		Co-integrated	

Source: authors' calculation using Eviews

Table E2: Co-integration Tests Results of ICT Usage effects Model II

		High Income		Upper Middle Income		Lower Middle Income		Low Income	
Pedroni Residual Co Integration Test		**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**
Within Dimention	V- Statistic	3.892182	(0.0000)	12.85981	(0.0000)	16.37491	(0.0000)	4.834301	(0.0000)
	Rho- Statistic	5.788827	(1.0000)	5.007844	(1.0000)	3.527623	(0.9998)	0.73833	(0.7698)
	PP- Statistic	0.20291	(0.5804)	2.088852	(0.9816)	-0.89376	(0.1857)	-2.28768	(0.0111)
	ADF- Statistic	-5.387473	(0.0000)	0.131115	(0.5522)	-2.4273	(0.0076)	-3.11521	(0.0009)
	V- Weighted Statistic	2.397315	(0.0083)	6.695869	(0.0000)	5.619311	(0.0000)	2.280773	(0.0113)
	Rho- Weighted Statistic	5.130025	(1.0000)	4.418576	(1.0000)	3.661797	(0.9999)	0.754229	(0.7746)
	PP- Weighted Statistic	-2.39049	(0.0084)	-1.75912	(0.0393)	0.014761	(0.5059)	-2.01746	(0.0218)
	ADF- Weighted Statistic	-4.825118	(0.0000)	-3.56352	(0.0002)	-1.8784	(0.0302)	-2.35276	(0.0093)
Between Dimension	Group rho - Statistic	7.548893	(1.0000)	6.281189	(1.0000)	4.435284	(1.0000)	1.678953	(0.9534)
	Group PP- Statistic	-4.083341	(0.0000)	-10.3628	(0.0000)	-4.88583	(0.0000)	-2.17992	(0.0146)
	Group ADF- Statistic	-6.165859	(0.0000)	-5.345873	(0.0000)	-4.736873	(0.0000)	-3.590678	(0.0002)
Kao Residual Co-integration Test		**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**
	ADF	-2.262008	(0.0118)	-1.52048	(0.0642)	-1.77114	(0.0383)	-2.53531	(0.0056)
Fisher Residual Co-integration Test		**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**
	None	1738	(0.0000)	774.7	(0.0000)	872.4	(0.0000)	178.4	(0.0000)
	At most 1	901.9	(0.0000)	385	(0.0000)	431.3	(0.0000)	92.48	(0.0000)
	At most 2	453.3	(0.0000)	222.2	(0.0000)	223.9	(0.0000)	61.27	(0.0000)
	At most 3	278.3	(0.0000)	136	(0.0000)	131	(0.0000)	52.68	(0.0000)
	At most 4	240.9	(0.0000)	98.98	(0.0000)	90.86	(0.0000)	_	_
Results		Co-integrated		Co-integrated		Co-integrated		Co-integrated	

Source: authors' calculation using Eviews

Table E3: Co-integration Tests Results of ICT Usage effects Model III

		High Income		Upper Middle Income		Lower Middle Income		Low Income	
Pedroni Residual Co Integration Test		**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**
Within Dimention	V- Statistic	3.4216	(0.0003)	16.58124	(0.0000)	24.09528	(0.0000)	4.765359	(0.0000)
	Rho- Statistic	5.446471	(1.0000)	4.985114	(1.0000)	5.516701	(1.0000)	0.894055	(0.8144)
	PP- Statistic	0.881281	(0.8109)	0.179747	(0.5713)	-1.45757	(0.0725)	-4.25915	(0.0000)
	ADF- Statistic	-1.306906	(0.0956)	-2.27296	(0.0115)	-2.3849	(0.0085)	-2.88419	(0.0020)
	V- Weighted Statistic	1.528707	(0.0632)	9.151405	(0.0000)	-4.53661	(1.0000)	1.995003	(0.0230)
	Rho- Weighted Statistic	5.234402	(1.0000)	4.887174	(1.0000)	7.299903	(1.0000)	0.984893	(0.8377)
	PP- Weighted Statistic	-0.949073	(0.1713)	-3.26999	(0.0005)	-4.29309	(0.0000)	-3.75456	(0.0001)
	ADF- Weighted Statistic	-2.651154	(0.0040)	-3.68088	(0.0001)	-2.34054	(0.0096)	-1.99646	(0.0229)
Between Dimension	Group rho - Statistic	7.402698	(1.0000)	6.127325	(1.0000)	6.13358	(1.0000)	2.329307	(0.9901)
	Group PP- Statistic	-3.167495	(0.0008)	-8.92939	(0.0000)	-9.84484	(0.0000)	-4.957	(0.0000)
	Group ADF- Statistic	-3.997933	(0.0000)	-3.92616	(0.0000)	-4.99821	(0.0000)	-4.40932	(0.0000)
Kao Residual Co-integration Test		**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**	**t- Statistic**	**Prob.**
	ADF	-2.788079	(0.0027)	-1.03131	(0.1512)	-0.72753	(0.2335)	-2.31976	(0.0102)
Fisher Residual Co-integration Test		**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**	**Fisher Stat.***	**Prob.**
	None	1705	(0.0000)	744.7	(0.0000)	789.7	(0.0000)	259	(0.0000)
	At most 1	945	(0.0000)	409.1	(0.0000)	456.9	(0.0000)	145.5	(0.0000)
	At most 2	488.8	(0.0000)	233.9	(0.0000)	250.8	(0.0000)	70.93	(0.0000)
	At most 3	263.3	(0.0000)	143.6	(0.0000)	142.4	(0.0000)	47.41	(0.0000)
	At most 4	205.2	(0.0000)	91.11	(0.0000)	96.81	(0.0000)	34.04	(0.0000)
Results		Co-integrated		Co-integrated		Co-integrated		Co-integrated	

Source: authors' calculation using Eviews