Impact of Information and Communication Technology on Economic Growth for Upper-Middle Income Economies

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Abstract

In this paper I analyze the impact of information and communication technology (ICT) on the economic growth of selected upper-middle income countries for a period of 20 years (1997-2016). Using panel growth models, I investigate how core ICT infrastructure indicators affect the economic growth, which in my study is proxied by GDP per capita. Several macroeconomic control variables are included in the model. In order to avoid reverse causality and endogeneity issues, lagged variables are selected for the model. My key findings suggest that ICT infrastructure along with other macroeconomic factors has positive and significant effect on economic growth of the selected countries. Particular ICT indicators have stronger impact on economic growth compared to others.

Keywords: Information and communication technologies (ICT), economic growth, upper-middle income economies

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Introduction

Information and communication technology (ICT) is defined as a set of activities that facilitate by electronic means the capturing, storage, processing, transmission and display of information (World Bank, 2002). ICT main components are information technology equipment (computers and related hardware), software and telecommunication equipment (OECD, 2005). ICT infrastructure indicators are “Fixed telephone subscriptions (per 100 people)”, “Mobile cellular subscriptions (per 100 people)”, “Broadband subscriptions (per 100 people)” and “Individuals using the internet (% of population)” (International telecommunication Union, 2018).

ICT may influence economic growth through several important channels. The impact of ICT plays a crucial role in allowing people, companies and governments to have quick and easy access to information and knowledge (Sepehrdoust, 2018). ICT improves the speed and quality of corporate communication, which leads to reduced production costs and improved productivity (Meijers, 2014). ICT mitigates information asymmetry and reduces agency costs, thus promoting the development of entrepreneurship in a country (Chen, 2018). The relationship between ICT and unemployment rate has been extensively studied, however it is still an arguable topic. Most studies show that the development of ICT creates new work opportunities, reducing the unemployment rate. However, some studies bring out the point that ICT may negatively affect employment through the reduction or elimination of positions for unskilled workers, especially in developing countries (Aghion and Howitt, 1998). ICT may serve as a channel to international markets, allowing access to lower capital costs and human resources (Pradhan, 2018). Overall, the link between ICT diffusion and economic growth has become a topic of interest in the research world during the last three decades.

Some part of the literature highlights that the impact of ICT on economic growth largely depends on the income level of the country (Romer and Mankiw, 1992). The increasing enthusiasm towards ICT carries substantial risk of making wrong and expensive investments. In order to avoid optimistic exaggerations and technological booms, more research is required in this topic, particularly for developing countries. Starting from 2016, the World Bank made a decision not to distinguish between developed and developing countries but to have four separate country groups (Low income, Low middle income, Upper middle income, Higher middle income) based on GNI per capita. The main aim of this study is to contribute to knowledge about the impact of ICT on the economic growth for upper middle-income economies within a period of 1997-2016.

This paper contributes to the existing literature in several aspects. First, the selected country group has not been aggregately studied before. Out of 32 countries within this group, 15 were included in other cross-country studies. Second, the link between ICT and economic growth is examined using four core ICT indicators, while most of the available studies investigate just three of them ("broadband subscription" is usually not included in the models). Third, most of the studies came to the conclusion that the relationship between ICT diffusion and economic growth is positive for the developed countries. However, conflicting results have been obtained for the developing countries, depending on the applied methodologies and selected regions of study. Investigation of the selected country group, will fill this gap about ICT's economic impact for developing countries.

Literature Review

The accelerated development of information and communication technology (ICT) over the past three decades has encouraged many researchers to investigate its economic implications. ICTs offer increased potential for advancing progress towards economic and social development objectives (United Nations, 2018). Different results about the link between ICT and economic growth have been obtained depending on the applied methodologies and selected regions for study.

Early studies indicated that ICT's impact on economic growth was very little (Oliner and Sichel, 1994; Stiroh and Jorgenson, 1999). Oliner and Sichel (1994) suggest that the contribution of computers to the economic growth in 1980s was more apparent rather than real and the expectations of both private and public sectors should not have been too high. According to Stiroh and Jorgenson (1999), the rewards from ICT accrue to the direct participants (innovating industries), however, the aggregate impact on economic growth is not significant. On the other hand, later studies showed that ICT has positive effect on economic growth. O'Mahony and Van Ark (2011) consider lack of ICT investments as a primary reason for European economic growth slowdown since the mid 1990s. Vu (2011) conducts three empirical exercises (cross-country regression, Generalized Method of Moment, time-series analysis) to demonstrate the important role of ICT as source of economic growth. At the same time, Vu's analysis shows that for an average country marginal effect of ICT penetration lessens as the penetration increases (Vu, 2011).

Series of studies brought out the point that ICT's impact on economic growth depends on income level of a country. Weil, Romer and Mankiw (1992) gathered data from 42 developing and 24 high income developed countries for 1985-1999 period. Their research showed that contribution of ICT in economic growth was positive and meaningful for high income countries, positive but not meaningful for developing countries (Weil, Romer and Mankiw, 1992). Similar results were obtained by Dewan and Kraemer (2001), who analyzed data from 32 countries and found relationship between ICT and economic growth only in prosperous and industrial countries. Even more, Yousefi's research suggests that ICT plays a major role in the growth of high and upper-middle income groups, but fails to contribute to the growth of the lower-middle income group countries (Yousefi, 2011). Dewan and Kraemer (2001) mention that this gap between countries is caused by low level of ICT investments and unavailability of complementary assets (e.g. knowledge-based structures for ICT) in developing countries.

Some studies analyzed the ICT influence on economic growth particularly for emerging and developing countries. Steinmueller (2001) mentions that ICT can enable emerging and developing countries to apply "leapfrog" development strategy. ICT may decrease transaction costs and foster the process of knowledge creation, thus positively affect the economic growth (Steinmueller, 2001). The concept of "leapfrog" strategy for developing countries is further discussed by Keller (2004) and Henry (2009). The direct effect on economic growth and the success of development strategy largely depends on country's ability and effort to apply new technologies (Keller, 2004). "Information Economy" report by United Nations (2011) highlights the role of ICTs in enabling private-sector development and economic growth in the long term. United Nations (2011) mentions that ICTs may have a strong impact on economic performance

of developing and emerging markets in case of appropriate adaptation. ICTs may be used to decrease administrative burden of firms, to organize educational services and to enhance access to relevant information. These benefits in aggregate may enable economic growth (United Nations, 2011).

The link between ICT and economic growth has been investigated both at the national and cross-country levels. Oliner and Sichel (2002), Jorgenson and Stiroh (2000) estimated the contribution of ICT to GDP growth of US, Oulton (2002) for the UK; Jalava and Pohjola (2002) for Finland; Colecchia and Schreyer (2002), Jorgenson and Motohashi (2005) for Japan. At the cross-country level, Roller and Waverman (2001) observe the impact of ICT investments on economic growth of OECD countries. Toader and Firtescu (2018) evaluate the effect of ICT infrastructure on economic growth for EU-member countries; Bahrini and Qaffas (2019) for Middle East and North Africa (MENA) region and the Sub-Saharan Africa (SSA).

Several studies analyze the empirical relationship between ICT investment and GDP growth. Positive relationship is identified in Central and Eastern Europe for the period 1990-1995 (Madden and Savage, 1998). Colecchia and Schreyer (2001) compare the impacts of ICT investment between nine OECD countries. Another strand of literature analyzes the effects of ICT on productivity. Dewan and Kraemer (2000), Pohjola (2001) and Zhoudong (2010) conducted a cross-country research coming to a conclusion that ICT diffusion is associated with significant productivity gains, especially in case of developed countries.

The effect of ICT on economic growth has been much studied for US, European, Asian and other developed countries. Even though some studies have been conducted also for the emerging and developing countries, as mentioned above, there are still some gaps to be filled in this regard. The question whether or not ICT positively impacts economic growth of developing countries still needs further elaboration. This paper is intended to examine the relationship of ICTs and the economic growth using panel data for 32 upper-middle income economies during 1997-2016.

Data and Methodology

This paper investigates the impact of ICT (core indicators) on economic growth in the upper-middle income countries, for a period of 20 years (1997-2016). After filtering variables due to missing data for certain countries, 32 upper-middle income countries were selected. As a result, I have obtained 640 observations for the variables of interest. The analysis includes 12 variables. All the data is obtained from the World Bank Database in order to avoid cross-country variations (differences in variable definition).

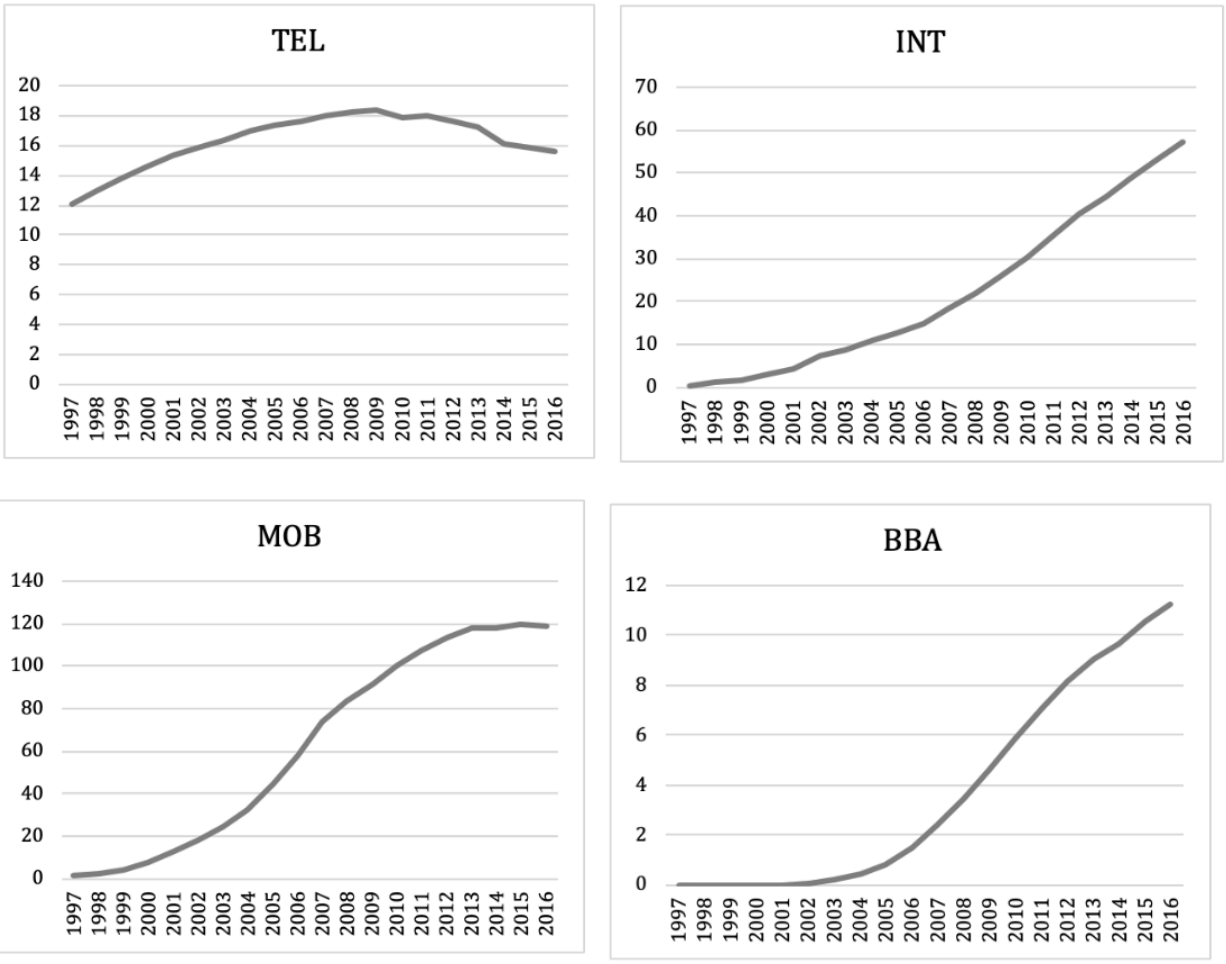
The dependent variable in the model is economic growth. An impact is considered as economic benefit if it increases the welfare of local population. For this reason, economic growth in the analysis is proxied by GDP per capita (current US$). Two types of explanatory variables are included in the model.

The first group of explanatory variables consists of four core ICT indicators (fixed-broadband subscriptions per 100 inhabitants, fixed broadband subscriptions per 100 inhabitants, percentage of individuals using the Internet, and mobile cellular subscriptions per 100 people). Similar

analysis with the same four ICT indicators was done by Bahrini and Qaffas (2019) for Africa, by Toader, Firtescu, Roman and Anton (2018) for EU countries.

The second group of explanatory variables refers to the macroeconomic control variables (gross fixed capital formation, inflation rate, unemployment rate, trade openness, inflows of foreign direct investment, general government final consumption expenditure, and the domestic credit to the private sector), which are included in the model with the purpose of emphasizing their impact on GDP per capita. The macroeconomic control variables are selected in line with the existing literature.

Figure 2: Average ICT indicators in the selected upper-middle income countries (1997-2016)



Source: World Bank Database

From the graphs above it can be observed that TEL (Fixed telephone) was the first information and communication technology adopted by the selected upper-middle income economies. 1997-2009, the number of fixed telephone subscriptions was increasing. Starting from 2010, a decreasing trend is noticed. Unlike TEL, the diffusion of INT (Internet), MOB (Mobile cellular) and BBA (Broadband) in the selected upper-middle income countries started later, in 2005. The annual growth rate of these technologies has been and still remains significantly higher compared to TEL. Since 2013, the average number of mobile cellular subscriptions has remained relatively stable, whereas a steady growth is observed for INT and BBA.

The description and the summary statistics for the main sample variables included in the analysis are presented in Table 1 below. Detailed definition of each variable is presented in Table A1 of the Appendix.

Table 4: Description and summary statistics for observations included in the model

Variable	Description		Mean	Std. Dev.	Min	Max
LNGDPPC	Gross domestic product per capita (current US$) (logarithmic values)	overall	8.27	0.66	6.23	9.68
		between		0.38	7.47	8.99
		within		0.54	6.79	9.53
LNLINT	Individuals using the Internet (% of population) (logarithmic values)	overall	2.04	1.97	-6.35	4.37
		between		0.69	0.71	4.03
		within		1.83	-5.02	5.09
LNLTEL	Fixed telephone subscriptions (per 100 people) (logarithmic values)	overall	2.59	0.65	-0.04	3.87
		between		0.58	0.76	3.54
		within		0.31	0.01	3.91
LNLMOB	Mobile cellular subscriptions (per 100 people) (logarithmic values)	overall	3.22	1.87	-2.84	5.19
		between		0.58	1.89	4.76
		within		1.77	-2.00	5.91
LNLBBA	Fixed broadband subscriptions (per 100 people) (logarithmic values)	overall	-0.11	2.64	-8.53	3.48
		between		0.89	-1.98	2.13
		within		2.47	-9.33	3.78
LNLGOV	General government final consumption expenditure (% of GDP) (logarithmic values)	overall	2.64	0.28	1.61	3.40
		between		0.25	2.14	3.07
		within		0.13	2.10	3.10

LNLINVEST	Gross fixed capital formation (% of GDP) (logarithmic values)	overall	3.14	0.25	1.68	4.05
		between		0.18	2.80	3.67
		within		0.18	1.86	3.86
LNLTRADE	Trade (% of GDP) (logarithmic values)	overall	4.27	0.44	2.75	5.39
		between		0.42	3.16	5.19
		within		0.16	3.26	4.92
LNLFIND	Domestic credit to private sector (% of GDP) (logarithmic values)	overall	3.45	0.84	0.15	5.11
		between		0.71	2.26	4.91
		within		0.47	1.34	4.83
LNLINF	Inflation, consumer prices (annual %) (logarithmic values)	overall	1.71	1.06	-3.30	6.96
		between		0.69	0.34	3.37
		within		0.82	-2.20	6.62
LNLUNEMP	Unemployment, total (% of total labor force) (logarithmic values)	overall	2.00	0.86	-0.72	3.62
		between		0.82	-0.22	3.49
		within		0.33	-0.60	3.40
LNLFDI	Foreign direct investment, net inflows (% of GDP) (logarithmic values)	overall	0.97	1.07	-3.83	4.01
		between		0.70	-0.95	2.55
		within		0.82	-3.93	2.93

Table 2 describes the sample of selected upper-middle income countries used in this study. It shows that the list of sample countries consists of 32 upper-middle income countries, out of which 6 countries are in the Africa and Arab States, 7 are in Europe, 9 are in Asia and Pacific and 10 countries are in South/Latin America.

Table 5: List of sample countries

Africa & Arab States	**Europe**	**Asia & Pacific**	**South/Latin America**
Botswana	Albania	Azerbaijan	Brazil
Gabon	Armenia	Belarus	Colombia
Mauritius	Romania	China	Costa Rica
South Africa	Russian Federation	Fiji	Dominican Republic
Algeria	Turkey	Iran, Islamic Rep.	Ecuador
Jordan	Bulgaria	Kazakhstan	Guatemala
	Macedonia, FYR	Malaysia	Jamaica
		Thailand	Mexico
		Tonga	Paraguay
			Peru

The following equation describes the growth model adopted in this study:

$$GDPPC_{it} = \beta_0 + \beta_1 ICT_{it-1} + \beta_2 Z_{it-1} + \varepsilon_{it-1}$$

Where "i" is each country in the panel data, "t" is the time period and β_0 is the constant. β_1 is the coefficient to be estimated in order to evaluate any significant impact of ICT variables (TEL, MOB, INT, BBA) on economic growth. β_2 is the coefficients to be estimated for each control variable Z_{it} (GOV, INVEST, TRADE, FIND, INF, UNEMP, FDI). ε_{it} represents the error terms. Because reverse-causality and endogeneity could also influence the results, lagged variables (t-1) are included in the model. For normalization purposes log-log transformation of variables is applied. For investigating the long-run effects, separate models with 4-year average variables are developed.

Estimation and Results

The main objective of this paper is to investigate the effect of ICT on economic growth, using four infrastructure variables as proxies, while controlling for the macroeconomic environment, employing seven control variables as a proxy. The null hypothesis is that there is a positive relationship between ICT (INT, MOB, TEL, BBA) and economic growth (GDPPC). The following general linear regression model for panel data is considered:

$$GDPPC_{it} = \beta_0 + \beta_1 ICT_{it-1} + \beta_2 Z_{it-1} + \varepsilon_{it-1}$$

The choice between possible models (fixed and random effects) is based on Hausman and Breusch-Pagan tests. The Hausman test, which is usually used in the literature, compares two estimators under the null of no significant difference: if this is not rejected, the more efficient

random effects estimator is chosen. Based on the results of the Hausman test, fixed effects model was selected. Detailed Hausman test results are presented in Table A2 of the Appendix. As the results of the Breusch-Pagan test showed, pooled OLS would not be consistent and one of the individual-specific models need to be selected. Detailed Breusch-Pagan test results are presented in Table A3 of the Appendix.

The correlation matrix was built to check the possible existence of multicollinearity. Detailed correlation matrix results are presented in Table A4 of the Appendix. As a result, multicollinearity was detected between four ICT indicators (INT, MOB, TEL, BBA). Based on these findings, four separate regressions were built for each ICT indicator (just one ICT indicator included in each regression). The primary analysis is done based on the results of these four regressions.

Equation (1): $\ln GDPPC_{it} = \beta_0 + \beta_1 \ln MOB_{it-1} + \beta_2 \ln GOV_{it-1} + \beta_3 \ln INVEST_{it-1} + \beta_4 \ln TRADE_{it-1} + \beta_5 \ln FIND_{it-1} + \beta_6 \ln INF_{it-1} + \beta_7 \ln UNEMP_{it-1} + \beta_8 \ln FDI_{it-1} + \varepsilon_{it-1}$

Equation (2): $\ln GDPPC_{it} = \beta_0 + \beta_1 \ln INT_{it-1} + \beta_2 \ln GOV_{it-1} + \beta_3 \ln INVEST_{it-1} + \beta_4 \ln TRADE_{it-1} + \beta_5 \ln FIND_{it-1} + \beta_6 \ln INF_{it-1} + \beta_7 \ln UNEMP_{it-1} + \beta_8 \ln FDI_{it-1} + \varepsilon_{it-1}$

Equation (3): $\ln GDPPC_{it} = \beta_0 + \beta_1 \ln TEL_{it-1} + \beta_2 \ln GOV_{it-1} + \beta_3 \ln INVEST_{it-1} + \beta_4 \ln TRADE_{it-1} + \beta_5 \ln FIND_{it-1} + \beta_6 \ln INF_{it-1} + \beta_7 \ln UNEMP_{it-1} + \beta_8 \ln FDI_{it-1} + \varepsilon_{it-1}$

Equation (4): $\ln GDPPC_{it} = \beta_0 + \beta_1 \ln BBA_{it-1} + \beta_2 \ln GOV_{it-1} + \beta_3 \ln INVEST_{it-1} + \beta_4 \ln TRADE_{it-1} + \beta_5 \ln FIND_{it-1} + \beta_6 \ln INF_{it-1} + \beta_7 \ln UNEMP_{it-1} + \beta_8 \ln FDI_{it-1} + \varepsilon_{it-1}$

Additionally, a regression with all four ICT variables included in it was built and is presented in Table A5 of the Appendix. Because of multicollinearity issues, some of the ICT variables (TEL, INT) become insignificant in this model and the quality of the regression model decreases significantly (R-sq within = 0.52).

Equation (5): $\ln GDPPC_{it} = \beta_0 + \beta_1 \ln MOB_{it-1} + \beta_2 \ln INT_{it-1} + \beta_3 \ln TEL_{it-1} + \beta_4 \ln BBA_{it-1} + \beta_5 \ln GOV_{it-1} + \beta_6 \ln INVEST_{it-1} + \beta_7 \ln TRADE_{it-1} + \beta_8 \ln FIND_{it-1} + \beta_9 \ln INF_{it-1} + \beta_{10} \ln UNEMP_{it-1} + \beta_{11} \ln FDI_{it-1} + \varepsilon_{it-1}$

In order to capture also the long-run effects, four more models with four-year average variables are built for all ICT indicators separately. These models confirmed the positive relationship between ICT variables and economic growth (GDP per capita). The coefficient of INT variable in the four-year average model is higher compared to the initial model, which means that the impact of Internet usage on economic growth is higher in the long run. The coefficients of all other ICT variables are relatively unchanged. Detailed results are presented in Table A6 of the Appendix.

Notes for the four-year average models: $(ICT_{it-3} + ICT_{it-2} + ICT_{it-1} + ICT_{it})/4 = ICT_{ik}$, where "k" is the average of four years

Table 6: Regression Results of Panel Data Analysis

Dependent Variable: GDP per capita (current US$) (logarithmic value)					
Variables		Model 1	Model 2	Model 3	Model 4
LN $LMOB_{it-1}$		0.19*** (0.01)			
LN $LINT_{it-1}$			0.18*** (0.01)		
LN $LTEL_{it-1}$				0.11*** (0.01)	
LN $LBBA_{it-1}$					0.35*** (0.06)
LN $LGOV_{it-1}$		-0.28*** (0.08)	-0.34*** (0.09)	-0.40*** (0.09)	-0.13 (0.11)
LN $LINVEST_{it-1}$		0.21*** (0.06)	0.43*** (0.07)	0.21*** (0.07)	0.41*** (0.09)
LN $LTRADE_{it-1}$		-0.44*** (0.08)	-0.48*** (0.08)	-0.55*** (0.09)	-0.32*** (0.10)
LN $LFIND_{it-1}$		0.33*** (0.03)	0.36*** (0.03)	0.21*** (0.04)	0.67*** (0.03)
LN $LINF_{it-1}$		-0.01 (0.01)	-0.00* (0.01)	-0.00 (0.02)	-0.07*** (0.02)
LN $LUNEMP_{it-1}$		-0.17*** (0.04)	-0.19*** (0.04)	-0.19*** (0.04)	-0.35*** (0.06)
LN $LFDI_{it-1}$		-0.03** (0.01)	-0.03** (0.01)	-0.02 (0.01)	0.02* (0.02)
R-sq	within	0.81	0.80	0.78	0.66
	between	0.05	0.03	0.00	0.01
	overall	0.49	0.44	0.31	0.20

*Notes: The 10%, 5%, and 1% significance levels are denoted by *, **, and ***, respectively.*

MOB (mobile cellular subscriptions per 100 inhabitants) is selected as a proxy of ICT in the Model 1. The impact of mobile cellular usage is positive and statistically significant for the panel of the selected upper-middle income countries. One percent increase in number of mobile cellular subscriptions per 100 inhabitants leads to 0.19% increase in upcoming year's GDP per capita. Mobile cellular improves information acquisition and mitigates distance constrains, thus improving economic growth of the selected upper-middle income countries. The results are in

line with the literature. Similar findings were obtained by Wamboye (2015), Ward and Zheng (2016) and Vu (2011).

In the Model 2, INT (number of Internet users per 100 inhabitants) is selected as an ICT indicator. The results reveal that INT (Internet usage) has a positive and significant effect on economic growth in the selected upper-middle income countries. One percent increase in the number of Internet users per 100 inhabitants leads to 0.18% increase in the next year's GDP per capita. Internet may improve the acceleration of innovation processes (Aghion and Howitt, 1998) and improve the overall business environment. By boosting the efficiency of business operations, Internet plays its significant role in the economic growth of the selected upper-middle income countries. The results are consistent with the studies of Bahrini and Qaffas (2019), Romer (1990), and Lucas (1998). According to Romer and Mankiw (1992), the impact of Internet usage on economic growth is positive but not meaningful for developing countries.

In the Model 3, TEL (number of fixed telephone subscriptions per 100 inhabitants) is selected as a proxy of ICT. According to Table 3, the effect of fixed telephone (TEL) is positive and statistically significant for the panel of the selected upper-middle income countries. One percent increase in number of fixed telephone subscriptions per 100 inhabitants leads to 0.11% increase of the upcoming year's GDP per capita. The magnitude of impact of fixed telephone usage is the lowest, compared to other ICT indicators (INT, MOB, BBA). This outcome may be explained by the recent substitution of fixed telephones with mobile telephones. 2002 was a turning point in the ICT history, when mobile phone subscriptions overtook fixed telephone subscriptions both worldwide and in the selected upper-middle income countries (ITU, 2003). As discussed

previously, fixed telephone subscriptions remained relatively stable within the period 1997-2016, which may be a reason for relatively smaller impact on economic growth. Similar results were found by Toader and Firtescu (2018), Hardy (1980), Matalqah and Warad (2017). However, the inverse relationship between fixed telephone subscriptions and economic growth is identified by Bahrini and Qaffas (2019) for the African continent.

In the Model 4, BBA (broadband subscriptions per 100 inhabitants) is selected as a proxy of ICT. The results of the regression indicate that broadband adaption has positive and significant effect on economic growth for the selected upper-middle income countries. One percent increase is the number of broadband subscriptions per 100 inhabitants lead to 0.35% increase of GDP per capita of the next year. The highest magnitude of economic impact is recorded for the broadband subscriptions compared to other ICT indicators. Even though broadband subscriptions are rapidly increasing in the developed world, certain barriers still exist for the developing world. Mobile broadband may be considered as a new opportunity for the developing countries, since it is a more affordable option compared to the fixed broadband. Economic benefits from broadband adoption may be in form of increased productivity and innovation, decreased operational costs and unemployment. Positive and significant effect of broadband availability on economic growth is identified by Gruber (2014), Aghion and Howitt (1998), Pradhan (2018) and Kolko (2012).

Regarding the macroeconomic control variables included in all four models, I found that financial development (FIND) and domestic investment (INVEST) affect positively and significantly the economic growth of the selected upper-middle income countries over the period of study. Different results have been obtained about and FDI in four models (from weakly

significant and positive to strongly significant and negative). Contrary to the initial assumptions, trade openness (TRADE) and the government final consumption expenditure (GOV) turned out to have negative impact on the economic growth of the selected upper-middle income countries. Several studies brought up the point that trade openness may have a negative impact on economic growth of countries which specialize in low-quality products (Hausmann, Hwang, 2007). This may be the case for the selected upper-middle income countries, however, trade openness is mostly viewed as an opportunity of economic growth in the literature. Results of the four models also showed negative impact of the unemployment rate (UNEMP) and inflation (INF) (in some cases insignificant) on the economic growth proxied by GDP per capita.

Conclusion

Given the accelerated diffusion of information and communication technology (ICT) during the last two decades, the main goal of this study was to determine the impact of ICT on economic growth (proxied by GDP per capita) in upper-middle income countries. ICT variables selected for the study were fixed telephone subscriptions (TEL), mobile cellular subscriptions (MOB), fixed broadband subscriptions (BBA) and individuals using the internet (INT). For investigating the link between ICT and economic growth, a panel data analysis was conducted for 32 upper-middle income countries for period of 1997-2016.

The results of the fixed effects panel model revealed positive and significant impact of ICT infrastructure on GDP per capita in the selected upper-middle income countries within a period of 1997-2016. Different magnitudes of impact were observed depending on which ICT indicator

(TEL, MOB, BBA, INT) was included in the model. The relatively small economic impact of fixed telephone may be explained by the substitution of fixed telephones with mobile phones. Another possible explanation may be the high infrastructural costs of fixed telephone lines. The highest positive economic impact was recorded for the broadband technology. Overall, ICT infrastructure along with other macroeconomic variables has important impact on economic growth in the selected upper-middle income countries

Based on the significant economic implications of ICT infrastructure, several recommendations may be derived. The selected upper-middle income countries are recommended to increase investment in ICT infrastructure, particularly in broadband (mobile broadband) and mobile cellular technologies. Investments in these technologies are both less expensive and more economically beneficial compared to two other ICT technologies. Besides infrastructural investments, additional incentives are required. Many governments of the selected upper-middle income countries have failed to promote ICT adoption in form of tax incentives, subsidies, public-private partnerships or stimulated competition. The lack of ICT trainings for households and businesses is another barrier for ICT adoption. The missing knowledge and fear of using technology leads to the ignorance of its economic implications. The selected upper-middle income countries are recommended to promote ICT literacy and improve ICT usage, which in turn will foster economic growth.

Regarding the macroeconomic control variables, given the positive impact of financial development (FIND) and domestic investment (INVEST) governments in the selected upper-middle income countries need to prioritize the improvement of financial sector. Here again, ICT

may be viewed as a development tool, by enabling mobile financial services, thus improving the efficiency and transparency of financial institutions. Certain policies and regulations should be adopted to mitigate the negative economic impact of unemployment and inflation. Concerning the government final consumption expenditure (GOV) and FDI, more flexible and convenient regulatory environment in required. The negative impact of these variables in some models may be explained by the existence of corruption in the selected upper-middle income countries thus more priority should be given to the transparency regulations.

ICT is an essential driver of economic development in upper-middle income economies. In order to capture the maximum economic benefit of ICT, corresponding environment and infrastructure development should receive a higher priority in government policies.

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Appendix

Table A1: Detailed Definition of Each Variable

Variable	Definition
GDP per capita (current US$)	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars.
Individuals using the Internet (% of population)	Internet users are individuals who have used the Internet (from any location) in the last 3 months. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc.
Fixed telephone subscriptions (per 100 people)	Fixed telephone subscriptions refers to the sum of active number of analogue fixed telephone lines, voice-over-IP (VoIP) subscriptions, fixed wireless local loop (WLL) subscriptions, ISDN voice-channel equivalents and fixed public payphones.
Mobile cellular subscriptions (per 100 people)	Mobile cellular telephone subscriptions are subscriptions to a public mobile telephone service that provide access to the PSTN using cellular technology. The indicator includes (and is split into) the number of postpaid subscriptions, and the number of active prepaid accounts (i.e. that have been used during the last three months). The indicator applies to all mobile cellular subscriptions that offer voice communications. It excludes subscriptions via data cards or USB modems, subscriptions to public mobile data services, private trunked mobile radio, telepoint, radio paging and telemetry services.
Fixed broadband subscriptions (per 100 people)	Fixed broadband subscriptions refers to fixed subscriptions to high-speed access to the public Internet (a TCP/IP connection), at downstream speeds equal to, or greater than, 256 kbit/s. This includes cable modem, DSL, fiber-to-the-home/building, other fixed (wired)-broadband subscriptions, satellite

	broadband and terrestrial fixed wireless broadband. This total is measured irrespective of the method of payment. It excludes subscriptions that have access to data communications (including the Internet) via mobile-cellular networks. It should include fixed WiMAX and any other fixed wireless technologies. It includes both residential subscriptions and subscriptions for organizations.
GDP per capita (current US$)	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars.
General government final consumption expenditure (% of GDP)	General government final consumption expenditure (formerly general government consumption) includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security, but excludes government military expenditures that are part of government capital formation.
Gross fixed capital formation (% of GDP)	Gross fixed capital formation (formerly gross domestic fixed investment) includes land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. According to the 1993 SNA, net acquisitions of valuables are also considered capital formation.
Trade (% of GDP)	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.
Domestic credit to private sector (% of GDP)	Domestic credit to private sector refers to financial resources provided to the private sector by financial corporations, such as

	through loans, purchases of nonequity securities, and trade credits and other accounts receivable, that establish a claim for repayment. For some countries these claims include credit to public enterprises. The financial corporations include monetary authorities and deposit money banks, as well as other financial corporations where data are available (including corporations that do not accept transferable deposits but do incur such liabilities as time and savings deposits). Examples of other financial corporations are finance and leasing companies, money lenders, insurance corporations, pension funds, and foreign exchange companies.
Inflation, consumer prices (annual %)	Inflation as measured by the consumer price index reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used.
Unemployment, total (% of total labor force) (modeled ILO estimate)	Unemployment refers to the share of the labor force that is without work but available for and seeking employment.
Foreign direct investment, net inflows (% of GDP)	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors, and is divided by GDP.

Table A2: Hausman Test Results

	Fixed	Random	Difference	S.E.
LN LTEL	0.04	0.03	0.01	0.02
LN LMOB	0.11	0.12	-0.01	0.00
LN LBBA	0.05	0.05	-0.00	0.00
LN LINT	0.11	0.11	0.00	0.00
LN LTRADE	-0.53	-0.44	-0.09	-0.04
LN LINVEST	0.18	0.17	0.01	0.01
LN LGOV	-0.48	-0.40	-0.08	0.03
LN LFIND	0.17	0.15	0.02	0.01
LN LINF	-0.01	-0.01	0.00	0.00
LN LUNEMP	-0.10	-0.06	-0.03	0.02
LN LFDI	-0.00	-0.01	0.00	0.00

b = consistent under H_0 and H_a; obtained from xtreg

B = inconsistent under H_a, efficient under H_0; obtained from xtreg

Test: H_0: difference in coefficients not systematic

Chi2(11) = (b-B) ‘ [(V_b-V_B)^(-1)](b-B) = 21.28

Prob>chi2 = 0.0306

(V_b-V_B is not positive definite)

Table A3: Breusch-Pagan Test Results

	Var	Sd = sqrt (Var)
LNGDPPC	0.30	0.55
e	0.03	0.19
u	0.13	0.36

Test: Var(u) = 0

Chibar2(01) = 1292.03

Prob > chibar2 = 0.0000

Table A4: Correlation Matrix

	TEL	MOB	BBA	INT	TRADE	INV	GOV	FIND	INF	UNEMP	FDI
TEL	1.00										
MOB	0.04	1.00									
BBA	0.22	0.82	1.00								
INT	0.23	0.81	0.86	1.00							
TRADE	0.05	0.13	-0.01	0.08	1.00						
INV	0.05	0.12	0.14	0.10	0.19	1.00					
GOV	0.09	0.06	0.05	0.07	0.05	0.03	1.00				
FIND	0.21	0.36	0.40	0.42	0.18	0.02	0.28	1.00			
INF	0.33	-0.08	-0.07	-0.13	-0.11	-0.01	-0.03	-0.17	1.00		
UNEMP	0.24	-0.09	-0.15	-0.17	-0.07	-0.07	0.17	-0.14	-0.04	1.00	
FDI	0.04	0.07	0.09	0.10	0.15	0.15	0.03	-0.00	0.01	0.09	1.00

Table A5: Regression Results of Panel Data Analysis (All ICT Indicators)

Variables		Model 5
LNLTEL		0.04 (0.05)
LNLMOB		0.11*** (0.02)
LNLBBA		0.05*** (0.01)
LNLINT		0.11 (0.03)
LNLTRADE		-0.53*** (0.08)
LNLINVEST		0.18** (0.07)
LNLGOV		-0.48*** (0.09)
LNLFIND		0.17*** (0.04)
LNLINF		-0.01 (0.04)
LNLUNEMP		-0.01** (0.04)
LNLFDI		-0.01 (0.01)
R-sq	within	0.52
	between	0.02
	overall	0.41

*Notes: The 10%, 5%, and 1% significance levels are denoted by *, **, and ***, respectively.*

Table A6: Regression Results of Panel Data Analysis with 4y Averages

	Dependent Variable: GDP per capita (current US$) (logarithmic value)			
Variables	Model 1	Model 2	Model 3	Model 4
LN $LMOB_{ik}$	0.18*** (0.02)			
LN $LINT_{ik}$		0.20*** (0.02)		
LN $LTEL_{ik}$			0.11*** (0.01)	
LN $LBBA_{ik}$				0.32** (0.12)
LN $LGOV_{ik}$	-0.17 (0.20)	-0.29 (0.19)	-0.42** (0.19)	-0.08 (0.25)
LN $LINVEST_{ik}$	0.23 (0.16)	0.47*** (0.15)	0.38** (0.16)	0.51** (0.20)
LN $LTRADE_{ik}$	-0.64*** (0.18)	-0.73*** (0.17)	-1.05*** (0.17)	-0.63*** (0.23)
LN $LFIND_{ik}$	0.51*** (0.06)	0.44*** (0.06)	0.41*** (0.07)	0.79*** (0.07)
LN $LINF_{ik}$	-0.01 (0.03)	-0.01 (0.03)	-0.01 (0.03)	-0.08** (0.04)
LN $LUNEMP_{ik}$	-0.25** (0.09)	-0.19** (0.09)	-0.30*** (0.09)	-0.44*** (0.12)
LN $LFDI_{ik}$	-0.13*** (0.04)	-0.10** (0.04)	-0.10* (0.05)	0.04 (0.05)
R-sq within	0.84	0.86	0.89	0.75
R-sq between	0.04	0.03	0.00	0.01
R-sq overall	0.38	0.39	0.26	0.17

*Notes: The 10%, 5%, and 1% significance levels are denoted by *, **, and ***, respectively.*