INFORMATION AND COMMUNICATION TECHNOLOGIES AND ECONOMIC DEVELOPMENT: A CROSS-COUNTRY ANALYSIS

[a]TAMARA PETRIKOVA, [b]KRISTINA KOCISOVA

Technical University of Kosice, Faculty of Economics, Nemcovej 32, 04001, Kosice, Slovak Republic
email: [a]Tamara.Petrikova@tuke.sk, [b]Kristina.Kocisova@tuke.sk

Work was supported by MINEDU of SR under Grant no. 1/0444/23

Abstract: The rapid adoption of Information and Communication Technologies (ICT) is creating new opportunities and challenges for businesses, people and economy in terms of increased efficiency, creation of new services, improved human well-being, economic productivity, employment and economic development (ED). This paper aims to analyze impact of ICT on ED in advanced (AM), emerging (EM), and low-income and developing (LIC) countries. A panel econometric model with fixed effects is used to analyze situation in 183 countries from 1997 to 2022. The main conclusion is that ICT positively and significantly impacts ED. The positive effect was most significant in LICs, where the biggest ICT boom occurred. While in 1997, only 0.125% of people in LIC used Internet, by 2021, it was 46.05%. A similar situation can be observed for mobile phone subscriptions (0.173 in 1997; 84.11 in 2021). Progress in ICT was also observed in EM and AM, but not as fast as in LIC. The positive impact of ICT in all countries is also evident when several control variables are considered.

Keywords: ICT, economic development, panel model, Robin Hood algorithm.

1 Introduction

Economic development is multifaceted process encompassing transformation of low-income economies into modern industrial economies. It involves a range of programs, policies, and activities to improve the community's economic well-being and quality of life. The primary goal of development cooperation is to enhance material living standards by increasing per capita income. However, definition and drivers of ED vary significantly across countries, influenced by their unique socio-economic characteristics, opportunities, challenges, and priorities. One critical factor influencing ED is investment in ICT. ICT includes all communication devices and applications, such as mobile phones, computers, network hardware and software, and satellite systems. ICT facilitates storing, retrieving, transforming, and transmitting information, automating processes, controls, and information production. It plays pivotal role in shaping new global economy, transforming societies, and altering communication patterns and business relationships. The COVID-19 pandemic accelerated adoption of ICT across globe, affecting individuals, companies, and governments. The pandemic underscored necessity of ICT for maintaining economic activities and highlighted its role in driving growth in online product purchases. ICT facilitates innovation, increases productivity, reduces operating costs, can help create new job opportunities while transforming existing ones, improves efficiency in various sectors, and opens up new economic opportunities by creating digital industries, innovation ecosystems and rise of digital economy. However, ICT diffusion also improves governance by increasing transparency, efficiency and accessibility of public services, thereby creating environment that facilitates economic growth. While ICTs can significantly enhance ED, extent and nature depend on several factors, such as infrastructure, policy frameworks, digital literacy and inclusiveness of access. Thus, understanding impact of ICT on ED is crucial for promoting sustainable growth.

Existing literature has extensively explored relationship between ICT and ED. Adeleye and Eboagu (2019) or Yang (2021) emphasize importance of ICT and its impact on economies and societies, while Lechman (2014) and Albiman and Sulong (2018) emphasize its role in enhancing productivity. Moşteanu et al. (2020) discuss critical role of ICT during pandemic, highlighting how enabled businesses and governments to continue operations amidst lockdowns, while De' et al. (2020) and Brychko et al. (2021) highlight shift in service usage patterns and growth of online commerce and payments. From sectoral point of view, Niebel (2018) found that ICT investment boosts productivity in services sector more than in manufacturing, while Hallová and Hanová (2018) underscore its role in job creation and resilience to economic crises. Many studies, such as those by Yousefi (2011), Cheng et al. (2021), or Mura and Donath (2023) employ cross-country regressions to estimate impact of ICT on GDP growth, which provides robust insights into dynamic relationship across different economic contexts. The literature on relationship between economic growth and ICT is rich and diverse, highlighting ICT's significant positive impact on productivity, economic activities, and resilience during crises. However, existing research reveals several gaps. First, while there is evidence that ICT enhances ED, extent and nature of its impact vary across countries with different ED. Second, most studies assume linear relationship between ICT and ED, but there may be non-linear dynamics at play, particularly concerning diminishing returns of ICT investments at higher levels of adoption.

Therefore, presented paper aims to address gaps by exploring research questions: What is level of ICT in economies with different levels of ED? To what extent does increasing ICT improve ED? To answer these questions, there is a need to explore these dynamics, particularly using advanced econometric techniques. It helps us to provide more comprehensive understanding of how ICT can drive sustainable and inclusive economic growth. We employ panel data approach, using both linear and non-linear methods. The novelty of this paper lies in introducing Robin Hood algorithm, enabling us to determine whether impact of ICT on ED changes after certain point.

We use three proxies for ICT infrastructure: percentage of individuals using Internet, mobile phone subscriptions and ICT services export as indicator of its ICT capabilities. These indicators reflect digital inclusion, connectivity, and technological readiness, which are crucial for understanding potential of ICT to drive ED. Our dependent variable is GDP per capita in constant prices, representing ED. Additionally, we incorporate control variables such as trade openness, urbanization rate, gross fixed capital formation, government consumption expenditure, CO2 emissions, financial development index and governance indicator in form of political stability to provide comprehensive analysis.

The structure of paper is as follows. Section 2 presents overview of studies. Section 3 provides information about data and methodology. Section 4 analyses effects of ICT and discusses main findings.

2 Literature review

ED and ICT have been extensively studied, with researchers employing various indicators and methodologies to explore this relationship. This review synthesizes key findings, highlights methodological approaches, and identifies gaps and contradictions in literature. Most studies measure ED using indicators such as GDP per capita, natural logarithm of GDP per capita, or annual GDP values. ICT is commonly measured through proxies such as adopting new technologies, mobile subscriptions, fixed telephone subscriptions, individuals using Internet, or Internet coverage, while only a few consider ICT services export in their evaluations (e.g. Kashif et al., 2024). Therefore, examining ICT´s role not only from traditional point of view will contribute to ED and technology-related literature.

The empirical literature showed studies with different findings when examining ICT and ED. These studies can be divided into two main groups. The first proved that ICT facilitates development process from social, political and economic perspectives (e.g. Sharma, 2016, Alshubiri et al., 2019, Sharma et al., 2021, Younas et al., 2022, Verma and Giri, 2022). Also, OECD (2010) shows that ICT is vital in reducing poverty, increasing employment, and improving living standards. Brychko et al. (2021) say that active use of ICT positively

impacts share of non-cash payments, financial services diversification, and financial and economic development. Therefore, Zhang et al. (2022), or Mura and Donath (2023) pointed to the fact, that countries should focus on new business models based on digitalization and adopt measures that support digitalization-related policies to encourage investment in digital technologies, improve labor efficiency and contribute to stable economic recovery and growth. The second group found negative or no impact of ICT on ED (e.g. Ishida, 2015, Nabi et al., 2022). Yousefi (2011) finds that ICT plays a vital role in economic growth for high- and upper-middle-income countries but does not contribute to growth in LIC countries. In these countries, economic growth may be driven mainly by mobile growth but not by Internet growth. The policy implications suggest that middle- and LIC should step up their mobile development in short term, as this will be more cost-effective and profitable. However, lack of competition in Internet services could lead to unreasonable prices and under-investment in infrastructure, with high prices being natural barrier to Internet. In longer term, policies should increase investment in infrastructure.

The literature mainly indicates that ICT positively impacts ED, but this relationship is contingent on various factors. Studies suggest that education, infrastructure, government policies, and innovation ecosystems are crucial for maximizing benefits of ICT on ED. Seo et al. (2009) found that high-quality economic infrastructure and open trading regimes acquire more investments in ICT, which can bring higher ED. According to Mura and Donath (2023), when public spending are not efficient enough and contribute to debt accumulation, they negative impacts ED. Also, Shi et al. (2023) pointed out that good governance plays a crucial role in creating conditions for firms and individuals, which can increase access to resources and their effective usage, leading to higher ED. Arcand et al. (2015) and Cheng et al. (2021) pointed to another determinant: financial development index (IMF, 2023). They report negative relationship between financial and economic development, mainly due to surge of financial crises. We can see that digitalization benefits specific sectors differently, with traditional industries requiring significant adaptation. Therefore, measuring ICT's impact on ED is challenging due to different methodologies and data limitations.

However, existing research reveals several gaps. Methodologically, majority of studies use panel linear analysis. Also, limitations include availability of data for extended periods, granularity of data (often only available at country level), and need to analyze sub-samples of countries with different ED. More research is needed to explore non-linear relationships between ICT and ED, particularly using advanced econometric techniques and examining impact of ICT in economies with different stages of ED.

Building on reviewed literature, this paper aims to analyze ICT in economies with different ED to determine if increasing ICT enhances ED similarly across LIC, EM, and AM. The hypotheses are:

Hypothesis 1: The level of ICT is not higher in countries with higher ED.

Hypothesis 2: The use of ICT has no linear impact on ED in LIC/EM/AM countries.

We employ GDP per capita as dependent variable and three proxies for ICT (Individuals using Internet (% of population), Mobile cellular subscriptions (per 100 people) and ICT services export measured in current US$). In line with previous studies, these proxies are indispensable prerequisites of digital development, which has evolved mainly through mobile devices and Internet. As Mura and Donath (2023) mentioned, it represents degree of penetration of new ICT in economy.

Using Robin Hood algorithm, we will verify presence of U-shape between ICT and ED. Panel model with control variables, including trade openness, urbanization rate, gross fixed capital formation, government consumption expenditure, CO2 emission, financial development index, and governance indicator in form of political stability indicator, will be tested to provide comprehensive insights.

By addressing the identified gaps and incorporating a novel methodological approach, this paper aims to contribute to deeper understanding of dynamic relationship between ICT and ED, offering valuable policy implications for leveraging ICT to promote sustainable and inclusive economic growth.

3 Data and methodology

3.1 Data information

The annual data selected from official sources (World Development Indicator, Worldwide Governance Indicators, IMF) are used to analyze situation in 183 countries from 1997 to 2022. Tab. 1 presents all relevant details of selected variables. Column one contains abbreviation. Next columns show basic descriptive statistics. The seventh column contains complete name and measure scale of variables. The last column presents expected impact (based on literature review) on dependent variable.

Tab. 1 Descriptive statistics of selected variables

Variable	Average	Maximum	Minimum	Std. Dev.	Obs.	Explain	Exp. sign
GDP	12630.40	112417.88	246.39	17693.29	4648	GDP per capita (constant 2015 US$)	Dep. variable
INTERNET	31.7474	99.6870	0.0002	30.7623	4421	Individuals using Internet (% of population)	+
MOBILE	70.1625	420.8531	0.0009	53.2530	4458	Mobile cellular subscriptions (per 100 people)	+
ICTExp	2402836	206000599	14.54	9741199	3914	ICT services export measured in current thousands of US$	+
TRADE	87.7250	442.6200	2.6988	54.2205	4250	The sum of exports and imports of goods and services (% of GDP)	+
URBAN	54.8036	99.3180	7.6180	22.4293	4654	People living in urban areas (% of population)	+
CAPITAL	22.8741	81.0210	-2.4244	7.6191	4023	Gross domestic fixed investment (% of GDP)	+
GOV	16.6706	147.7189	0.9126	8.9991	4100	Government current expenditures for purchases of goods and services (% of GDP)	+ / -
CO2	4.3149	47.6570	0.0218	5.5463	4291	Carbon dioxide emissions (metrics tons per capita)	+
FDI	0.3015	1.0000	0.0038	0.2271	4556	Financial development index	+ / -
POLITIC	48.2977	100	0	28.0510	4678	Political Stability and Absence of Violence/Terrorism measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism. (Percentile rank among all countries (ranges from 0 (lowest) to 100 (highest))	+

Source: Prepared by authors

According to GDP, countries are divided into three groups: LIC, EM and AM. Within AM, we can see the most developed countries, where average in 2022 was 44743.95. Most countries are within EM (average 10529.33), and last group consists of LIC (average 2426.07). The differences between countries result from several factors. Historical events, colonialism, wars, and geopolitical influences have shaped economic environment of nations. Some countries have benefited from previous industrialization or natural wealth, while others have faced exploitation or natural resource scarcity problems. Second, countries with stable political systems, low levels of corruption and effective legal frameworks tend to attract investment and foster development. The last factor involves country's demographics and education. Countries with productive working-age population and educated and skilled labor force can experience higher ED.

Mobile cellular telephone subscriptions are subscriptions to public mobile telephone service that provides access to public switched telephone network using cellular technology. The indicator includes number of postpaid subscriptions and number of active prepaid accounts. 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, tele point, radio paging and telemetry services. The average for LIC was 84.11, for EM 121.24; for AM 137.47. The significant differences between countries can be attributed to several factors. Developed countries often have more robust and widespread telecommunication infrastructure, making establishing and expanding mobile networks easier. In contrast, developing nations might struggle with inadequate infrastructure, limiting access to mobile services in rural or remote areas. The second factor is costs of mobile services and devices, which influence accessibility. In LIC, individuals might face challenges affording mobile devices and services, impacting subscription rates. The next factor is that government policies and regulations significantly influence telecommunications sector. Favorable policies in developed nations might encourage healthy competition, leading to better services and lower prices, while regulatory hurdles in developing countries can hinder market growth.

Internet users are individuals who have used Internet in last three months. Also, in this indicator exists significant differences between countries. The average for LIC was 46.05, for EM 76.12; for AM 91.04. Based on averages, we expect ICT to increase with country's ED. Also, in this case, we can speak about factors that lead to significant differences between countries. Developed nations typically have better-developed and widespread Internet infrastructure. They often invest more in broadband networks, leading to better access and higher penetration rates than developing countries. The second factor is cost of internet services and devices. In LIC, availability can limit access for significant portion of population due to high prices. On the other hand, higher-income and advanced countries often have more individuals who can afford internet services and devices, leading to higher penetration rates. The next factor is technological progress. Developed nations often adopt new technologies more rapidly, contributing to higher internet usage rates due to better access to advanced services and devices. Among other factors, we can mention digital literacy and education in country, share of urban population, and cultural and social factors.

As can be seen, differences exist between countries regarding ICT and ED. These findings able us to reject Hypothesis 1. We can conclude that level of ICT is higher in countries with higher ED. This lack of homogeneity in ED and ICT can influence results. On the other hand, we can see some homogeneity within countries divided according to stage of ED. We can see that most countries with the lowest ICT are located within LIC. In contrast, the highest ICT is within AM. The next signal of homogeneity is that LIC recorded the highest ICT growth between 1997 and 2022 and the highest economic growth.

3.2 Empirical model

To verify presence of U-shape between ICT and ED, we first apply Robin Hood algorithm presented by Simonsohn (2018). He suggests testing possibility of U-shape by merely testing if effect of x (an indicator of ICT) on y (ED) changes sign for low versus high x values. Such test involves computing two average slopes, which is done by estimating two regression lines, one for $x \leq x_c$ and other for $x \geq x_c$, where x_c is breakpoint. One may increase statistical efficiency by simultaneously estimating both lines in single regression, relying on what is often referred to as interrupted regression. Specifically, interrupted regressions conform to following general formulation:

$$y = a + bx_{low} + cx_{high} + d \times high + ZB_Z$$

where $x_{low}=x-x_c$ if $x < x_c$ and 0 otherwise, $x_{high}=x-x_c$ if $x \geq x_c$ and 0 otherwise, and high = 1 if $x \geq x_c$ and 0 otherwise, $\mathbf{Z}$ is (optional) matrix with covariates, and $\mathbf{B_Z}$ is its vector of coefficients.

Then, we test panel model with control variables, which can be expressed as follows:

$$\log(y_{i,t}) = a + \beta X_{m,i,t-1} + \sum_{k=1}^{7} \gamma C_{k,i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

where y is ED indicator (GDP), X is ICT indicator (INTERNET, MOBILE, ICTExp), C is vector of control variable (TRADE, URBAN, CAPITAL, GOV, CO2, FDI, log(POLITIC)), μ_i and τ_t represents country's fixed and time-specific effect, $\varepsilon_{i,t}$ is random error term, i and t are indicators of country and time.

The model is estimated separately for each ICT indicator. Logarithmic measure for dependent variable and ICT services export is used to reach smaller amplitude and better interpret results. The other variables are not transformed. The main assumption of our study is that ICT positively impacts ED in all types of countries.

The lagged explanatory variables are used to overcome problem of endogeneity concerns in observational data. The VIF test is applied to test potential multicollinearity. Tab. 2 shows no coefficient value more than 3, suggesting that model has no issue with multicollinearity.

Tab. 2 VIF test

Model	ICT indicator	TRADE	URBAN	CAPITAL	GOV	CO2	FDI	POLITIC
Model 1	2.0575	1.2751	2.0389	1.0430	1.1250	2.0532	2.6110	1.7561
Model 2	1.3749	1.2832	1.9789	1.0584	1.1031	2.0530	2.3169	1.7485
Model 3	2.7986	1.1252	1.9457	1.0467	1.1639	2.1913	4.2207	1.1902

* ICT indicator in models: INTERNET (Model 1), MOBILE (Model 2), ICTExp (Model 3)

Source: Prepared by authors

The standard procedure for panel model is applied. The Breusch-Pagan test is used to choose between pooled and fixed-effect model, and Hausman test is used to select between fixed- and random-effects models. The F-test tested time- and country-specific effects.

Quantile Regression (QR) is used to test robustness of model. As presented by Naseem et al. (2023), advantage of QR is its robustness against data outliers in response measurement. If data series are affected by heterogeneous effects concerning dependent and independent variables, QR avoids this issue and helps obtain accurate results. The standard methodology of QR is applied. Using QR, model of this research is presented below:

$$\log(y_{i,t}) = a + \beta^{\theta} X_{m,i,t-1} + \sum_{k=1}^{7} \gamma^{\theta} C_{k,i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

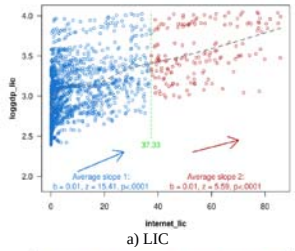
where theta (θ) is representative of QR. QR provides nuanced insights into effects of predictors across different points of dependent variable's distribution. By interpreting coefficients and graphical representations, we can better understand how ICT indicators influence entire distribution, not just mean. It is particularly useful for policy analysis and decision-making, highlighting differential impacts that mean-based regression methods might miss.

4 Analysis and discussion

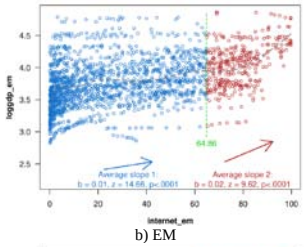
The results of Robin Hood algorithm for selected ICT indicator (INTERNET) separately in LIC, EM and AM are presented in Figure 1. The U-shape relationship was not confirmed, but constant positive relationship can be seen in LIC, EM and AM. The lowest ICT could be seen in LIC. We can see that increasing ICT lead to higher ED, where speed of positive influence increases after some breakpoint. However, as Figure 1a presents, most countries are under those breakpoints. So, increase in ICT could benefit ED. Similar situation could be seen in EM (Figure 1b), but breakpoint is higher. In AM (Figure 1c), impact of ICT on ED was not as significant as in previous groups. The reason could be that level of ICT is very high, so there is not so much space to increase it (e.g., for Individuals using Internet, close to 100%, representing overall population in country). In Mobile subscriptions and ICT services export, results are very similar. It

confirmed our assumption that ICT positively impacts ED, while intensity is lower in AM. Based on Robin Hood algorithm results we cannot confirm Hypothesis 2. Therefore, we must reject the assumption that ICT has no linear impact on ED.

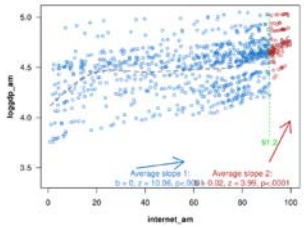
Figure 1 Two-line test – ED vs. Internet use



a) LIC



b) EM



c) AM

Source: Prepared by authors

Next, we tested linear model presented in methodology part, which was separately estimated for LIC, EM, and AM. We apply fixed effects with time and individual effects based on Breusch-Pagan, Hausman and F-test results. The results are presented in Tab. 3. Based on results of F-statistics, we can conclude that results were associated with significance level lower than 1%, which suggests that models' estimations are correct and statistically significant.

Tab. 3 Empirical results of panel regressions

Independent variables	LIC		
INTERNET	0.0063 *** (0.0005)		
MOBILE		0.0031 *** (0.0002)	
ICTExp			0.0659 *** (0.0083)
TRADE	0.0004 (0.0003)	-0.0002 (0.0003)	-0.0020 *** (0.0003)
URBAN	0.0137 *** (0.0018)	0.0035 * (0.0019)	0.0145 *** (0.0017)
CAPITAL	0.0026 *** (0.0007)	0.0011 * (0.0006)	0.0045 *** (0.0007)
GOV	-0.0015 (0.0011)	0.0001 (0.0010)	0.0001 (0.0011)
CO2	0.0836 *** (0.0228)	0.0602 *** (0.0219)	0.2426 *** (0.0239)
FDI	1.5363 *** (0.2423)	1.1625 *** (0.2328)	1.8698 *** (0.222)
POLITIC	0.0029 *** (0.0004)	0.0032 *** (0.0004)	0.0020 *** (0.0004)
Unbalanced panel	n = 54, T = 6-23, N = 1024	n = 54, T = 6-23, N = 1013	n = 52, T = 1-23, N = 842
Adjusted R-squared	0.5607	0.5896	0.5452
F-statistics	170.833 ***	189.386 ***	133.385 ***

Independent variables	EM		
INTERNET	0.0036 *** (0.0002)		
MOBILE		0.0022 *** (0.0001)	
ICTExp			0.2190 *** (0.0117)
TRADE	0.0001 (0.0002)	-0.0002 (0.0003)	-0.0010 *** (0.0003)
URBAN	0.0130 *** (0.0015)	0.0119 *** (0.0014)	0.0126 *** (0.0015)
CAPITAL	0.0007 (0.0008)	-0.0024 *** (0.0008)	-0.0009 (0.0006)
GOV	-0.00664 *** (0.0015)	-0.0087 *** (0.0014)	-0.0075 *** (0.0015)
CO2	0.0519 *** (0.0047)	0.0445 *** (0.0046)	0.0382 *** (0.0056)
FDI	1.0995 *** (0.0918)	0.9091 *** (0.0928)	1.6406 *** (0.0925)
POLITIC	0.0031 *** (0.0004)	0.0034 *** (0.0004)	0.0023 *** (0.0004)
Unbalanced panel	n = 74, T = 5-23, N = 1611	n = 74, T = 5-23, N = 1633	n = 67, T = 5-23, N = 1401
Adjusted R-squared	0.5982	0.6179	0.6527
F-statistics	309.711 ***	339.948 ***	338.096 ***

Independent variables	AM		
INTERNET	0.0062 *** (0.0002)		
MOBILE		0.0039 *** (0.0001)	
ICTExp			0.3246 *** (0.0001)
TRADE	0.0007 *** (0.0002)	0.0011 *** (0.0002)	0.0013 *** (0.0002)
URBAN	-0.0144 *** (0.0022)	-0.0041 * (0.0022)	-0.0005 (0.0021)
CAPITAL	0.0078 *** (0.0011)	0.0059 *** (0.0011)	0.0049 *** (0.0012)
GOV	-0.0057 ** (0.0026)	-0.0093 *** (0.0027)	-0.0114 *** (0.0027)
CO2	0.0097 *** (0.0028)	-0.0038 (0.0028)	0.0124 *** (0.0029)
FDI	-0.0693 (0.0683)	-0.1298 * (0.0718)	0.3429 *** (0.0666)
POLITIC	0.0021 *** (0.0005)	0.0016 *** (0.0005)	0.0020 *** (0.0005)
Unbalanced panel	n = 34, T = 20-23, N = 779	n = 34, T = 23, N = 782	n = 34, T = 9-23, N = 703
Adjusted R-squared	0.6837	0.6608	0.6889
F-statistics	215.313 ***	195.308 ***	194.444 ***

Notes: ***, **, and * denote significance levels 99%, 95% and 90%, respectively. The standard errors are reported in parentheses.
Source: Prepared by authors

All ICT indicators were marketed as significant, positively impacting ED in LIC, EM and AM. As presented in other studies, ICT is crucial for ED, mainly in LIC, while significance decreases in EM and AM, which aligns with our findings. It confirmed our assumption and results of two-line tests that ICT is significant factor, where intensity is lower in countries with higher ED.

Mura and Donath (2023) state that trade openness impacts ED by increasing income per capita and boosting productivity through competition. Openness supports technological transfer across borders and, hence, a more efficient economic organisation. As can be seen in Table 3, positive impact was confirmed only in AM. We can suppose that for those countries, increasing competition is one of crucial factors in improving ED and well-being of people in country.

According to World Bank (2023), gross fixed capital formation includes land improvements, plant, machinery, and equipment purchases, and construction of roads and railways, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Meyer and Sanusi (2019) state that gross fixed capital formation, as primary component of domestic investment, is seen as essential process that could accelerate economic growth. Our analysis confirmed similar results through positive significant impact of capital in LIC and AM.

CO2 emissions stem from burning fossil fuels and cement manufacture, from solid, liquid, and gas fuels and gas flaring consumption. Acheampong (2018) states that CO2 emissions positively cause economic growth, while Onofrei et al. (2022) found that higher ED leads to increased demand for environmental protection. The findings of previous authors are in line with our results. Based on regression coefficients, we can see that CO2 was always significant variable with positive impact. Also, decreasing regression coefficients signalise that effect is the highest in LIC. In contrast, in AM, intensity was lower.

Government consumption expenditure includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most national defence and security expenditures but excludes government military expenditures that are part of government capital formation. Mo (2007) states that identifying impact of government consumption expenditure is not so clear as it affects development through three channels – total factor productivity, investment and aggregate demand. If we exclude government investments, we can expect that government expenditure will hurt ED. However, positive effect could be expected in government investments. Therefore, question is if investments' impact is higher than other government expenditures' effect. According to results, this variable significantly negatively impacted ED in EM and AM. As most government expenditures have unproductive nature, we can suppose that effect of other

government expenditures, usually associated with social policy, was higher than that of government investments.

Urban population refers to people living in urban areas defined by national statistical offices. Nguyen & Nguyen (2018) found that relationship between urbanisation and ED is non-linear. Urbanisation tends to increase ED while urbanisation rate is low. However, after some threshold, when urbanisation is relatively high, it can hurt ED. It is in line with our results presented in Table 3. The variable was significant in LIC, EM and AM, but signs differed. While impact was positive in LIC and EM, it was negative in AM. The effect of urban populations on ED in developed countries can be negative due to various factors. For example, urban areas in advanced economies often face higher living costs, traffic congestion and housing shortages. These problems can hamper further economic growth as business costs increase, and firms may seek more affordable locations.

The FDI is relative ranking of country's financial institutions and financial markets. Van and Anh (2019) and Nguyen et al. (2022) pointed to positive effect of financial development on ED. However, they mentioned that it is necessary to pay attention to characteristics of each group (AM, EM, LIC) in evaluating financial development. We see significant impact of FDI, where in LIC and EM (weaker in EM), influence is positive, while in AM it is negative (or weakly positive in case of ICTExp). So, we can conclude that increasing financial development benefits ED, but after some breakpoints it is negative. We can suppose that in AM, financial services are used by majority of population daily and form normal part of economy. Therefore, space to increase this development within the economy is relatively small. Thus growing interconnectedness of financial market can lead to institutions' ability to provide financial services and higher activity in capital markets. The disadvantage is that during crisis in another country, its adverse effects can be transferred to other countries, leading to decreased ED.

As mentioned by Singha and Singh (2022), political stability and good governance are important in influencing economic growth. They can promote rule of law, transparency, accountability, and even efficient use of resources. Also, results of our study confirmed importance of political stability in increasing ED in analysed countries, where the highest impact could be seen in EM countries. Stable political conditions create conducive environment for foreign investments, ensuring continuity in economic activities, strengthening institutional quality, reducing macroeconomic volatility, supporting infrastructure development and improving international trade relations. Therefore, promoting and maintaining political stability should be priority for governments aiming to achieve sustained ED.

In last step, QR is used to check robustness of our findings. QR estimation results in detail for Model 1 are displayed in Tab. 4, while selected ICT indicator for each model of QR is displayed in Figure 2.

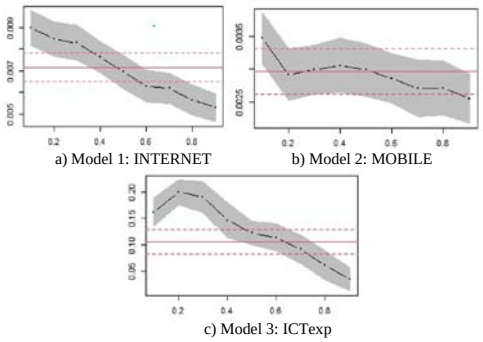
Tab. 4 Empirical results of quantile regressions – Internet as ICT indicator

Quantiles	INTERNET	TRADE	URBAN	CAPITAL	GOV	CO2	FDI	POLITIC
0.1	0.0090 ***	0.0005 ***	0.0206 ***	0.0090 ***	-0.0034 ***	0.0533 ***	1.7312 ***	0.0094 ***
0.2	0.0085 ***	-0.0001	0.0213 ***	0.0093 ***	-0.0032 ***	0.0529 ***	1.8911 ***	0.0101 ***
0.3	0.0083 ***	-0.0005	0.0232 ***	0.0075 ***	-0.0062 ***	0.0465 ***	1.8360 ***	0.0110 ***
0.4	0.0079 ***	-0.0003	0.0230 ***	0.0043 ***	-0.0060 ***	0.0462 ***	1.8163 ***	0.0118 ***
0.5	0.0069 ***	-0.0001	0.0222 ***	0.0020 **	-0.0036	0.0428 ***	1.8117 ***	0.0128 ***
0.6	0.0063 ***	0.0007 *	0.0213 ***	-0.0022 **	-0.0005	0.0405 ***	1.7973 ***	0.0132 ***
0.7	0.0062 ***	0.0012 ***	0.0203 ***	-0.0047 ***	-0.0010	0.0411 ***	1.7601 ***	0.0132 ***
0.8	0.0056 ***	0.0021 ***	0.0186 ***	-0.0068 ***	-0.0027 ***	0.0486 ***	1.7257 ***	0.0130 ***
0.9	0.0053 ***	0.0017 ***	0.0149 ***	-0.0026	-0.0061 ***	0.0723 ***	1.5970 ***	0.0129 ***

Notes: ***, **, and * denote significance at the 99%, 95% and 90% levels, respectively.

Source: Prepared by authors

Figure 2 QR results



a) Model 1: INTERNET b) Model 2: MOBILE

c) Model 3: ICTexp

Source: Prepared by authors

The horizontal red line and red dot lines represent regression coefficient and confidence interval of panel regression, while black line with grey zone represents coefficients and confidence interval of QR. We can see that we have significantly different results from panel regression for lower and upper quantiles in case of Internet use and ICT services export. In medium quantiles we don't have significant difference from panel regression. Also, in Model 2, results of QR are in line with panel regression. However, we can conclude that ICT indicators are positively significant from 1st to 9th quantile in all estimations, which confirms that these variables positively contribute to ED in all countries. The decreasing value of coefficients in upper quantiles indicates decreasing impact of ICT on ED in countries with higher ED, which confirmed our previous findings that effect is the lowest in AM.

Conclusion

The aim was to analyse effects of ICT on ED in LIC, EM and AM. Based on literature review, we supposed that ICT positively impacts ED. We can see constant positive relationship from plots of two-line tests. The results of analysis did not confirm existence of U-shape. We can see that increased ICT was always connected with higher ED, while this relationship was more intense in LIC. ICT tends to be a more crucial factor in ED for LIC than AM due to its potential to rapidly address various developmental challenges. In LIC, ICT can act as catalyst to bridge developmental gaps. It offers opportunities for leapfrogging traditional development stages by providing access to information, education, healthcare, and financial services that might otherwise be limited or absent. ICT can jumpstart economic transformation by enabling new business models, improving efficiency, and facilitating trade and access to global markets, even in regions with limited physical infrastructure. It can overcome geographical barriers, providing access to essential services like healthcare and banking in remote areas where physical infrastructure might be lacking. ICT infrastructure can enhance country's resilience to external shocks by enabling remote work, digital transactions, and communication during crises, contributing to economic stability. In AM, while ICT remains crucial for economic growth and innovation, relative impact might differ due to existing infrastructure, higher levels of development, and saturation of specific ICT markets. However, even in AM, continuous advancements in ICT play significant role in maintaining competitiveness, driving innovation, and enhancing various sectors of economy.

We found that countries' GDP per capita and ICT are heterogeneous, but positive development could be seen in all groups mentioned. The use of ICT worldwide has seen significant development in recent years. The highest boom could be seen in LIC. Looking at primary indicators of ICT, we can see that share of Individuals using Internet increased by 36901% between 1997 and 2021, and value of Mobile cellular subscriptions increased by 48459%. It can be attributed to several factors. Some LIC without infrastructure have adopted newer technologies without replacing existing systems. They

have skipped traditional development stages and have quickly adopted mobile phones and internet technologies. Mobile phones are essential in LIC due to their affordability and accessibility. They have enabled communication and access to banking services and information, thus supporting growth of ICTs. Also, some governments have introduced policies and initiatives to promote ICT infrastructure development, recognising its potential to support ED and improve various sectors such as health, education and commerce. In summary, confluence of factors such as innovative technologies, affordability, entrepreneurial efforts, supportive policies and international initiatives has enabled significant growth of ICTs in LIC, allowing them to use technology for development.

Although LIC experienced the most remarkable boom, we can see that level of ICT was higher in countries with higher ED. The reason could be that advanced countries tend to have well-established infrastructure, including robust telecommunications networks and internet connectivity. Also, citizens in these countries have greater purchasing power, making ICT devices and services more affordable and accessible. These countries also often prioritise education and digital literacy, leading to population which is more technologically adept and inclined to adopt and use ICT tools effectively. ED is often accompanied by robust innovation ecosystem and research institutions, which leads to development of high technology, fostering culture of innovation and adopting new ICT solutions. Advanced countries often have policies and investments to advance ICT infrastructure and foster technological innovation, including initiatives to promote research, development, and digital infrastructure expansion. These factors create environment where technology adoption becomes more widespread and deeply integrated into various aspects of life and economy.

The increasing ICT opens up opportunities for new companies in new industries. However, future of doing business in digital age will mainly depend on outlook of digital progress and business climate and how policy and regulatory challenges are addressed simultaneously. Given disparities in ICT, ED, and other indicators' points of view, we can conclude that applying uniform policy and approach is not desirable to ensure higher economic growth. The dedicated digitalisation policies should be adapted to regional specificities of each country. Each country's economic, cultural, and digital behaviour characteristics can influence success of political decisions. However, in general, we can conclude that policymakers could make concerted effort to exploit inherent benefits of ICT use, which includes reducing rising costs associated with use of communication technologies, such as cost of buying mobile phone, price of internet connection, cost of subscription and others.

As mentioned in paper, other indicators of ICT also exist. The application of only traditional indicators can be considered research limitation. As more data becomes available, empirical analysis and comparison between ICT would help depict which policies are the most effective. The suggestion for future research could be to analyse role of ICT in the growth and competitiveness of companies, examine the contribution of smart infrastructure, e-government and fintech innovations in enhancing economic resilience to crises and promoting economic development in rapidly evolving environment.

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Primary Paper Section: A

Secondary Paper Section: AH