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A CROSS-COUNTRY ANALYSIS OF ICT: DIFFUSION, ECONOMIC GROWTH AND GLOBAL COMPETITIVENESS*

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Overview/Introduction

Forty years ago, virtually the entire telecommunications sector was state owned, managed and controlled – owned, managed and controlled by the state since their inception.¹ In the mid-1980s a movement towards privatization, liberalization and de-regulation took hold. Now the sector has been privatized in most countries and subjected to regulatory reform. The major reform occurred in the late 1990s (Estache *et al.* 2006). Since then the internet and cellular-mobile industries have advanced significantly. Mobile service has exploded, particularly, in the developing world. This has changed the dynamics of the industry dramatically.

The paper updates and expands the research on the contribution of Information and Telecommunications Technology's (ICT) on the growth of Gross Domestic Product (GDP) using cross-country analysis of selected countries. It follows the framework of Czernich (1991), *et al.* in its use of instrumental variables and Farhadi, *et al.* (2012) in its use of International Telecommunication Union's (ITU) ICT Development Index (IDI) but enhances the analysis by use of Global Competitiveness Index (GCI) and more recent data. It also uses the Conference Board Total Economic Database.

This paper empirically evaluates the impact of ICT on economy growth in selected countries and *vice versa*. For the 2008-2017 period, it shows lack of evidence causality in both directions. This finding is in contrast to results obtained looking at earlier periods. A central question is, if these results hold going further, what changed?

The paper is organized as follows: A brief Literature Review following this Introduction/Overview. It reviews the economic literature of Information and Telecommunications Technology's (ICT) impact on economic growth and development. The third section describes the data. The fourth section describes the methodology and; the results are in the fifth section. The final section presents Future Research and Remaining Questions.

* This paper is dedicated to the memory of Professor Gary Madden (1952 – 2017) who inspired all of us with his academic rigor and energy – and with his wry sense of humor. Not only was he a prolific researcher, he freely helped the rest of us in our research. He had wry sense of humor. He was a most decent human being; we feel the pain of his untimely death.

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¹ The exceptions were the United States and Canada where the inventor of the telephone started companies and some Scandinavian systems.

Literature Review

A variety of papers review the economic literature on ICT's contribution to growth and development – including internet, broadband, mobile services as well as fixed line service.

Growth

The determinants of economic growth have been a concern of researchers since the beginning of the discipline. It is only relatively recently, beginning in the early 1980's, that the contribution of the ICT sector has been a concern.² Earlier research by Alleman *et al.* (1991) addresses the research on telephony's impact on economic growth and development and has a comprehensive literature review of the work up to 1991. Koutroumpis (2009, pp. 2-4) has a review of the literature on the determinants of economic growth in general, as well as telephony and broadband. Vu (2011, pp. 354-355) has a brief review of the ICT cross-country studies as well as the national studies.

Early work on ICT's contribution to growth was relatively modest in its approach, using simple regression models of GDP growth against telephone penetration (in logarithmic transformations) or similar variables. The more recent work has attempted to account for endogeneity and to determine the magnitude and direction of causality. Two strategies have emerged to address this – the use of instrumental variables (Czernich *et al.* 2009) and the use of a structural model of the sector (Röller and Waverman 2001). Röller and Waverman's (2001) seminal work constructed a micro supply and demand model before addressing the macroeconomic impacts. They provide a strong critique of the earlier models. The variance in others' results could be clarified by their approach. Others followed in their footsteps: Koutroumpis (2009); and Waverman *et al.* (2005).

Koutroumpis (2009) estimates the impact of broadband on the infrastructure and growth for 15 European countries over the period 2003 to 2005. He finds a significant positive causal impact, particularly when the infrastructure has a critical mass. Similarly, Waverman *et al.* (2005) estimated the impact of mobile telephone service on growth. They found it contributed significantly in low income countries; indeed, it may be twice as large in developing countries as in developed.

Katz and his coauthors (2009a, b, c; Katz, *et al.* 2009, and Katz and Suter 2009) have done several studies on the economic impact of ICT in Latin America and elsewhere. The global, national and regional studies of the economic impact of ICT are reviewed in Katz (2009). More recently, Vu (2011) showed that the marginal effect on growth of the penetration of internet users was larger than that of cellular phones, which was larger than that of personal computers for the average country.

Jung (2014) does a review of the literature of ICT's infrastructures impact on economic growth. While his focus is on broadband, he does a comprehensive review of ways in which ICT can enhance economic activities as suggested by the literature.

² Solow (1987) famously stated that "You can see the computer age everywhere but in the productivity statistics"; this became known as Solow's Paradox (Brynjolfsson 1993). The ICT literature addressed this "Paradox."

Contribution of paper

The above studies, in most cases, do not cover the entire ICT sector. This is one of the contributions of this paper. We use ICT Development Index (IDI) as a proxy for investment in the ICT sector. Farhadi, *et al.* (2012) is the only research which uses this variable and is closest to this paper. They use a Generalized Method of Moments (GMM), dynamic panel of 159 countries from 2000 to 2009. Although our data is later, from 2008 to 2017, and is enhanced, as noted before, by Global Competitiveness Index (GCI). In addition, we test for Granger Causality.

ICT Environment

A summary of the ICT environments is shown in Figure 1. The traditional fixed-line telephone service has declined while mobile service has increased substantially. Indeed, the mobile service is a substitute for it, although the fixed-line does offer the opportunity to provide an internet or even broadband internet services. Even in developing countries, individuals are “cutting-the-cords” – that giving up their fixed-line in favor of cellular service (Banerjee *et al.* 2014). Figure 1 shows that the growth of cellular telephone service has been spectacular. And while the pattern for internet penetration is not as dramatic as wireless-mobile service, it has made considerable progress over the last dozen years of growth.

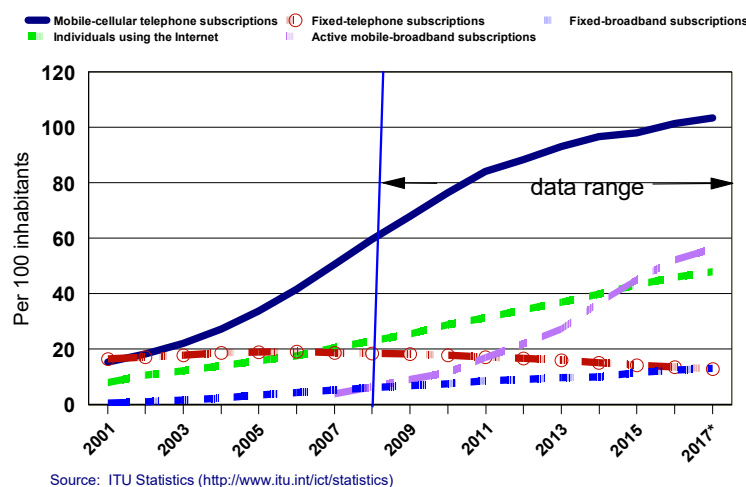


Figure 1. Information and Communications Technology (ICT) per 100 inhabitants

The pattern is different for fixed-line telephone service. The penetration rates have decreased over time in many countries. This is due, no doubt, to the substitution of mobile for the fixed-line phone.

Data

The data set was obtained from several sources. We consolidated data, i.e., by country, region, and income group on the GCI, IDI, and Gross Domestic Product (GDP) per capita growth. The GCI is a composite of “The Twelve Pillars of Competitiveness,” (see Figure

2) – each of which is constructed from underlying indicators. GCI is used as a control measure in the panel analysis.

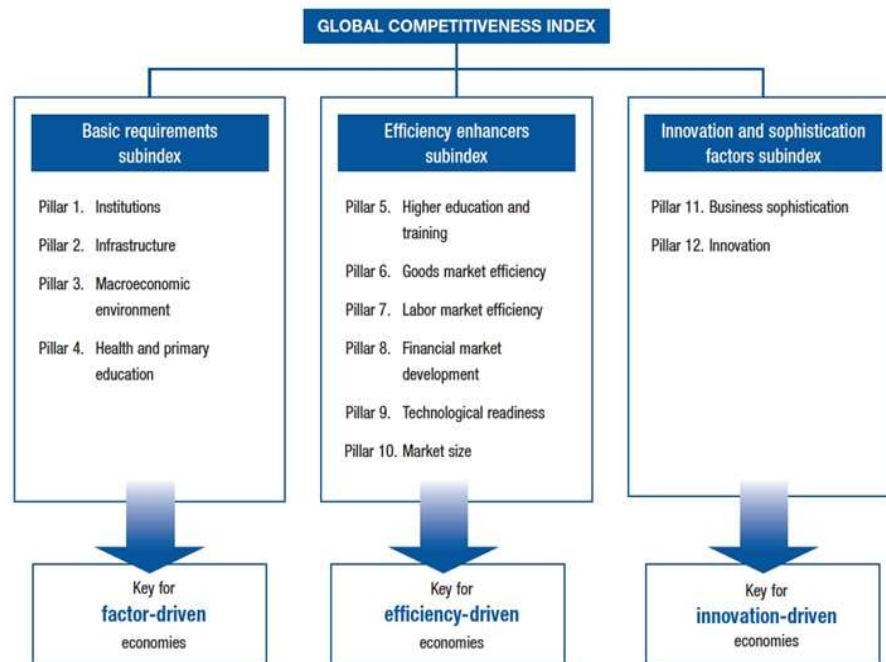


Figure 2. Global Competitiveness Index.

The IDI (or ICT development index) is from the ITU data file and the GDP per capita rate is from the Output Conference Board. These files were trimmed for countries with all or most of the data. As a result, only 107 countries remained, but still a sizable sample.

The IDI is development index which is a composite of ICT readiness, use, and impact measurements (see Figure 3). It is a weighted composite of various internet access, internet use, and internet skills variables. But it is not a measure of ICT investment. Other studies have used ICT investment variables, it is not easy to measure. In many cases it had to be estimated from underlying data (See Vu 2011) or is simply not available for developing or poorer countries. By default, this study is on ICT development but, within the proper context. (Additional relationships among the data are in the Appendix.)

For economic growth, the GDP per capita is a better metric than GDP *per se* (because of obvious scale effects in the latter). We use a percent change for the growth measure from Output Conference Board data.

There is one potential issue with isolating a relationship between GDP per capita growth and the IDI index: The years in the sample (especially the early part) span the period just after the Great Recession and growth rates show up as persistently negative for several years in many countries. So, a part of what happened to economic growth may have less to do with ICT and more with other shocks. This is an empirical issue.

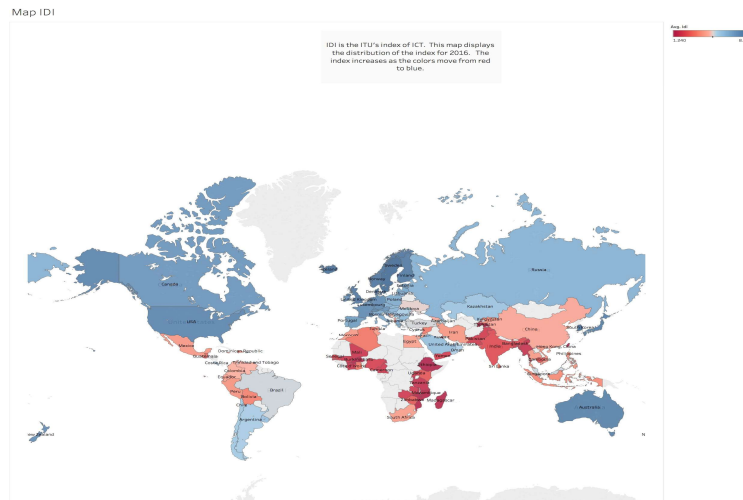


Figure 3 ITU Development Index

Methodology

The impact of ICT on economic growth in selected countries is examined following the Farhadi, *et al.* (2012) approaches: Data from 107 selected countries from 2008 to 2018 are used. As noted in the literature review, others have shown that ICT, most recently cellular mobile phone and broadband services, have an impact on economic growth as did fixed-line service in an earlier period. The question addressed in this paper is what is the impact of ICT on economic growth and *vice-a-versa*?

As indicated earlier internet and, particularly, mobile telephone services have grown spectacularly in the last decade. Privatizations have had time to settle and regulation has had time to mature. Thus, it is appropriate to examine their combined impact.

The focus in this study is on three sets of variables:

- Lngdppc, natural log of real per capita GDP
- Lnidi, natural log of the ITU's ICT Development Index (IDI)
- Lngci, natural log of the World Economic Forum's Global Competitiveness Index (GCI)

This is only the second study to use the IDI to represent the state of ICT,³ rather than the more traditional "ICT investment" variable which is constructed in various ways by different researchers. The IDI is broader than any of the traditional investment measures because it incorporates indicators of both infrastructure access and usage (which the traditional measures try to capture) but also internet use skills which,

³ Farhadi, *et al.* 2012 was the first to our knowledge.

arguably, captures the potential of a population to use ICT for GDP-affecting economic activities.

Given how easy it is to leapfrog technology and the reduced costs of entering a market providing ICT services, that market potential (usage) is the key measure here. (Is this tantamount to saying supply creates its own demand?) The argument is: If people are using broadband services (fixed and mobile) then that implies (new) value added services are in play. Of course, some of those (travel) might disrupt brick and mortar businesses and hence have somewhat reduced impacts on GDP. A well-functioning wireless network provides signals to those who are thinking about other investments.

The hypothesis to be tested is that any causality between GDP growth and ICT development is likely a two-way street, i.e., bi-directional, rather than solely from one to the other. The literature is replete with such tests, but there appears to be little consistency in the pattern of findings. Much depends on the types and numbers of countries used in sample data, the time periods studied (absolutely since next generation technology (faster and cheaper) occurs with increasing frequency), and whether controls were used in models to account for other factors that affect the environment in which the GDP-ICT relationship arises. In this study, rather than relying on unobserved panel fixed effects as those controls, the GCI is explicitly used as a control to isolate the GDP-IDI relationship. If GDP is a proxy for income (think demand) then we would expect GDP to influence usage, not the other way around.

Granger-Causality Test in Dynamic Panel Data Fixed Effects Model

Consider the dynamic fixed effect panel data model

$$y_{it} = \alpha_0 + \sum_{k=1}^m \alpha_k y_{i,t-k} + \sum_{k=0}^m \delta_k x_{i,t-k} + \mu_i + \varepsilon_{it} \quad i = 1, 2, \dots, N, t = m+1, \dots, T$$

(time-specific terms omitted)

Granger-Causality test: H_0 : x does not Granger-cause y if all δ_k are jointly zero

A parallel test of the H_0 : y does not Granger-cause x can be conducted in a similar manner by reversing x and y in the above equation and testing whether the coefficients of lagged y are all jointly zero.

- One-way Granger causality is established if one of the null hypotheses is rejected but the other is not.
- Bi-directional Granger causality is established if neither null hypothesis is rejected.
- Instantaneous Granger causality is established if the coefficient is statistically significant at the zero lag.

Consistent Estimation of the Dynamic Panel Data Fixed Effects Model

$$y_{it} = \alpha_0 + \sum_{k=1}^m \alpha_k y_{i,t-k} + \sum_{k=0}^m \delta_k x_{i,t-k} + \mu_i + \varepsilon_{it} \quad i = 1, 2, \dots, N, t = m + 1, \dots, T$$

- By construction, the fixed effects μ_i are correlated with lagged-dependent terms, so they are first “swept out” by first-differencing the equation, although this introduces serial correlation in the differenced errors.
- More seriously, it introduces correlation between the differenced lagged dependent variable and the differenced error term.
- Arellano and Bond (1991) proposed a GMM estimator (akin to an instrumental variable estimator) to consistently estimate the dynamic panel data model with lagged-dependent variables. These instruments can be levels and differences of various lags of the dependent variable.
- In the presence of heteroskedasticity, robust standard errors should be used.
- A test of the order of serial correlation in the differenced errors can be conducted.
- Holtz-Eakin et al. (1988) formulated an early prototype of the Arellano-Bond estimator and the estimator was used for causality testing in panel data by Nair-Reichert and Reinhold (2000)

Econometric Issues

From an econometric standpoint, there are two issues of note.

To test for Granger causality (and its direction) between two variables X and Y, the procedure first calls for regressing current Y on its past values and on the current and past values of X. If the coefficients for X (current and lagged values) are statistically significant, then there is an indication of at least one-way causality from X to Y (although causality itself is a stronger condition about the variation in Y being reduced by the inclusion of the X variables than their omission). To confirm that there is potentially one-way causality, a reverse regression of X on Y is then conducted, and the coefficients of current and lagged Y are tested for statistical significance. If those coefficients are individually and collectively zero, then one-way causality is said to be established from X to Y. Otherwise, there is potentially two-way (or bi-directional) causality between Y and X. If the coefficients of interest are not statistically significant in both regressions, then there is no Granger causality between Y and X.

Carrying out the causality test in this manner requires the inclusion of lagged dependent variables. In the context of panel data, this means the estimation of a dynamic panel data regression model (with either fixed or random effects). In such a model, it is conventional to first “sweep out” the fixed effects by first-differencing. However, even after that, the correlation between the lagged dependent variables and, presumably, the independent and identically distributed random variables (IID) error term renders standard estimators biased and inconsistent. The only way to overcome that is by use

of instrumental variables. This approach, first proposed by Anderson and Hsiao (1981), unfortunately suffers from asymptotic inefficiency. Arellano and Bond (1991) got around this problem by use of a Generalized Method of Moments (GMM) estimator, which replaces the differenced lags of the dependent variable with deeper lags of that variable. While in traditional panel data estimation, taking deeper lags means the loss of some observations, the Arellano-Bond GMM estimator compensates for this by increasing the number of moment restrictions on the lags of the dependent variable as the number of time periods increases.

We used the Arellano-Bond GMM estimator of dynamic linear panel data models to test for Granger causality. This procedure is well suited to circumstances in which the number of units (here, countries) is large but there are few time periods (here 2008-2017). Usually, it is assumed that the error term is IID, so that the first differencing to eliminate the fixed effects causes the differenced errors to be serially correlated. Arellano and Bond (1991) have proposed a test for autocorrelation of orders 1 and 2. If the test finds autocorrelation of order 1 but none of order 2, then the model has been properly specified and estimated. Sometimes, differencing may induce the error terms to behave like a low-order moving average process, in which case Arellano-Bond suggest an alternative set of instruments to use at the estimation step. Finally, the initial hypothesis is of homoscedastic errors, but clustering by countries (e.g., by different income groups) can cause heteroskedasticity to arise and render the estimators inefficient. At that point, robust heteroskedastic-consistent standard errors should be used.

Estimation/Results

Table 1 and Table 2 show several models in which $Lngdppppc$ is regressed on $Lnidi$ and $Lngci$ (the control). Different lags are used in accordance with the GMM procedure. Results of the Arellano-Bond autocorrelation test are also shown. Separate models are estimated for the all-countries sample (107 countries), high income countries, upper middle-income countries, lower middle-income countries, low income countries, more affluent (high income and upper middle income) countries, and less affluent (lower middle income and low income) countries.

Table 1. Test of Granger-Causality: IDI to GDP per Capita

Test of Granger Causality: ICT Index (IDI) to GDP per capita (GDPPC)

GMM Estimation	All Countries			High Income			Upper Middle Income			Lower Middle Income			Low Income		
Dep Var: GDPPC	Coeff	Std Err	Sig	Coeff	Std Err	Sig	Coeff	Std Err	Sig	Coeff	Std Err	Sig	Coeff	Std Err	Sig
ln(GDPPC) Lag 1	0.7662	0.0633	***	0.8087	0.1951	***	0.9490	0.1342	***	0.8713	0.0596	***	0.8743	0.2778	***
ln(GDPPC) Lag 2				-0.0627	0.1051								-0.0914	0.2725	
ln(GCI)	0.0455	0.0120	***	0.1764	0.0922	*	0.0247	0.0229		0.0626	0.0179	***	0.0695	0.0539	
ln(GCI) Lag 1	-0.0224	0.0092	**	-0.0372	0.0180	**	-0.0292	0.0174	*	-0.0110	0.0170		-0.0510	0.0589	
ln(GCI) Lag 2	0.0195	0.0132		0.0132	0.0226		0.0079	0.0133		0.0352	0.0295		-0.0441	0.0676	
ln(IDI)	0.0005	0.0029		-0.0008	0.0048		0.0005	0.0082		-0.0061	0.0083		0.0022	0.0079	
ln(IDI) Lag 1	-0.0024	0.0019		-0.0057	0.0037		0.0027	0.0044		-0.0047	0.0028	*	0.0015	0.0041	
ln(IDI) Lag 2	-0.0022	0.0027		0.0007	0.0037		-0.0047	0.0089		-0.0081	0.0060		-0.0128	0.0057	**
Mob Int Pen	0.0001	0.0001	*	0.0002	0.0001		0.0001	0.0003		0.0003	0.0003		0.0000	0.0003	
Mob Int Pen Lag 1	0.0000	0.0001		-0.0000	0.0001		0.0000	0.0002		0.0002	0.0003		-0.0006	0.0002	**
Mob Int Pen Lag 2	-0.0004	0.0001	***	-0.0005	0.0001	***	-0.0002	0.0003		-0.0002	0.0004		0.0001	0.0003	
Year	0.0089	0.0031	***	0.0148	0.0036	***	-0.0000	0.0106		0.0005	0.0040		0.0143	0.0032	***
Wald chi2	4327.60		***	3353.41		***	4318.84		***	3746.22		***	5.5e+10		***
Obs	723			276			178			167			56		
Groups	107			46			27			25			9		
Instruments	45			44			45			45			42		
AR(1) z-stat	-2.95		***	-2.31		**	-1.67		*	-2.31		**	-1.98		**
AR(2) z-stat	-1.05			-1.25			0.88			-0.61			1.37		

Table 2. Test of Granger-Causality from GDP per Capita to IDI

Test of Granger Causality: GDP per capita (GDPPC) to ICT Index (IDI)

GMM Estimation	All Countries			High Income			Upper Middle Income			Lower Middle Income		
Dep Var: IDI	Coeff	Std Err	Sig	Coeff	Std Err	Sig	Coeff	Std Err	Sig	Coeff	Std Err	Sig
ln(IDI) Lag 1	-0.0083	0.0312		-0.0758	0.0490		0.0413	0.0437		0.0190	0.0470	
ln(IDI) Lag 2	-0.6644	0.0315	***	-0.6251	0.0461	***	-0.4997	0.0794	***	-0.6851	0.0675	***
ln(GCI)	0.1639	0.1609		0.9315	0.3802	**	0.3040	0.2147		-0.0599	0.2859	
ln(GCI) Lag 1	0.0948	0.1019		-0.2820	0.1502	*	-0.0835	0.1549		0.6003	0.2004	***
ln(GCI) Lag 2	0.1037	0.1483		-0.4853	0.3236		-0.2470	0.2727		0.2421	0.2184	
ln(GDPPC)	-0.1345	0.5388		-0.1062	0.9138		0.1098	0.7616		-1.2034	1.0157	
ln(GDPPC) Lag 1	0.7780	0.4611	*	0.1211	0.6072		0.5886	0.9785		0.8093	0.9690	
ln(GDPPC) Lag 2	-0.5953	0.4012		-0.1161	0.5486		0.3028	0.9033		0.0401	0.6452	
Mob Int Pen	-0.0004	.0012		-0.0019	0.0018		0.0013	0.0018		0.0055	0.0025	**
Mob Int Pen Lag 1	0.0001	0.0011		0.0008	0.0015		0.0010	0.0028		-0.0048	0.0027	*
Mob Int Pen Lag 2	-0.0022	0.0012	*	0.0002	0.0013		-0.0051	0.0030	*	-0.0025	0.0020	
Year	0.0781	0.0162	***	0.0798	0.0243	***	0.0769	0.0410	*	0.0614	0.0337	*
Wald chi2	1245.02		***	1335.87		***	1188.75		***	1065.31		***
Obs	723			322			178			167		
Groups	107			46			27			25		
Instruments	46			45			45			45		
AR(1) z-stat	-5.66		***	-3.97		***	-2.50		**	-2.70		***
AR(2) z-stat	0.51			-0.54			-0.42			-0.36		

Considering only the all-countries sample (the first model). The following independent variables are statistically significant: lag 1 of $\ln gdp$ and current and first lag of GCI . All but the coefficient of Lag 1 of GCI is positive, signifying a positive effect. The sole exception is counter-intuitive, but it is consistent with the sign reversals also seen in the Farhadi *et al.* (2012) paper. There is some variation on the theme in the other models that apply to specific income-based country blocs.

Findings from Granger Causality Tests (IDI vs. GDP per capita)

Causality from IDI to GDP per capita					
Lag	All Countries	High Income	Upper Middle Income	Lower Middle Income	Low income
0	No	No	No	No	No
1	No	No	No	Yes	No
2	No	No	No	No	No
Reject Null Hypothesis that all Lag Coefficients are Jointly Zero? (Wald Test)					
	No	No	No	Yes	No

Causality from GDP per capita to IDI					
Lag	All Countries	High Income	Upper Middle Income	Lower Middle Income	Low income
0	No	No	No	No	Yes
1	Yes	No	No	No	No
2	No	No	No	No	No
Reject Null Hypothesis that all Lag Coefficients are Jointly Zero? (Wald Test)					
	No	No	No	No	Yes

Table 3. Table Causality: GDP per capita to IDI and IDI to GDP per capita

This paper empirically evaluates the impact of ICT on economy growth in selected countries and *vice versa*. The results are promising. Summarizing for the 2008-2017 period, shows no evidence of causality in both directions.

IDI to GDP per capita

From IDI to GDP per capita, no causality evident for the full all-countries panel.

GDP per capita to IDI

From GDP per capita to IDI no causality is evident.

Future Research and Remaining Questions.

Significant issues remain: What about wireless? Is growth in wireless more a demand-based phenomenon, implying growth in GDP drives wireless? Is there a better measure for ICT going forward?

Findings from Granger Causality Tests (Mobile Internet Penetration vs. GDP per capita)

Causality from Mobile Internet Penetration to GDP per capita					
Lag	All Countries	High Income	Upper Middle Income	Lower Middle Income	Low income
0	Yes	Yes	No	No	No
1	No	No	No	No	Yes
2	Yes	Yes	No	No	No
Reject Null Hypothesis that all Lag Coefficients are Jointly Zero? (Wald Test)					
	Yes	Yes	No	No	Yes

Causality from GDP per capita to Mobile Internet Penetration					
Lag	All Countries	High Income	Upper Middle Income	Lower Middle Income	Low income
0	Yes	Yes	No	No	No
1	No	No	Yes	No	No
2	Yes	No	No	No	No
Reject Null Hypothesis that all Lag Coefficients are Jointly Zero? (Wald Test)					
	Yes	Yes	Yes	No	No

There is strong evidence for bi-directional causality – Mobile Internet Penetration to GDP per capita and GDP per capita to Mobile Internet Penetration.

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Appendix

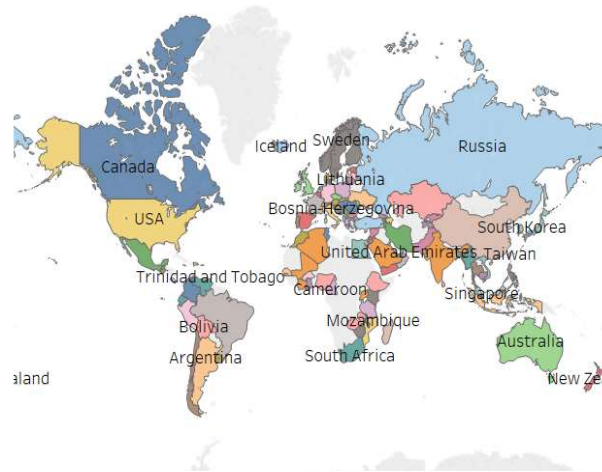


Figure A 1. Technological Readiness

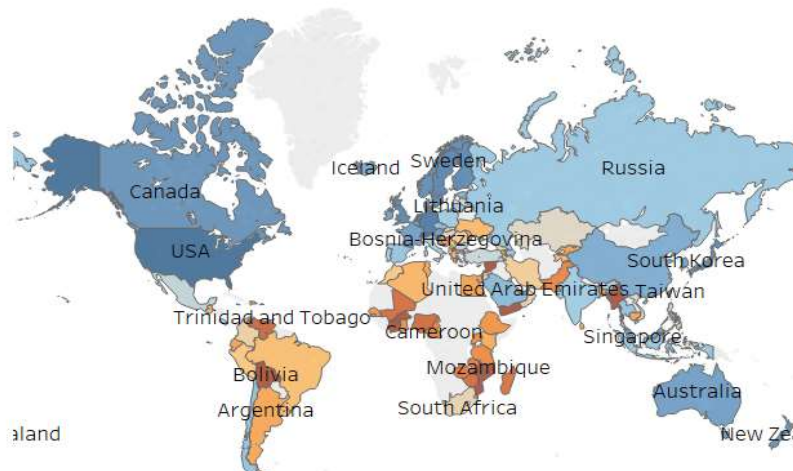


Figure A 2. Global Competitiveness Index (GCI)

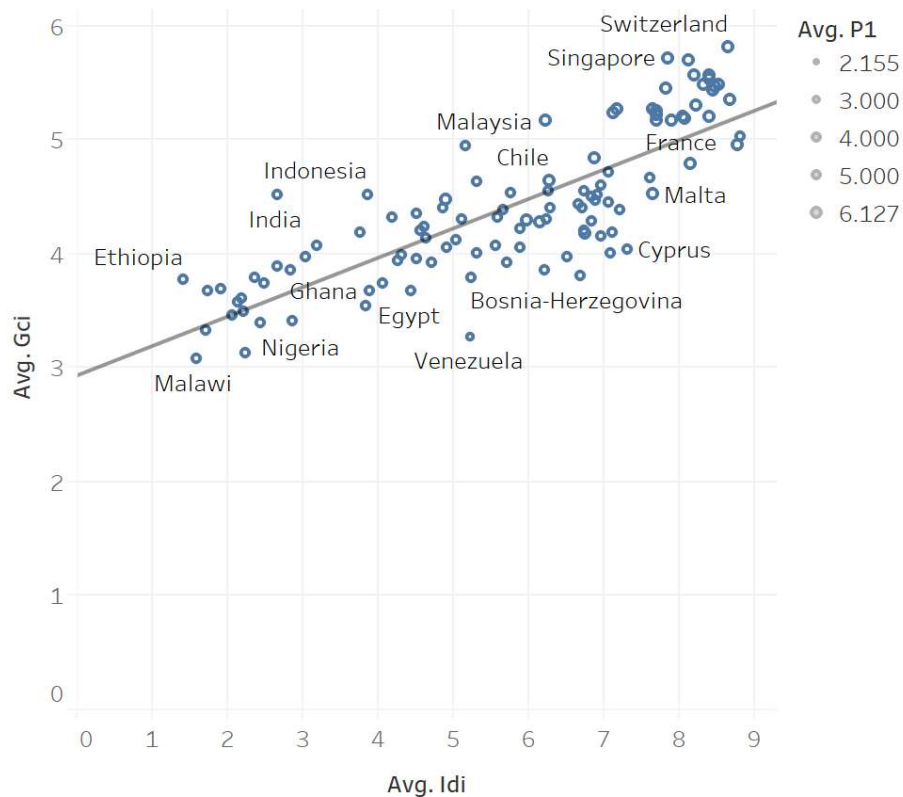


Figure A 3. Global Competitiveness Index (GCI) v. ICT Development Index (IDI)

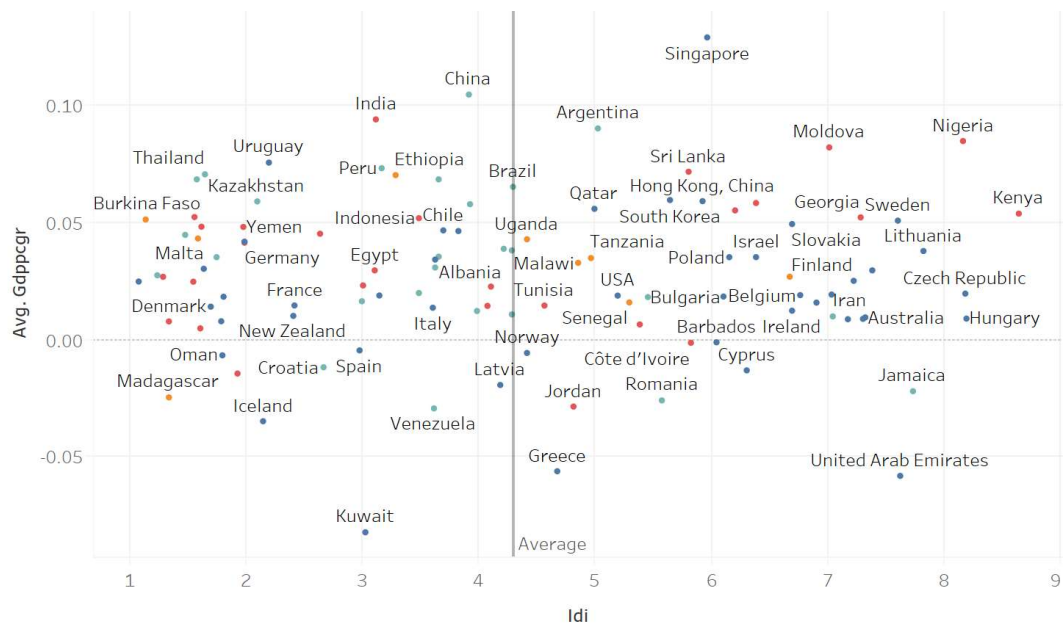


Figure A 4. GDP/pop & IDI

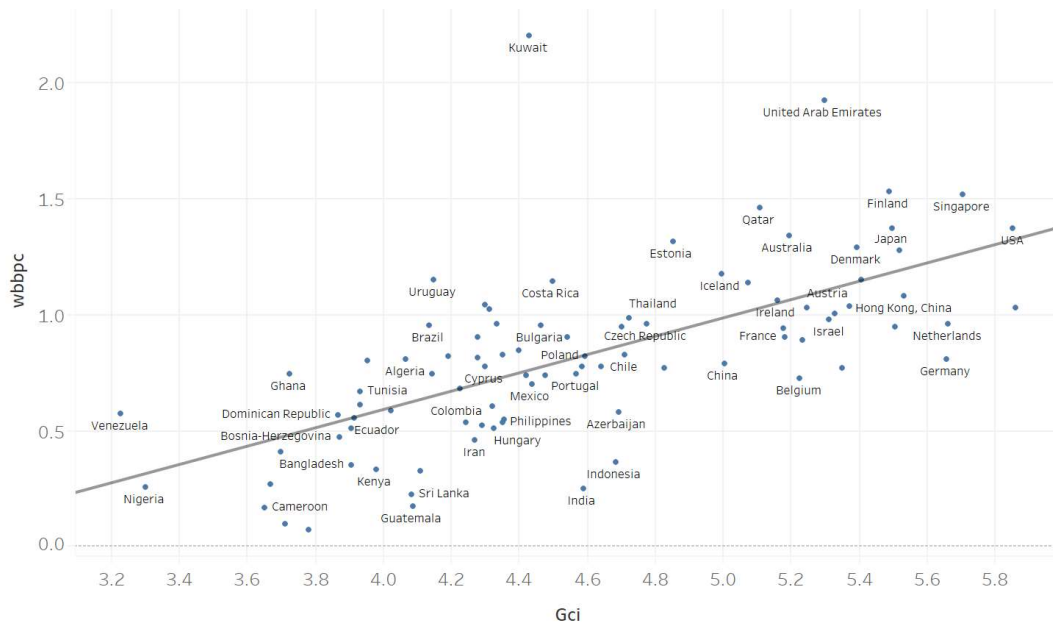


Figure A 5. Wireless BB per capita & GCI