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The Effect of Education, R&D and ICT on Economic Growth in High Income Countries

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Abstract

This document examines the causal relationship between information and communications technology (ICT), education, research & development (R&D) and economic growth in high income countries using panel data set from 1990 to 2015. We employ panel data set using various tests such as panel unit root test, panel cointegration in order to detect the relationship between the dependent variable (GDP) and independent variables (ED, RD, MCS and IU). The empirical results of the vector error correction model (VECM) show that there exists a unidirectional relation causality from education and mobile cellular telephone to economic growth, from internet users and mobile cellular telephone to research and development and from education to research and development, while bidirectional causality between internet users and economic growth, between research and development and economic growth, between education, internet users and mobile cellular telephone in the short-run. In addition, the results also show that there is a bidirectional relationship between education, internet users and mobile cellular telephone, while there is a unidirectional relationship from internet users to economic growth and research and development and from mobile cellular telephone to economic growth and research and development in the long-run.

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1. Introduction

The research on the determinants of economic growth has been one of the most important elements of economic research for several decades. From the great traditional theories of production to the new theories of growth, all these determinants are invoked to explain the growth of the gross domestic product or the production process.

We note that in several empirical studies on growth, the concept of human capital, or that of education, was at the center of the debate. In literature, the nexus education and GDP per capita has attracted attention of researchers in different countries for a long time. The new theories of neo-classical economic growth, among which we can cite the contributions of Romer (1986) and Lucas (1988), tend to explain the process of economic growth, with particular emphasis on the role of capital human in Innovation, and consequently in long-term growth. There are divergent views on the positive role and significant impact of education on economic growth. Despite theoretical and empirical advances and the widely held belief that education contributes directly to economic growth through its effects on productivity, labor mobility, Technological innovation, etc., there is doubt about the functional form of the relationship between production and human capital produced by the education system.

The indirect role of education in GDP per capita is through research and development activity (R&D). Thus, some models from endogenous growth theories no longer consider education as a factor of production but as a factor of innovation. Which make it possible to increase the efficiency with which it is possible to produce wealth from capital and labor, by the accumulation of intangible stock of ideas and knowledge? Thus, education can have another role, to promote technological innovations, and also their adaptation (Luca, 1988). Therefore R&D not only creates knowledge, but also makes better use and capitalization of existing knowledge and the most efficient technologies are adopted and implemented faster by the countries with the richest advanced human capital(Nelson and Phelps, 1996; Cohen and Levinthal, 1989).

Another key factor in the economic literature is the relationship between ICT and growth. Over the past thirty years, accelerating the widespread use ICT has been one of the most impressive developments. ICT has emerged as one of the main vectors of economic and social activity in both developed and emerging and developing countries. Increased investment in ICT has led to accelerated productivity and performance growth in the second half of the decade 1990 in many developed and newly industrialized countries (Lee et al., 2009). For most authors, encouraging ICT is essential, both for improving the living conditions of Africans and for stimulating entrepreneurship, innovation and economic growth Indicating that ICT can facilitate cross-border communication, financial transactions and the sharing of knowledge and information, and can also play a catalytic role in regional integration and trade facilitation.

The aim of this study is to determine whether education, R&D and ICT contributes to improving the performance of GDP per capita in high income countries during the period from 1990 to 2015, using econometric tools. The rest of the paper is structured as follows. A brief overview of the literature on similar studies is outlaid in ***section 2***. The ***section 3*** presents the data and the model specification. ***Section 4*** discusses the empirical results. Finally, ***section 5*** concludes and proposes policy implications.

2. Review of Empirical Literature

2.1. Impact of education on economic growth

The relationship between education and economic growth essentially is based on the microeconomic work of Denison (1962), Becker (1964), Mincer (1958), Romer (1986) and Lucas (1988). In the early 1990s, several empirical studies of growth tend to confirm the positive role of education in economic growth. Barro (1991) estimate that the shift from the secondary school enrollment rate of 50% to 100% increases the annual growth rate of income by about 1%. In addition, Benhabib and Spiegel (1994) have studied if the educational attainment of the labor force affects the output and the growth of an economy. They propose an approach associated with the theory of endogenous rooting, which consists in modeling technological progress as a function of the level of education or of human capital and have shown that the stock of human capital plays a key role. Moreover, Benhabib and Spiegel (1994), using panel data and Cobb–Douglas aggregate production function, show that by introducing in their regressions the influence of human capital on the overall productivity of factors - to take into account the processes of innovation and the diffusion and catch-up processes technological - they get a positive influence of human capital on growth. In addition, they show that in the richest countries, the direct effect of education on innovation capacity influences growth, while in poorer countries, Effect of catching up. Thus, the impact of education on growth varies according to the level of development of countries. While Krueger and Lindahl (2001) noted that education is statistically significant and positively related to growth, only for countries with low levels of education. Barro (2001) uses an endogenous growth model and also finds a positive role of education on growth with its sample of 100 countries over the period 1960-1995. These results show that taking into account the quality of education is more important than its quantity measured by the average levels of completion of secondary and higher education. Prtichett (1996, 2001) shows that there is no relationship between the increase inhuman capital and the growth rate in the MENA region using cross-sectional data. For Pritchett, this weak link can be explained by three factors: first, education does not increase human capital but increases private wages. Second, the marginal return to education is declining rapidly. Finally, the dominant institutional environment in many countries does not favor the accumulation of human capital already concentrated in income-producing activities that stifle economic growth. On their part, Aghion and Cohen (2004) find that the increase in growth is linked by the increase in the number of years of studies. To this end, these authors confirm the existence of a positive relationship between education and economic growth.

Altinok (2006) uses new indicators, constructed from international surveys of student achievement, to test the relationship between education and growth. Taking into account the endogeneity of education, it leads to a positive effect, both of the quantitative and qualitative indicators of human capital, on the growth of a sample of 105 countries over the period 1960-2000. Creel and Poilon (2006) examined the impact of human capital (as measured by ordinary education spending) and public investment on growth using an augmented Solow model. Human capital and public investment prove to be a driving force for economic growth in Europe. Al-Yousif (2008) analyzed the nature and meaning of the relationship between education spending as a proxy for human capital and economic growth in six GCC countries during the period 1977-2004. The empirical results obtained are mitigated and vary according to the country and the measure of human capital used. On the other hand, Pradhan (2009) examines the causal link between education and economic growth in India during the period 1951-2001 through an empirical survey carried out by correlation error modeling. The results of this survey confirmed that there is a unidirectional causality between education and economic growth. In fact, education and especially at the higher level contributes directly to economic growth by making workers more productive and indirectly by leading to the creation of knowledge, ideas and technological innovations. In addition, Barro and Lee (2010) argue that education is at the heart of the process of economic growth. They study the implications of the level of human capital on economic growth. To do so, they use the fixed effects and the random effects approach to indicate that the rate of return on education is equal to 20% and that the world economy grows at a rate of 2% for a study additional year. However, the return is negative with the primary level, while that of the secondary and higher levels is higher. Quenum (2011) proposes to isolate the effect of human resources of each level of education on growth in sectors of economic activity. It concludes that post-primary levels have a negative and significant effect on economic growth. Thus, the problems of the quality of education or the demand for competence of human capital can explain these intuitive effects.

Recently, Wang and Liu (2016) have proposed a panel data model to investigate the impact of education on economic growth, using the latest education data of 55 countries and regions from 1960 to 2009. The results obtained indicated that whether it is developed country or developing country education human capital and economic growth all showed a significant positive correlation and that primary education and secondary education doesn't have significant positive impact on economic growth while higher education has significant positive effect on economic growth. Hanif and Arshed (2016) used three variables for the education for the panel data of SAARC countries, collected from 1960 to 2013, to see whether higher education has better marginal impact on the growth of the this countries. The empirical results reveal that tertiary education enrollment has highest impact on growth as compare to primary and secondary education enrollment.

2.2. Impact of research and development on economic growth

Coe and Helpman (1995) are modeling the diffusion of technological activities between the industrialized countries through the channel of trade flows. To do this, these authors based their empirical research on theoretical growth models "*innovation- driven*". Their objective was to assess how foreign technological advances contribute to improving domestic productivity. Coe and Helpman (1995) found from a sample of 22 industrial countries that a country's productivity depends not only on its own R&D capital stock but also on that of its trading partners. Moreover, they have shown that the positive effect of foreign R&D on a country's productivity depends on its degree of openness. Subsequently, Bayoumi et al. (1999) provided a quantitative assessment of the importance of R&D and trade between industrialized countries in the influence of TFP growth and hence of output growth. This approach is taken from Coe and Helpman (1995). The authors conclude that, in a world with endogenous growth, international externalities of North-North R&D through trade play an important role in improving growth in industrialized countries. Frantzen (2000) supports the view that both R&D and human capital play an important role in productivity. Using data for several OECD countries over the period 1965-1991, the author shows that both domestic and foreign R&D have a significant impact on productivity but the impact of domestic R&D played more significant role in growth in richer countries, because of their size, as compared to smaller economies, which benefit more from foreign technology spillovers.

Bronzini and Piselli (2009) re-examined the Italian regional data between 1980 and 2001 to evaluate this causal relationship using a model that takes into account investments in research and development, capital Human and public infrastructure. They find that a larger stock of R&D is associated with productivity expansion. However, the contribution to productivity is rather small and less than that of the other variables. In addition, according to Granger-causality tests, R&D efforts turns out to be endogenous in the long and short run, that is R&D stock is granger-caused by productivity. The results obtained suggest again that encouraging R&D activity can be considered only a weak instrument for reducing regional disparities. Hall and Mohnen (2010) conclude that the private returns to R&D are strongly positive in many countries and somewhat higher than those for ordinary capital, while the social returns are even higher, although variable and imprecisely measured in many cases. In addition, most estimates for public government-funded R&D suggest that it is less privately productive than private R&D, as it should be, given the fact that it targets goals that either do not show up in conventional productivity or have substantial positive externalities. Wu (2010) used regional data to examine the impact of R&D efforts on innovation and hence economic growth in China for the period 1998-2007. It notes that innovation affects China's economic growth positively while R&D intensity has a positive impact on regional innovation. Both innovation and economic growth respond to R&D investment significantly and the calculated elasticities are comparable with those reported in studies of other economies. Khan and Rehman (2014) examine the significance of R&D for economic growth in Pakistan over a period of 1971 to 2009. The results obtained from the Ordinary Squares method showed that R&D contributes significantly in the Real GDP per capita in Pakistan. The Johansen Cointegration test confirmed the existence of long run relationship between R&D and economic growth. Thus, according to the authors, it is recommended to increase investment in R&D to achieve sustained economic growth. It is also recommended to collect and record quality R&D data for effective policy making in the field of science and technology, and social sectors in Pakistan. Blanco et al. (2016) studied the impact of R&D on Economic Growth of the private sector of the U.S. states from 1963 to 2007. The two authors find that states with more human capital have higher own- and other-R&D elasticities, and those in lowest tier of economic development have the least own-state R&D elasticity but the highest other-R&D elasticity. In addition, they also found that the positive effect of R&D spillovers across states is larger when we consider R&D spillovers across states based on economic similarity of R&D across sectors. Luintel and Khan (2016) investigate the relationship between R&D and economic growth in emerging countries by using a panel of 31 emerging countries. The results indicate convincing evidence of scale effects which make government policies potent for long-run growth. Innovations show increasing returns to knowledge stock, implying that the diminishing returns assumed by some semi-endogenous growth models might not be generalized. International R&D spillovers raise the innovation bar. Econometric tests of scale effects reveal a statistically significant proportional relationship between the level of R&D inputs and the growth rates of per capita real, productivity and technology.

2.3. Impact of ICT on economic growth

Several authors have studied the relationship between ICT and Economic growth. Early studies by Jorgenson and Stiroh (1995) reported a modest contribution of informatics to productivity growth (about 6% contribution to annual productivity growth of 2.94% for the period 1959-1973 in all of the Countries studied). In subsequent periods, they found that the contribution of ICT to be considerably greater. Jorgenson and Stiroh (2000) and Oliner and Sichel (2000) observed a very low contribution of ICT to US economic growth until 1995, when it began to grow substantially. Over the period 1973-1995, Jorgenson and Stiroh (2000) found that ICT contributed about 13% of economic growth of 3.04% and 27% of labor productivity growth of 1.4% in US. Oliner and Sichel (2000) found higher contributions.

Schreyer (2000) found that ICT had a positive contribution to productivity and economic growth in all countries forming the old G7 during the period 1990-1996. Oulton (2001) indicate the same trend in the United Kingdom. For Canada, Gera et al. (1999) explained that investment in ICT and international R&D spillovers in the ICT sector is the most important source of labor productivity growth in the manufacturing sectors. Piatkowski (2003) examined the impact of ICT on labor productivity and GDP in Poland. It found that, between 1995 and 2000, investment in ICT contributed to 8.9% to GDP growth and 12.7% to growth in labor productivity. Van Ark and Piatkowski (2004) show that the increased use of ICT has contributed to the restructuring process of manufacturing industries in Central and Eastern Europe and thus to the process of convergence of these countries with the former EU-15. In addition, they show that the adoption of ICT in countries in Central and Eastern Europe contributed much more to productivity growth than in the EU-15. The OECD (2007, 2008) examined the contribution of the ICT sector to labor productivity growth. Its main conclusions are that the contribution of ICT producing sectors to labor productivity has increased sharply since 1995.

More recently, the link between investment in ICT and economic growth has been the subject of a large number of studies. Fukao and Miyagawa (2007) analyzed the impact of ICT investment on labor productivity and TFP in Japan. They found that the Japanese economy knew the same levels of growth in Total Factor Productivity (TFP) as the four largest economies in the EU (Germany, France, the United Kingdom and Italy) in the period after 1995. Hausmann et al.(2007) suggested that countries with high specialization ICT export have higher productivity and higher economic growth rates. Qiang (2009) estimated the effect of ICT on growth for a sample of 120 developed and developing countries over the period 1980-2006. Its results indicate that increase a 10% of the ICT adoption rate has resulted in an increase of 0.81% of economic growth in low- and middle-income countries. For 22 OECD countries over the period 2002-2007, Koutroumpis (2009) found that ICT have a significant causal link with economic growth when a critical mass of technological infrastructure is present. Hawash and Lang (2010) tested whether higher ICT adoption results in higher total factor productivity growth of developing countries or not, by conducting a panel data regression for 33 developing countries over the period 2002-2006. This study shows that ICT adoption and higher educational attainment tend to relatively be the most significant factors affecting productivity growth in developing countries. Gruber and Koutroumpis (2010), using data from 192 countries for the period 1990-2007, found significant effects of ICT on productivity growth. Vu Khuong (2011) conducted an empirical study to examine the impact of ICT on growth in a sample of 102 developed and developing countries over the period 1996-2005. Its results showed that ICT have been an important source of growth over this period. Niebel (2014) analyzes the effect of ICT on economic growth in developing, emerging and developed countries by using a sample of 59 countries for the period 1995 to 2010. They concludes that There is no clear statistical indication that developing and emerging countries are gaining more from investments in ICT than developed economies and that political and societal aspects such as the simplified access to information should be taken into account when investigating the impact of ICT in developing and emerging countries.

The ICT plays a significant role in development of each economic sector, especially during liberalization process. So, Kais et al. (2014) investigated the effects of ICT on economic growth in Tunisia. Their findings show that there is a positive link between the GDP and ICT. Samimi et al. (2015) examines the impact of ICT on economic growth in developed and developing countries. To do this, they used a sample of both countries for the period 2001-2012. They have shown that in general significance and positive relationship between ICT and economic growth exists in both developed and developing countries. The results also indicate that here is a difference between performance of developing countries and that of developed countries regarding the impact of ICT on economic growth. Naym and Hossain (2016) investigate whether investment on ICT leads to higher economic growth considering Bangladesh case for the period 1997-2013. They indicate that though statistically not significant, positive association between ICT investment and economic growth has been found. According to the authors, this result can be explained by the smaller share of ICT investment in GDP and shorter time span available for the country than required for conducting rigorous statistical analysis.

3. Data and specific model

3.1. The data: source and description

In this study, the sample used is annual data covering the period 1990-2015 for 28 high income countries (*Australia, Austria, Bahrain, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea Rep., Kuwait, Luxembourg, Netherlands, New Zealand, Norway, Oman, Portugal, Saudi Arabia, Singapore, Spain, Sweden, Switzerland, Trinidad and Tobago, United Kingdom, and United States*).The choice of sample and period was dictated by the availability of data. All data was extracted from the WDI database (2016), and the missing values were completed by WDI online. Table 1 presents the descriptive statistics and correlation matrix of the variables used in the study. According to the correlation matrix, education (ED), Internet users (IU), mobile cellular telephone (MCS) and research and development (RD) which are explanatory variables of our study are positively correlated with economic growth. The variables internet users, mobile cellular telephone and research and development are correlated positively with education. A detailed definition of the variables is presented in Table 2.

Table 1: Descriptive statistics and Correlation Matrix of the Variables

	GDP	ED	IU	MCS	RD
Mean	10.42201	5.091847	40.74267	67.16551	1.542988
Median	10.51405	5.034018	39.18073	75.55068	1.489215
Maximum	11.60825	14.19883	98.76152	231.7632	4.291630
Minimum	8.744501	1.241365	0.001007	0.025438	0.012315
Std. Dev.	0.510672	1.436207	33.84384	51.75956	0.953191
Skewness	-0.684944	0.546396	0.128924	0.137188	0.299858
Kurtosis	3.946481	4.786573	1.464994	1.903092	2.541245
Jarque-Bera	84.09663	133.0431	73.48946	38.78086	17.29352
Probability	0.000000	0.000000	0.000000	0.000000	0.000176
Sum	7587.224	3706.865	29660.67	48896.49	1123.295
Sum Sq. Dev.	189.5910	1499.576	832709.8	1947671.	660.5325
Observations	728	728	728	728	728
Correlation Matrix	**GDP**	**ED**	**IU**	**MCS**	**RD**
GDP	**1.000000**				
ED	0.277595	**1.000000**			
IU	0.435902	0.249272	**1.000000**		
MCS	0.321713	0.132160	0.864697	**1.000000**	
RD	0.475335	0.217715	0.505733	0.297099	**1.000000**

Table 2: Definitions of the variables

Variables	Measurement units	Definition
Research and Development (RD)	As measured by the research and development expenditure (% of GDP)	This consists of current and capital expenditures (both public and private) on creative work undertaken systematically to increase knowledge, including knowledge of humanity, culture, and society, and the use of knowledge for new applications. R&D covers basic research, applied research, and experimental development
Mobile cellular telephone (MCS)	As measured by the mobile cellular subscriptions (per 100 people)	This consists of 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
Internet users (IU)	As measured by the internet users (per 100 people)	These are individuals who have used the Internet (from any location) in the last 12 months. Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc….
Gross domestic product (GDP)	As measured by the GDP per capita (constant 2010 US$)	This 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
Education (ED)	Total	This is General government expenditure on education (current, capital, and transfers) expressed as a percentage of GDP. It includes expenditure funded by transfers from international sources to government. General government usually refers to local, regional and central governments.

3.2. Presentation of the model

The main objective of this study is to analyze the impact of education (ED), Research & Developpement (R&D) and Information and Communication Technology (ICT) on Economic growth (GDP) for high income countries using annual data over the period of 1990–2015. Kais et al. (2014), Vu (2013), Yousefi (2011), among others, included the ICT variables in their empirical models to examine their impacts on economic growth. Furthermore, Aghion et al. (2009), Obit, (2010), Solaki (2013), among others, include the education variables in their empirical models to examine their impacts on economic growth. In addition, several authors include the R&D variables in their empirical models to examine their impacts on GDP per capita (as, Bronzini and Piselli (2009), Hall et al. (2010), Khan and Rehman (2014), Blanco (2016), among others). The general specification of the model we want to estimate can be written as follows:

$$lnGDP_{it} = \alpha_i + \beta_{1i} lnED_t + \beta_{2i} lnRD_t + \beta_{3i} lnMCS_t + \beta_{4i} lnIU_t + \varepsilon_{it} \qquad \textbf{(1)}$$

$$\text{for } i = 1, \ldots . N; t = 1990 \text{ to } 2015$$

Where GDP_{it} is referred to the real gross domestic product, ED is the education, RD is the research & development, MCS is mobile cellular telephone and IU is the internet users. The parameter $\alpha_i$is a fixed-effect parameter whileβ_{1i},β_{2i}, β_{3i}, and $\beta_{4i}$are the slope parameters.ε_{it} are the estimated residuals which represent deviations from the long-run relationship.

Studies written by Pedroni (1999), (1997), (2000) and (2001) are used to estimate the cointegration of the panels among the variables in question. These studies provide not only a different short-term dynamic, but also different co-integration vector. On the basis of Pedroni (1999), (1997) two estimators are used to estimate the long-term parameters of the cointegration relationships given by (1).

4. Empirical results and interpretation

4.1. Unit root and co-integration test in panel

4.1.1. Unit root test

Several panel unit root tests have been proposed in the literature to examine the stationarity hypothesis. hese panel unit root tests can be classified in many ways. To present the unit root tests, we rely on the work of Hurlin and Mignon (2005), Guillaumant (2008), Araujo and all (2004) and Banerjee and Zanghieri (2003).The unit root panel tests are based on LLS and IPS tests of time series. Moreover, the central hypothesis of these tests is based on the notion of independence between the individuals of the panel. In the following, an attempt is made to present the various tests in the following table 3:

Table 3: LLC and IPS tests on series

Unit root tests		LLC		IPS	
Variable	***Panel Specifications***	***Levels***	***First differences***	***Levels***	***First differences***
GDP	*Individual effets*	-6.244	-7.700*	-0.099	-8.663*
	Individual effects and trends	0.437	-7.965*	3.038	-8.455*
IU	*Individual effects*	1.598	1.147**	6.774	-4.944*
	Individual effects and trends	3.113	3.185**	2.139	-2.473*
ED	*Individual effects*	-3.208	-18.138*	-4.266	-17.479*
	Individual effects and trends	-1.528	-15.807*	-3.677	-14.889*
MES	*Individual effects*	-4.750*	1.697*	1.994	-4.637*
	Individual effects and trends	-3.957*	-4.383*	2.293	-1.810**
RD	*Individual effects*	-1.838	-18.930*	0.284	-18.317*
	Individual effects and trends	0.786	-18.272*	0.091	-16.525*

Notes: The unit root hypothesis is accepted at * 1%, ** 5%. . LLC, IPS, correspond to the test results of Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), and. (.) Are the p-values. All tests are conducted with fixed effects, regardless of the model.

The results of the table show that the majority of the series are non-stationary with the two tests. However, the two tests would lead us to accept the null hypothesis of non-stationarity for the variables (GDP), (ED) and (RD) at level, at the risk level of 1% Stationary in first difference, goal at 5% risk level variable (IU) is stationary in first difference. Finally, the statistic of LLC (2002) allows rejecting the hypothesis of stationarity for the variable (REC) at the level of risk of 1%, whereas this hypothesis is accepted by IPS (2003).

In conclusion, the results of the tests LLC (2002) and IPS (2003) show that the series are non-stationary in level. Acceptance of the unit root hypothesis for all level variables leads us to verify whether these variables become stationary in first difference in order to show the existence of a long-term relationship between GDP per capita, education, R&D and Information and Communication Technology (ICT).

The results of the LLC (2002), and IPS (2003) tests applied on the first difference series show that the series are all I (1). The verification of the stationarity of all the variables of the panel in the first difference leads us to study the existence of a long-term relation between these variables and consequently the existence of a cointegration relation by resorting to the tests of Cointegration of Pedroni.

Based on these results, we will try to test the cointegration between the dependent variable, education (ED), research & development (R&D), Mobile cellular telephone (MCS) and Internet users (IU). For this we will apply in the first place the test of Pedroni for the whole panel.

4.1.2. Co-integration test in panel

We then carry out cointegration tests using the work of Pedroni (1997, 1999) and Kao (1999). The verification of the non-stationarity properties for all the variables of the panel leads us to study the existence of a long-term relation between these variables. That is to say the study of the existence of a cointegration relationship and applying the cointegration test of Pedroni (1997, 1999). The results of cointegration of Pedroni and Kao are presented in Table 4 and Table 5.

The Tables heterogeneous of Pedroni (1999) reject the null of non-cointegration when they have large negative values with the exception of the panel-v test which rejects the null of cointegration when it has a high positive value. The results of this test suggest a rejection of the null hypothesis of non-cointegration at least at the level of significance of 5%. There is therefore a long-term relationship between variables.

Table 4: Pedroni cointegration Test

Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	**Prob.**	**Statistic**	**Prob.**
Panel v-Statistic	5.5681**	0.0477	5.5742***	0.0802
Panel rho-Statistic	-2.1756**	0.0148	-1.4814***	0.0692
Panel PP-Statistic	-8.8252*	0.0000	-9.1478*	0.0000
Panel ADF-Statistic	-4.8922*	0.0000	-4.2624*	0.0000
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	**Prob.**		
Group rho-Statistic	0.382662	0.6490		
Group PP-Statistic	-10.60828*	0.0000		
Group ADF-Statistic	-4.556278*	0.0000		

Notes: *, ** and *** denotes significance at the 1%, 5% and 10% level.

While the results of the Kao (1999) residual co-integration tests also reject non-cointegration at the 5% significance level. Thus, we conclude that there is a long-run equilibrium relationship between these two variables, which means that GDP, ED, R&D, mobile cellular telephone and internet users evolve together in the long term.

Table 5: Kao Cointegration Test

	t-Statistic	**Prob.**
ADF	-2.161479	0.0153**

Note: ** indicates statistical significance at the 5% level.

4.2. Vector Error Correction Model (VECM)

This approach allows us to distinguish between "*short-term*" and "*long-term*" Granger causality. The elimination or non-significance of any of the "*delayed error correction terms*" affects the implied long-term link and may constitute a violation of the theory. Masih and Masih (1996) reported that the elimination of any of the "*differentiated*" variables reflects only the short-term link. Thus, the following models can be used to explore the causal relationships between variables:

$$\begin{bmatrix} \Delta GDP_{it} \\ \Delta ED_{it} \\ \Delta IU_{it} \\ \Delta MCS_{it} \\ \Delta RD_{it} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} + \begin{bmatrix} \pi_{11,1}\pi_{12,1}\pi_{13,1}\pi_{14,1}\pi_{15,1} \\ \pi_{21,1}\pi_{22,1}\pi_{23,1}\pi_{24,1}\pi_{15,1} \\ \pi_{31,1}\pi_{32,1}\pi_{33,1}\pi_{34,1}\pi_{35,1} \\ \pi_{41,1}\pi_{42,1}\pi_{43,1}\pi_{44,1}\pi_{54,1} \\ \pi_{51,1}\pi_{52,1}\pi_{53,1}\pi_{54,1}\pi_{55,1} \end{bmatrix} \begin{bmatrix} \Delta GDP_{t-1} \\ \Delta ED_{t-1} \\ \Delta IU_{t-1} \\ \Delta MCS_{t-1} \\ \Delta RD_{t-1} \end{bmatrix} + \cdots$$
$$+ \begin{bmatrix} \pi_{11,k}\pi_{12,k}\pi_{13,k}\pi_{14,k}\pi_{15,k} \\ \pi_{21,k}\pi_{22,k}\pi_{23,k}\pi_{24,k}\pi_{25,k} \\ \pi_{31,k}\pi_{32,k}\pi_{33,k}\pi_{34,k}\pi_{35,k} \\ \pi_{41,k}\pi_{42,k}\pi_{43,k}\pi_{44,k}\pi_{45,k} \\ \pi_{51,k}\pi_{52,k}\pi_{53,k}\pi_{54,k}\pi_{55,k} \end{bmatrix} \begin{bmatrix} \Delta GDP_{t-k} \\ \Delta ED_{t-k} \\ \Delta IU_{t-k} \\ \Delta MCS_{t-k} \\ \Delta RD_{t-k} \end{bmatrix} + \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \varphi_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_{6t} \\ \varepsilon_{7t} \\ \varepsilon_{8t} \\ \varepsilon_{9t} \\ \varepsilon_{10t} \end{bmatrix} \quad \textbf{(2)}$$

Table 6: The null hypothesis for Granger causality test

	Short-run Causality					Long-run Causality
	ΔGDP	**ΔED**	**ΔIU**	**ΔMCS**	**ΔRD**	φ_i
ΔGDP	-----------	$\pi_{12,1} = \cdots = \pi_{12,k} = 0$	$\pi_{13,1} = \cdots = \pi_{13,k} = 0$	$\pi_{14,1} = \cdots = \pi_{14,k} = 0$	$\pi_{15,1} = \cdots = \pi_{15,k} = 0$	$\varphi_1 = 0$
ΔED	$\pi_{21,1} = \cdots = \pi_{21,k} = 0$	----------	$\pi_{23,1} = \cdots = \pi_{12,k} = 0$	$\pi_{24,1} = \cdots = \pi_{24,k} = 0$	$\pi_{25,1} = \cdots = \pi_{25,k} = 0$	$\varphi_2 = 0$
ΔIU	$\pi_{31,1} = \cdots = \pi_{31,k} = 0$	$\pi_{32,1} = \cdots = \pi_{32,k} = 0$	-------------	$\pi_{34,1} = \cdots = \pi_{34,k} = 0$	$\pi_{35,1} = \cdots = \pi_{35,k} = 0$	$\varphi_3 = 0$
ΔMCS	$\pi_{41,1} = \cdots = \pi_{41,k} = 0$	$\pi_{42,1} = \cdots = \pi_{42,k} = 0$	$\pi_{43,1} = \cdots = \pi_{43,k} = 0$	--------------	$\pi_{45,1} = \cdots = \pi_{45,k} = 0$	$\varphi_4 = 0$
ΔRD	$\pi_{51,1} = \cdots = \pi_{51,k} = 0$	$\pi_{52,1} = \cdots = \pi_{52,k} = 0$	$\pi_{53,1} = \cdots = \pi_{53,k} = 0$	$\pi_{54,1} = \cdots = \pi_{54,k} = 0$	--------------	$\varphi_5 = 0$

With, $\varepsilon_{6t}, \varepsilon_{7t}, \varepsilon_{8t}, \varepsilon_{9t} and \varepsilon_{10,t}$ are the residual terms, independently and normally distributed with zero mean and constant variance. Using equation (2), causality relationships can be examined in two ways: **(1)** The Granger causality in the short term is detected by the F statistic for the significance of relevant πcoefficients on the first differentiated series. **(2)** Another possible source of causality is the ECT in the equations; in the long term, the causes are examined using the t-test for the significance of the relevant φ coefficient on the delayed error correction term (Table 6).

The results of the Vector Error Correction Model (VECM) are presented in Table 7. We conclude that there is a short-term causality from education to economic growth. The results indicate there a positive impact of education on economic growth is consistent with most of the previous studies mentioned above. Specifically, it is in line with the studies, such as Lin (2006), Loening, Bhaskara and Singh (2010), Shaihani et al. (2011), Villa (2005), Chi (2008), and Gyimah, Paddison and Mitiku (2006).

Moreover, we note that at the 1% threshold, the Granger test suggests a unidirectional causal link between mobile cellular telephone and economic growth. In other words, in the case of these countries, it is the mobile cellular telephone that causes economic growth and not the other way around, supporting the thesis that it is the expansion of mobile cellular telephone that determines economic growth. Moreover, in the short term, there is a two-way causality relationship between economic growth and internet users, between research and development and economic growth, between internet users and education, between mobile cellular telephone and education and between internet users and mobile cellular telephone. On the contrary, there is a unidirectional relation from education to research and development, from internet users to research and development and from mobile cellular telephone to research and development.

In the long-run, causality results show that there is a two-way relationship between ED and internet users and between education and mobile cellular telephone, but there is a unidirectional relationship from internet users to economic growth and research and development and from mobile cellular telephone to economic growth and research and development.

Table 7: Panel VECM causality test results

Dependent variable	Short-run causality					Long-run causality
	ΔGDP	**ΔED**	**ΔIU**	**ΔMCS**	**ΔRD**	**ECT**
ΔGDP	-----------	2.5952 (0.6478)	3.6425** (0.0397)	8.8476 (0.5986)	0.2609** (0.0212)	**-0.4484* (0.0005)**
ΔED	0.3001* (0.0017)	----------	-0.0724** (0.0240)	-0.2095** (0.0427)	-0.1042* (0.0094)	**0.2979** (0.0137)**
ΔIU	0.3982* (0.0002)	0.5928* (0.0046)	-------------	0.2112*** (0.0688)	1.38662* (0.0015)	**0.1398* (0.0014)**
ΔMCS	1.1788* (0.0001)	0.7097* (0.0027)	0.0626** (0.0224)	------------	0.9422* (0.0008)	**0.3020* (0.0083)**
ΔRD	-0.4236* (0.0069)	0.2103 (0.1143)	0.7413 (0.9521)	-1.2721 (1.6934)	--------------	-1.0581 (0.2501)

Notes: * Denotes 1% level of significance. ** Denotes 5% level of significance. ***Denotes 10% level of significance

We have summarized these results in Figure 1 below:

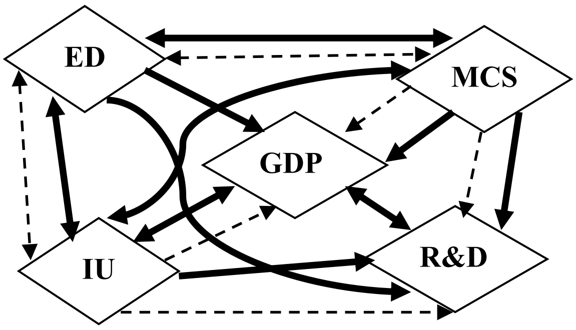

Fig.1: The links between the five variables

Note: Light arrows show the short run relationship, and dark arrows show the long run relationship.

5. Conclusions and policy implications

This document examines the relationship between ICT, education, R&D and GDP per capita in high income countries during the period 1990-2015. Using the cointegration test to determine if a stable linear combination exists between the four variables, and one cointegration relationship was observed in the model. Since a cointegration relationship exists between the four time series, granger-causality was tested using the vector error correction model (VECM).

The results indicate, there is bidirectional causality between ICT and R&D in the short-run and between education and ICT in the long-run. When total ICT and R&D was classified into public sector and private sector, the private ICT and R&D had stronger relationship with economic growth compared to the public ICT, R&D. In the short-run, the results also reported bidirectional causality between GDP per capita and IU, between GDP per capita and R&D, while a unidirectional relationship from ED and MCS to economic growth. In addition, a bidirectional relationship between education and ICT is found, while a unidirectional relationship from IU to GDP per capita and from MCS to GDP per capita and R&D in the long-run.

The implications from this study are as follows. First, the bidirectional causality between ICT, R&D and GDP per capita implies that ICT is driven by economic growth and vice versa. Based on the long-run causality from total ICT to economic growth, we can presume that high income countries economic growth was driven by R&D in ICT over the long-run.

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