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ICT AS A SOURCE OF ECONOMIC GROWTH IN THE INFORMATION AGE: EMPIRICAL EVIDENCE FROM ICT LEADING COUNTRIES

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ABSTRACT

The goal of this paper is to undertake a panel data investigation of long-run and short run Granger causality between total factor productivity, ICT contribution and real GDP for panel of six countries. We use a Generalized Method of Moment (GMM) to test causality and find out that there are unidirectional Granger causality running from ICT contribution to TFP and economic growth in the long-run where ICT contribution did not have a robust short-run causality relationship with economic growth. The negative and statistically significant coefficient of ICT confirms the slow acceleration of TFP among the EU countries. Finally, the long-run relationship between growth and ICT contribution in the 2000s is higher, more significant and robust than in the 1990s. These results point to several important policy implications such as prevailing arguments in favour of technological capacity-enabled growth has not taken into account short-term costs that may include reduced economic growth as shown by our results for the 1990-2000 periods.

JEL CLASSIFICATION & KEYWORDS

■ O33 ■ O47 ■ O52 ■ FIRST DIFFERENCE GMM ■ EU COUNTRIES ■ TFP ■ ICT ■ PANEL DATA

INTRODUCTION

The acronym ICT refers to two unconnected concepts: (1) information technology and (2) telecommunications technology. Information Technology (IT) is the phrase employed to explain the equipment and software program components that enable us to access, recover, save, organize, manipulate and exhibit information by electronic means. Communications Technology (CT) on the other hand, is the phrase employed to express the devices, infrastructure, and software whereby information can be obtained and accessed (for example; phones, faxes, modems, digital networks, and DSL lines). ICT is consequently the result of the convergence of the IT and CT. One initial instance of ICT convergence is the crossing of photocopy machine and telephone, leading to the creation of fax. Above all, the clearest example in this area is the convergence of computer and telephone which resulted in the upsurge of the internet. The growth in ICT was global in coverage over the last two decades. A number of research studies have attempted to measure the impact of ICT on economic development, a major concern of policy makers. As a result of globalization, different countries seek to improve their ICT infrastructures as well as enhance the quality of ICT services to stimulate economic growth.

The relationship between ICT, economic growth (EG), and Total Factor Productivity (TFP) has been much studied using the concept of Granger causality. In its conventional sense, Granger causality does not normally indicate that ‘X causes Y’, but that ‘X possesses information that is reasonably enough to predict the nature of Y’. Moreover, there are disagreements in the literature as to this effect. The main reason for disagreement is that Granger tests are affected by bias from omitted variables. The majority of the studies carried out in Europe also consider only TFP or GDP in bivariate settings. To overcome this problem, we extend Granger’s causality to assess the relationship between the contribution of ICT, non-ICT, labor capital, and TFP in the EU, using an improved aggregate neo-classical production model. Thus, the main objective of the current paper is to verify ICT spillover effects in European countries with highly developed ICT infrastructure and use via causality analysis in the short-run and long-run.

The link between contribution of ICT and growth has been investigated by a wealth of studies. At the national level, the literature on the contribution of investment in ICT to growth can be separated into two main parts. In one stream, the studies employ the growth accounting technique to estimate the contribution of ICT investments to GDP growth. These studies include Oliner and Sichel (2002), and Jorgenson and Stiroh (2003) for the US; Oulton (2002) for the UK; Jalava and Pohjola (2002) for Finland; Colecchia and Schreyer (2002), Jorgenson and Motohashi (2005) for Japan; Jorgenson (2001) for the G7 economies; Jorgenson and Vu (2007) for 110 countries; Van Ark, Melka, Mulder, Timmer, and Ypma (2002), Daveri (2002), Timmer, Inklaar, O’Mahony and Van Ark (2010), Vu (2011), and González-Sánchez (2012) for EU economies.

In the second stream, studies use cross-country regression techniques to assess the causality effects of ICT on economic growth. The seminal paper by Hardy (1980), which analyzed the data for 60 nations over the period 1968–1976, found strong evidence for the contribution of telephones to economic development. Causality tests to assess the causal relationship between economic growth and development of telecommunications were undertaken by Cronin, Parker, Colleran and Gold (1991), Cronin, Colleran, Herbert and Lewitzky (1993), and Madden and Savage (1998). They found bidirectional Granger causality between infrastructural telecommunication and economic growth in the United States and Central and Eastern European (CEE) countries. Röller and Waverman (2001) have also reported that investment in telecommunication infrastructure impacted GDP growth in 21 OECD countries and emerging industrialized non-OECD countries from 1970 to 1990, although, this effect is not linear and higher in OECD countries compared to non-OECD countries.

Gust & Marquez (2004), Pilat (2004), Esteban-Pretel, Nakajima, & Tanaka (2010) and Dahl, et al. (2011) have explored the development of the IT sector as well as cross-country differences. These studies measured the recent productivity divergence between industrial

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countries and the United States through the role of many practices in influencing the dispersion of IT as well as positive and significant productivity impacts of ICT on Europe, mainly due to progress in TFP. Their results challenged the general argument of studies based on growth accounting that there has been no acceleration of productivity growth in Europe because of the delay in technology adoption compared to the US (Stiroh, 2002).

In recent research on the General Propose Technology (GPT) hypothesis, Engelbrecht and Xayavong (2006); Martínez et al. (2010); and Kretschmer (2012) found strong positive evidence of ICT and TFP growth for data, but it was more difficult to find such evidence in Europe. Maliranta and Rouvinen (2008) and Arvanitis (2009) proved that in Finland and Switzerland's manufacturing sector the internet does not play an important role in terms of performance as compared to the service sector, probably due to the lack of desk job work, personal computer and internet connection for the manufacturing worker. Therefore, it has been suggested that investigating ICT spillovers may answer many questions on the subject of possible externalities. However, there also exists evidence of short-run and long-run bidirectional causal relationships between ICT and economic growth in individual EU countries such as Sweden (Khalili et al. 2012).

Most studies on ICT impact only consider the income level of countries in comparative studies specially between the EU and US but not to the level of ICT development in countries. To fill this research gap, we use panel data of in 6 European countries which are leaders in ICT development.

Data Description

The main purpose of this study is to explore the impact of ICT on economic growth among the top ICT developed countries in Europe. We collected aggregate level data for 6 top ranked ICT countries in the EU from the World Bank Indicator database. EU countries' ICT ranking has been based on International Telecommunication Union (ITU) reports in 2012 (Table 1).

Table 1: Six top ranking of ICT development index (IDI) among EU countries

European Economy	Regional Rank 2010	Global Rank 2010
SWEDEN	1	2
ICELAND	2	3
DENMARK	3	4
FINLAND	4	5
LUXEMBOURG	5	7
SWITZERLAND	6	8

Source: Author International Telecommunication Union (ITU), 2012

Annual data collected between 1990 and 2011 are used for this study. The variables used for estimation are shown in Table 2.

EU Growth Decomposition

Since the mid-1990s, the progress and diffusion of ICT have accelerated substantially, with the rapid penetration of personal computers, mobile phones, and the internet across nations in the world (Vu, 2011). Table 3 reveals that there were notable improvements in economic growth over 1990–2011. The highest contribution of ICT was recorded by Switzerland (1.435%) with 3.283% annual GDP growth rate in EU zone countries, while Luxembourg experienced the highest GDP growth rate (3.989%).

Table 2: Descriptive of variables used in models

EG	"GDP growth (annual %)"
L	"Contribution of Labour Composition Index to GDP Growth (annual %)"
ICT	"Contribution of ICT Capital Services to GDP Growth (annual %)"
Non-ICT	"Contribution of Non-ICT Capital Services to GDP Growth (annual %)"
TFP	"Total Factor Productivity Growth (annual %)"
ICT-IM	" ICT Goods Imports (% total goods imports)"
PTN	" Patent Applications, Non-residents"
PTR	" Patent Applications, Residents"
TERIT	" School Enrolment, Tertiary (% gross)"
HT	" High-Technology Exports (% of manufactured exports)"
UPL	" Unemployment, Total (% of total labour force)"
EXP	" Exports of Goods and Services (% of GDP)"
IMP	" Imports of Goods and Services (% of GDP)"

Source: World Bank Indicator database, 2012

The annual mean TFP and GDP growth for EU economies as a group were 0.559% and 2.538% during 1990–2011 respectively. During this period Luxembourg recorded negative TFP growth while Iceland has the highest growth rate of TFP (1.625%) among EU countries. The mean contributions of labor and non-ICT capital to GDP growth were 0.234% and 0.574% respectively. However, the highest contribution of labor and non-ICT capital to GDP growth belongs to Luxembourg.

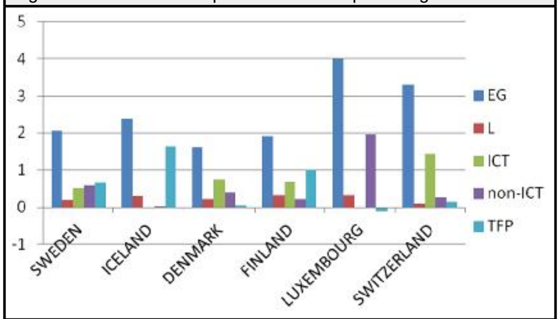
Table 3: European growth decomposition

COUNTRY	EG (%)	L (%)	ICT (%)	non-ICT (%)	TFP(%)
SWEDEN	2.054	0.19	0.508	0.587	0.655
ICELAND	2.376	0.299	No record	0.025	1.625
DENMARK	1.601	0.221	0.759	0.396	0.048
FINLAND	1.926	0.321	0.675	0.219	1.1
LUXEMBOURG	3.989	0.336	No record	1.966	-0.113
SWITZERLAND	3.283	0.085	1.435	0.249	0.132
TOTAL	2.538	0.234	0.844	0.574	0.559

Source: World Bank Development Indicators, 1990-2011

Figure 1 shows economic growth and TFP growth as well as the contribution of; ICT and non-ICT capital, and labor for EU countries.

Figure 1: Growth decomposition for six top ranking of ICT



Source: World Bank Development Indicators, 1990-2011

Generally, the Nordic countries (Denmark, Finland and Sweden) have greater shares for software in ICT industries with considerable diffusion (Aghion and Howitt, 1997). However, this has not yet translated into substantial acceleration of growth. In particular, Finland is characterized by a robust growth of ICT capital as well as a significant contribution from ICT service to TFP and EG growth since it is a key ICT producer in the EU (Aghion and Howitt, 1997). Thus, ICT improvement is not the only factor explaining differences in productivity and GDP growth between Europe countries; ICT penetration could also have played a key role because of difference in lagging of ICT diffusion between EU countries.

Methodological Issues and Findings

This study uses panel data to estimate an error correction model (ECM) to determine the short and long-run ICT effect on output growth. This is a common approach to finding the causal relationship between variables using the method of Engle-Granger tests. Three new techniques have been used for the non-stationary dynamic panel estimation. These are dynamic fixed effect (DFE), mean group (MG), and pooled mean group (PMG) estimators (Pesaran et al., 1999). Like the PMG estimator, DFE estimators not only limit the co-integrating vector coefficients to be equivalent across all the panels but also restrict the short-run coefficients to be equal. In contrast, the PMG estimator relies on a combination of pooling and averaging of coefficients (Blackburne and Frank, 2009). Next, if there is a long run causality relationship running from variables to output growth, we employ the system Generalized Moment of Method (GMM) panel data estimator to deal with the issue of the endogeneity of regressors.

Panel Unit Root Tests

Before proceeding to using co-integration techniques, we need to determine the order of integration of each variable. One way is to implement the panel unit root test of Im et al. (2003) (hereinafter IPS). This test is less restrictive and more powerful than the tests developed by Levin et al. (2002) and Breitung (2000), which do not allow for heterogeneity in the autoregressive coefficient. We have added some additional variables to our model. First generation tests such as Levin et al. (2002), Breitung (2000), and Hardi (2000) requires strongly balanced panels, but due to additional controlling variables our new panels are not strongly balanced.

The test proposed by IPS (2003) solves Levin & Lin's serial correlation problem by assuming heterogeneity between units in a dynamic panel framework. IPS tests have the drawback of assuming that the cross- sections are independent; the same assumption is made in all first-generation panel unit root tests. However, it has been pointed out in the literature that cross-section dependence can arise due to unobserved common factors, externalities, regional and macroeconomic linkages and unaccounted residual interdependence. Recently, a new panel unit root test proposed by Pesaran (2007) has addressed the question of the dependence and correlation given the prevalence of macroeconomic dynamics and linkages. Therefore, we employed IPS (2003), and Pesaran (2007) tests for the EU panel of countries.

First generation panel data integration tests such as IPS (2003) and Maddala & Wu (1999) assume cross-sectional independence among panel units (except for common time effects), whereas second generation panel data unit root tests (Pesaran 2007) allow for more general forms of cross-sectional dependency (not limited to common time effects). The results of the Fisher-type (1999), IPS (2003) and Pesaran (2007) panel unit root tests are presented in Table 4 for EU countries. For all fourteen variables, the null hypotheses of the unit roots cannot be rejected in level terms. These results indicate that the variables in level terms are non-stationary and become stationary only in first-differences.

Table 4: EU countries, panel unit root tests

Variables	**Pesaran (2007) Pescadf**	**Im, Pesaran & Shin(2003) IPS**	**Maddala & Wu (1999) Fisher-type**
EG			
Level	-0.498 (0.309)	-2.655* 0.004)	-0.386 (0.650)
First-difference	-1.978*(0.024)	-9.937* 0.000)	2.636 * (0.004)
L			
Level	0.109 (0.543)	-1.892* (0.029)	-0.361 (0.641)
First-difference	-3.322 (0.000)	-8.191* (0.000)	5.162* (0.000)
ICT			
Level	1.574 (0.942)	-2.368* (0.009)	-0.177 (0.570)
First-difference	-1.598**(0.055)	-4.998* (0.000)	8.541* (0.000)
Non-ICT			
Level	-0.456 (0.324)	-3.322*(0.000)	0.487 (0.313)
First-difference	-4.001* (0.000)	-5.424*(0.000)	1.763* (0.039)
TFP			
Level	-0.792(0.214)	-4.271*(0.000)	0.879 (0.189)
First-difference	-1.833*(0.033)	-5.071*(0.000)	6.209*(0.000)
ICT-im			
Level	-0.664 (0.254)	-0.109 (0.456)	3.725* (0.000)
First-difference	-3.084* (0.001)	-3.769*(0.000)	16.332*(0.000)
PTR			
Level	0.885 (0.812)	0.368 (0.643)	-1.667 (0.952)
First-difference	-1.599**(0.055)	-5.802*(0.000)	1.843*(0.033)
PTN			
Level	-0.514 (0.304)	-0.669 (0.251)	0.894 (0.185)
First-difference	-2.296*(0.011)	-9.665*(0.000)	2.059*(0.019)
RDE			
Level	------	-------	-0.514(0.696)
First-difference	4.704 (1.000)	-------	14.950*(0.000)
TERIT			
Level	5.233(1.000)	1.079 (0.859)	0.687(0.246)
First-difference	0.459 (0.677)	-2.686*(0.003)	1.775*(0.038)
HT			
Level	1.095 (0.863)	0.646 (0.740)	0.362 (0.358)
First-difference	-1.980*(0.024)	-3.737*(0.000)	8.364*(0.000)
UPL			
Level	0.112 (0.545)	-1.441(0.075)	-0.118(0.547)
First-difference	-2.399*(0.008)	-2.731*(0.003)	17.925*(0.000)
EXP			
Level	0.840 (0.799)	-0.868(0.192)	0.684(0.247)
First-difference	-0.306(0.380)	-5.218*(0.000)	4.913*(0.000)
IMP			
Level	1.147(0.874)	0.444 (0.671)	-0.716 (0.763)
First-difference	-2.039*(0.021)	-3.388*(0.000)	4.244*(0.000)

Notes: The null hypothesis is that the series is a unit-root process except Hadri(2000) test. P-values are given in parentheses.
Probabilities for the Fisher-type tests are computed using an asymptotic Chi-square distribution. All the other tests are assumed to be asymptotic normal. The lag length is selected using the Modified Schwarz Information Criteria.
All of values are z(t-bar).
* Indicates the parameters are significant at the 5% level.
**Indicates the parameters are significant at the 10% level.

Source: Authors

Panel Co-integration Tests

As indicated, the basic idea behind co-integration is to test whether a linear combination of variables that are individually non-stationary is itself stationary. Kao's (1999) residual-based test was an ADF stationary test on residuals of a first difference model with all variables. Since the Pedroni (2004) co-integrating test limits the number of variables, we will employ only the Kao (1999) co-integration test for countries.

The test results (Table 5) show that all 14 variables in the countries are co-integrated. We have disregarded controlling variables and only performed Pedroni (2004) and

Table 5: Kao's residual co-integration test results				
		Lag [a]	**t-statistic**	**Probability**
EU Countries	ADF	3	-2.0757*	0.0190
Note: Null Hypothesis: No co-integration. [a] lag selection using Parzen kernel. *Indicate that the parameters are significant at the 5% level.				
Source: Authors				

Kao (1999) tests on EG, ICT, non-ICT, L and TFP at the aggregate level and we have found the variables co-integrated as well. Therefore we can apply the error correction model.

Panel Granger Causality Results

One of the augmented neoclassical models of economic growth takes the Cobb-Douglas functional form. The basic Solow model is thus extended to include the contribution of labor employment and ICT, in addition to the contribution of non-ICT capital (Solow, 1987). Hence, we have the following augmented production function:

$$Y_{it}=A\ ICT_{it}^{\beta 1}\ non\text{-}ICT_{it}^{\beta 2}\ L_{it}^{\beta 3}\ e^{Uit} \qquad (1)$$

Where Y is value added growth, labor employment (L), non-ICT and ICT capital are contributions to value added growth; A is a constant representing other unobservable factors of production. Finally, β_1, β_2, and β_3 are the elasticities of the production resources. We have approximated growth rates by employing the log differences, as is normal in the growth literature:

$$\Delta (\ln Y_{it}) = \alpha + \beta_1\Delta(\ln ICT_{it}) + \beta_2\Delta(\ln non\text{-}ICT_{it}) + + \beta_3\Delta(\ln L_{it}) + U_{it} \qquad (2)$$

Growth decomposition analysis showed that most of the EU countries as a group have lower rates of ICT adoption compared to their potential levels as predicted on the basis of their current level of development (GDP/capita) and competitiveness (World Competitiveness Index). As already pointed out, disparities in ICT diffusion are quite large, indicating that a significant 'digital divide' exists even among the EU countries. It was apparent that the ICT contribution across countries is correlated with the level of GDP and TFP growth but not strongly due to other factors such as non-ICT and labor. Consequently, the impacts of the other factors on both ICT adoption and GDP growth should be controlled before conclusions can be drawn about the causal relationship between these variables.

The co-integration relationship tests only shows causal relationship but not the direction of causality among variables. Consequently it is common to examine the causal relationship among variables by using the Engle-Granger test procedure via modifying equation (2). In the presence a co-integration relationship, applying the Engle & Granger (1987) causality test in the first differenced level of variables by vector auto-regression (VAR) structure will yield misleading results. Therefore the insertion of an additional variable such as the error correction term (ECT) to the VAR system would help capture the long-run relationship (O'Mahony and Vecchi, 2005). The augmented error correction model is used to test multivariate Granger causality as formulated in is given matrixes as follows:

$$\begin{bmatrix} LnEGit \\ LnICTit \\ LnNICTit \\ LnLit \\ LnTFPit \end{bmatrix} - \begin{bmatrix} C1 \\ C2 \\ C3 \\ C4 \\ C5 \end{bmatrix} \Sigma_{i=0}^{p} \begin{bmatrix} \beta 11,k\beta 12,k\beta 13,k\beta 14,k\beta 15,k \\ \beta 21,k\beta 22,k\beta 23,k\beta 24,k\beta 25,k \\ \beta 31,k\beta 32,k\beta 33,k\beta 34,k\beta 35,k \\ \beta 41,k\beta 42,k\beta 43,k\beta 44,k\beta 45,k \\ \beta 51,k\beta 52,k\beta 53,k\beta 54,k\beta 55,k \end{bmatrix} . \begin{bmatrix} LnEGit-k \\ LnICTit-k \\ LnNICTit-k \\ LnLit-k \\ LnTFPit-k \end{bmatrix} + \begin{bmatrix} \lambda 1 \\ \lambda 2 \\ \lambda 3 \\ \lambda 4 \\ \lambda 5 \end{bmatrix} ECM_{t-1} + \begin{bmatrix} \varepsilon 1it \\ \varepsilon 2it \\ \varepsilon 3it \\ \varepsilon 4it \\ \varepsilon 5it \end{bmatrix} \qquad (3)$$

The C's, β's and λ's are the parameters which will have to be estimated. ECM_{it-1} represents the one period lagged error-term derived from the co-integration vector and the ε's are serially independent with finite covariance and matrix and zero mean. The above matrixes yield a vector error correction model (VECM) in which all variables are assumed as endogenous variables.

We estimated the VECM employing Pooled Mean Group (PMG), Mean Group (MG) and Dynamic Fixed Effect (DFE) estimators. Based on PMG estimator results in Table 6, ICT did not appear as a significant factor explaining GDP growth in the EU countries over 1990-2011. However, the return to ICT (coefficient of ICT) in the EU (1.437 per cent) is quite high, while there is a significant long-run causality relationship running from ICT, L, non-ICT and TFP to GDP growth. In contrast to Hwan-Joo, et al.'s (2009) results on 29 countries, labour contribution has a causal relationship with economic growth and plays a key role in the growth process. ICT contribution does not have a strong interdependent relationship with economic growth in the period 1990-2011.

With respect to TFP, ICT has a negative and significant effect (-1.7473 per cent). A negative effect of ICT on TFP, coupled with slow TFP growth among these EU countries is in line with a large number of previous studies that investigated the EU productivity paradox (Stiroh, 2002; Dahl et al., 2011. Table 6 shows that the main short-run source of growth is non-ICT capital which has a positive and significant effect on GDP growth (2.241 per cent). Therefore countries will be able to capture higher GDP growth by continuing to invest in non-ICT industries.

Table 6: Panel causality test results, EU countries							
	Source of causation (independent variable)						
Dependent Variable	Short Run					Long Run	Estimation Method, Based on Hausman test
	ΔEG	ΔL	ΔICT	Δnon-ICT	ΔTFP	ECT	
ΔEG	-----	22,2106 -0,287	1,4379 -0,215	2.2419** -0,052	0.3738 (0.181)	-0.4511* -0,036	PMG
ΔL	-0,0136 -0,63	-------	-0,297 -0,26	-0.3514 (0.215)	-0.0198 (0.111)	-0.5209** -0,086	MG
ΔICT	-0.0192* -0,673	3.7241* -0,311	------	0,3071 -0,677	0.0551 (0.664)	-0,1439 -0,189	PMG
Δnon-ICT	-0.0335* -0,018	0.0235 (0.575)	-0,0168 -0,256	-------	0,0051 -0,838	-0.3332* 0	DFE
ΔTFP	0.4524* -0,003	-1,636 -0,131	-1.7473** (0.065)	-0.9525** (0.073)	--------	-0.3713* -0,016	PMG
Note: The reported values in parentheses are the p-values of the F-test. * indicates significant at 5% level, ** indicates significant at 10% level.							
Source: Authors							

Table 7: Panel industries causality direction in short-run and long-run, EU

Short run causality		*Long run causality*	
Direction of Causality	*Wald F-test*	*Direction of Causality*	*Wald F-test*
ΔEG No causality ΔL	(0.287)	EG ↔ L	(0.036)*
	(0.650)		(0.086)**
ΔEG No causality ΔICT	(0.215)	EG ← ICT	(0.036)*
	(0.673)		(0.189)
ΔEG ↔ Δnon-ICT	(0.052)**	EG ↔ non-ICT	(0.036)*
	(0.018)*		(0.000)*
ΔEG ← ΔTFP	(0.181)	EG ↔ TFP	(0.036)*
	(0.003)*		(0.016)*
ΔL No causality ΔICT	(0.260)	L ← ICT	(0.086)**
	(0.311)		(0.189)
ΔL No causality Δnon-ICT	(0.215)	L ↔ non-ICT	(0.086)**
	(0.575)		(0.000)*
ΔL No causality ΔTFP	(0.664)	L ↔ TFP	(0.086)**
	(0.151)		(0.016)*
ΔICT No causality Δnon-ICT	(0.677)	ICT → non-ICT	(0.189)
	(0.256)		(0.000)*
ΔICT → ΔTFP	(0.664)	ICT → TFP	(0.169)
	(0.055)**		(0.016)*
Δnon-ICT → ΔTFP	(0.858)	non-ICT ↔ TFP	(0.016)*
	(0.073)**		(0.000)*

Note: The reported values in parentheses are the p-values of the F-test.
* indicates significant at 5% level
** indicates significant at 10% level

Source: Authors

Table 7 shows no causal relationship between ICT capital and GDP growth in the short-run but in the long-run unidirectional causality flows from ICT to GDP growth, consistent with findings by Papaioannou (2007) and Yousefi (2011). Therefore, short-run ICT investment policies do not have any growth impact on these countries, but they will in the long-run.

Panel Long-run Relationship Using First-Difference GMM

To establish long-run relationships, new variables need to be added for two main reasons:

1. Due to the limitation on the number of variables for applying PMG, MG, and DFE estimators, it was not possible to employ more sophisticated models that would control for the impacts of other variables. The study, however, identified several factors that were strongly correlated with levels of ICT growth. In addition to GDP growth, these are education level, share of employment in the service sector and trend variables. It was also apparent from Table 6 that ICT contribution across countries is not strongly correlated with the level of GDP growth in long-run. Consequently, the impacts of the other important factors influencing GDP growth should be controlled by employing more related factors in model like education, innovation, and trade.
2. According to endogenous growth models innovation is a medium for technological spillovers that allow less developed countries to catch up with highly developed countries. At the same time, ICT capital seems to have characteristics of both forms of capital, traditional forms of capital as a production technology and knowledge capital in its informative nature (Dedrick et al., 2003). A critical feature of the debate over the existence of ICT spillover is whether the ICT capital stock may also boost economic growth through positive spillover effects on TFP, if ICT capital is like knowledge capital. The sources for TFP growth may be different over time and across countries, but technological change and innovation have been acknowledged as determinants of TFP growth and ICT has been considered as the major form of technological change in recent decades (Madden and Savage, 2000). Thus, if we added new variables which are related to spillover effects of ICT the statistical significance of the model should increase.

Moreover, GMM estimators are particularly useful for panel data with a relatively small time dimension (T), as compared to the number (N) of cross sections (Roodman, 2008). In contrast, as T becomes larger, the GMM estimator can produce inconsistent and misleading coefficient estimates unless the slope coefficients are identical across cross sections (Pesaran and Smith, 1995). We address the problem of the relatively large time dimension (T = 21, N = 6), by estimating separate regressions for the sub periods of 1990–2000 and 2001–2011. In this way, we will also be able to search for varying effects of ICT across time.

In this paper, first difference GMM developed by Arrelano and Bond (1991) is selected rather than system GMM. Since

Table 8: Results of GMM panel long-run estimators for European countries

Independent Variable	Dependent variable: EG Difference GMM Estimates,one step	
	1990-2000	2001-2011
L	1.8805*	0.8415*
	0	0
ICT	-0.9477*	1.2236*
	0	0
NON-ICT	-9.1465*	1.0359*
	0	-0,007
TFP	2.8129*	0.7356*
	0	0
ICT-IM	-3.1629*	1.1440*
	0	0
PTN	0.0034*	0.0209*
	0	0
PTR	-0.0126*	0.0024*
	0	0
TERIT	-0.1948*	-0.0459*
	0	-0,012
HT	1.5442*	-0.2856*
	0	-0,001
UPL	-3.006*	-0,2989
	0	-0,422
EXP	0.0710*	0.4223*
	-0,032	0
IMP	-0.7907*	-0.0439*
	0	-0,584
Obs	13	14
Countries	6	6
Wald test	545,23	25,69
Sragan test(p-value)[a]	0	0,008
Hansen test (p-value)[b]	1	1
Serial correlation test AR(1) (p-value)[c]	0,103	0,126
Serial correlation test AR(2) (p-value)[c]	0,103	0,096
Serial correlation test AR(3) (p-value)[d]	0,103	0,171

a.Sargan test is for evaluating overidentifying restrictions in Ivs.The null hypothesis is that the instuments used in the regression are valid.
b. Hansen test is for evaluating overidentifying restrictions in GMM. The null hypothesis is that the instuments used in the regression are exogenous.
c. d. The null hypothesis is that the error in the first-difference regression exhibit no first or second order serial corrolation.
The value is in parentheses denote significance level for rejection.
*Indicates that the parameters are significant at the 5% level.

Source: Authors

system GMM uses more instruments than first difference GMM, it may not be appropriate when only a small number of countries are studied (Mileva, 2007).

Arrelano and Bond (1991) GMM regressions are performed according to production function, after employing the heteroscedasticity robust one-step estimator, as set out in separate regressions for EU countries. Table 8 presents the estimation results separately for each decade (columns 1 and 2). In these columns, we wish to check for differential effects before and after 2000. Sichel and Oliner (2002) have estimated a higher ICT growth contribution in the US during 1996–1999 and we wish to test whether it holds for EU panels as well. From Table 8, it seems that the impact of employment of labor capital and TFP on EU countries' growth was highly positive and significant during the two periods, while, ICT and non-ICT capital seems to correlate with output growth positively only in the 2000s. Interestingly the positive effects of labor employment and TFP on economic growth have decreased dramatically in the second period.

The ICT impact in 2000-2011 rose significantly from a decade earlier, indicating a highly positive and significant association with output growth. In the 2000s, its effect increased substantially in magnitude and significance compared to 1990-2000. These results show that ICT should be able to play a significant role in improving growth among the EU countries by accelerating capital accumulation. The coefficient of ICT increased significantly from -0.94 the first period to 1.22 in the second period. In general, it seems that the ICT impact on the EU economies is not only from direct effects of ICT-capital but also indirectly through TFP growth by positive spillover effects. Thus, ICT was an engine of growth in the 2000s in the EU countries. The results here show that the impact of ICT on growth is felt later than what most other studies found.

Most other explanatory variables for controlling spillover effects of ICT are significant in the EU countries only during first period. For example, the coefficient of patent application for residents and non-residents, and school enrollment (PTN, PTR, TERIT) are statistically significant at the 5 per cent level. Therefore in these groups of countries, the patent application and school enrollments have been important factors explaining growth only during the 2000s.

Similar patterns are also observed for unemployment, ICT import and high-technology export and import goods and services (UPL, ICT-IM, HT, EXP, and IMP). HT, EXP, and IMP are significant whereas the unemployment rate has anegative insignificant impact on growth in the second period. ICT imports have a significant impact on GDP growth, negative in the first period and positive in the second. However, their estimates in the regressions in first period are more in line with what is expected. In short, spillover effects of ICT are greater during 1990-2000 than during 2001-2011.

As already discussed, the consistency of the GMM estimator is based on the validity of the instruments used in the GMM regression and the absence of second-order serial correlation in the error term. For this reason, Table 8 also reports the results of the Hansen J test and the second and third order serial correlation test. In all of the cases the Hansen J test fails to reject its null hypothesis that the instruments used in the regressions are valid. Furthermore, the test which examines for serial correlation fails to reject its null hypothesis, implying that the error term does not exhibit serial correlation in first and second order correlation.

Conclusion

Since the mid-1990s the ICT revolution has rapidly spread across nations and transformed the way people communicate, work, and live. At the core of this transformation is the quantum progress across countries in the speed, scope, intensity, and quality of access to information, knowledge diffusion, and communications. These powerful impacts are expected to have been translated into economic performance. This paper examines the hypothesis that ICT contribution has a positive effect on economic growth through both direct effects and spillover effects. On the econometric side, the paper presents two approaches to support this hypothesis.

The first approach is to determine the causal effect of ICT contribution to growth. PMG, MG and DFE estimators are used for dynamic panel data analysis. Results from this estimation show that there is unidirectional robust causality running from ICT contribution to economic growth in the EU countries in the long-run, confirming previous findings by Yousefi (2011); Vu (2011); Dimelis (2011) and Dahl et.al, (2011). Furthermore, ICT contribution did not have a robust short-run causality relationship with economic growth. The negative and statistically significant coefficient of ICT confirms the slow acceleration of TFP among the EU countries, already described as a productivity paradox by a large number of previous studies (Hall et al., 2012).

The second approach examines whether the association between ICT contribution and growth over 1990–2011 was significant, controlling for spillover effects of ICT via including other potential growth determinants such as education, innovation, and trade. The addition of variables related to spillover effects of ICT has increased the significance of the endogenous growth model specified at the aggregate level.

Three important findings from this are that: (i) the long-run relationship between growth and ICT contribution in the 2000s is higher, more significant and robust than in the 1990s; (ii) ICT's long-run relationship is negative and insignificant in the 1990s; (iii) TFP growth has significant and positive effects on GDP growth for the two sub-periods, with the magnitude higher for the first than for second period; and (iv) in terms of the long-run relationship between other controlling variables and growth, only the unemployment rate is not statistically significant, probably because it is has not varied much over the period of interest. Indeed, there seems to be still a productivity paradox in EU countries in line with findings of Broersma and Van Ark (2007) and Engelbrecht and Xayavong (2007).

These results have implications for the discourse on economic development in general. First, the prevailing arguments in favor of technological capacity-enabled growth has not taken into account short-term costs that may include reduced economic growth as shown by our results for the 1990-2000 periods. Such a strategy has also been silent on the distributional consequences of this growth strategy[1].

Second, introduction of policies and mechanisms that aids the education sector should be the main focus of investment from both non-government and government sectors. Additionally, regarding to negative coefficient of education variable government should play a proactive role in reforming the education sector with major investments to make it a key engine driving the economy towards a knowledge-based economy. Generous and extensive

[1] Although not covered by this paper, this is a subject receiving increasing attention in the US. See Cowen (2012) and Brynjolfsson and McAfee(2011).

support for ICT-related training should be provided by encouraging people to augment ICT skills and their understanding of ICT applications. Moreover, continuous learning should be consistently supported because new technologies and ICT continue to evolve at a fast pace.

Third, all countries need a strategic focus on promoting ICT penetration as an important source of growth. This promotion should not be confined only to upgrading the ICT infrastructure and reducing the costs of ICT use, but also on increasing the spillover effects of ICT penetration on growth. For this effort, investing in broadband infrastructure, reforming education system to better prepare people for the information age, and fostering Internet-enabled services and Internet presence, including e-government and e-commerce should be of top priorities. Encouraging competition among people is in line with the effectiveness and depth of ICT diffusion and controls their development of ICT over time.

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