Impact of information and communication technologies on productivity growth

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Abstract: In modern economy information and communication technologies (ICT) play the essential role. The improvement of ICT infrastructure, developing ICT knowledge and usage can lead to economic growth due to higher productivity. However, this impact can depend on countries' ICT investment or expenditure amount, reached ICT development and productivity levels. Moreover, ICT impact on productivity growth can occur after a certain period. Consequently, forming the ICT development strategies it is important to identify ICT impact period and impact differences between relatively high and low productivity countries. Authors examined the impact of ICT investments on productivity in EU countries covering the period of 1995–2015. Research results have revealed that ICT development positively and directly influences productivity, but this effect manifests with a lag in time. Moreover, it was found that the impact of ICT development on productivity is about twice bigger in countries with relatively high productivity level compared with countries that have relatively low productivity level.

Keywords: information and communication technologies; ICT; ICT investment; labour productivity; productivity growth.

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1 Introduction

One of the EU's, as a group of countries, economic problems is differences in productivity level, leading to unequal economic development. According to the data of World Bank, in 2015 productivity in the lowest EU productivity country – Romania – was 1.8 times lower than EU average and 2.7 times lower than in the highest productivity country – Ireland. This disbalance causes an increase in migration flows. This process is especially dangerous for low productivity countries, because large emigration causes demographic challenges (population aging), the outflow of human capital (brain drain), reduces the potential of economic growth and development of society welfare. Nevertheless, research (Maciulytė-Sniukienė, 2014) suggests that EU countries converge in terms of productivity, but this process started to slow down after 2010. Thus, it is necessary to search for sources of productivity growth, especially in low productivity countries. In the context of information society development, one of the sources of productivity growth can be information and communication technologies (ICT) development. Previous empirical studies (Roach, 1987, 1991; Loveman, 1988; Baily and Chakrabarti, 1988; Brynjolfsson, 1993; Brynjolfsson and Hitt, 1995, 1998; Stiroch, 2001; Pilat et al., 2002; Belorgey et al., 2006; Sobhani, 2008; Shapiro and Mathur, 2011; Vu, 2013; Maciulytė-Sniukienė, 2014; Mamun and Wickremassinghe, 2016; Chen et al., 2015; Savulescu, 2015; Hofman et al., 2016 and etc.) show that ICT impact on productivity and economic growth varies between countries. The unanimous results of retrospective studies could be due to the differences of productivity levels between countries. Moreover, the impact of ICT development on productivity can occur with the time lag, especially when ICT expenditures or investment in ICT indicators are used to proxy ICT development. Taking into account this premise, the *aim of this study* is to identify the impact of ICT development on productivity delay, and differences of this impact in countries with relatively low and high productivity. Seeking to achieve this aim in the second section we theoretically grounded the impact of ICT on country's productivity growth; in the third – presented research methodology and data; in the fourth – research results and interpretations.

2 Theoretical framework of ICT impact on country's productivity growth

At the theoretical level ICT impact on productivity and/or economic growth has been discussed by many authors. According to traditional Solow (1956) growth model capital deepening and growth of labour and technological progress are treated as the main sources of growth. This theory was adopted by many authors in order to justify the impact of ICT on economic growth dividing capital into ICT and non-ICT. Dedrick et al.

(2003) analysed around 50 empirical studies, which results were published in the period of 1985–2002. Evaluating limitations of the research they developed the conceptual system defining correlations between ICT and economic growth. The system shows that the inputs of ICT capital improvement in the production process happen/are possible due to:

1 capital deepening

2 technical progress

3 labour quality.

It rises value-added at micro, mezzo and macro level, and contributes to economic performance (economic growth, labour productivity, profitability and consumer welfare).

A similar approach is revealed in the article of Qiang et al. (2003). According to the authors, there are three channels for ICT to influence total factors productivity (TFP) and economics growth:

1 TFP growth in sector producing ICT

2 capital deeping

3 TFP growth through reorganisation and ICT usage.

The difference between Dedrick et al. (2003) and Qiang et al. (2003) models is that the Dedrick et al. (2003) model includes not only ICT capital but also non-ICT capital and labour impact on economic system outcomes at firm, industry and country level. Qiang et al. (2003) model reflects ICT impact on productivity through ICT producing and ICT using sector. Which model is more appropriate depends on research aims: whether it seeks to determine the impact of ICT decoupled from other factors, or in integrated system.

Hodrob and Awad (2016) discussing the impact of ICT on economy, emphasise ICT role on humans, governments and organisation changes through renovate information into knowledge and innovations as a key cause in increasing productivity and growth rate.

Summarising the theoretical approaches towards ICT impact on productivity and economic growth, it can be stated that ICT influenced productivity and economic growth mainly through three channels:

1 ICT producing sector

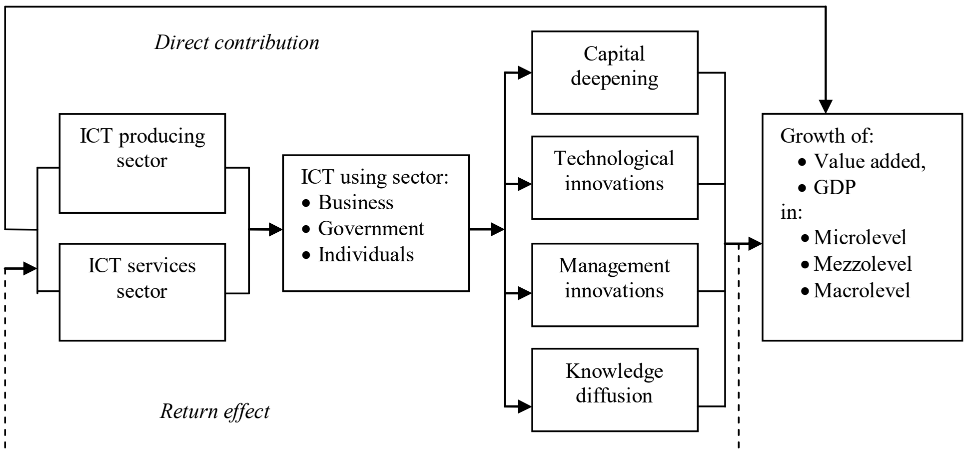
2 ICT service sector

3 ICT using sector.

We formed model of the ICT impact on productivity and economic growth involving those three channels (see Figure 1).

ICT sector is composed of ICT manufacturing and ICT services. Development of ICT production and ICT service sector directly contributes to value added and GDP sequentially at firm, industry and country levels. The model also shows that ICT using sector consists of three main components: business, government and individuals. All these common market participants, including ICT service business, use ICT equipment and intermediate products of ICT infrastructure and have indirect impact on productivity and economic growth through capital deepening; creation, implementation and development of technological and management innovations; and knowledge diffusion.

Figure 1 Model of ICT impact on productivity and economic growth



Source: Formed by authors

First of all, classical economic theory treats physical capital and capital-labour ratio as the main source for productivity growth. By purchasing ICT equipment enterprises accumulate capital and contribute to micro level productivity, what positive influences industry and macro level value added. Furthermore, enterprises usually purchase advanced information technologies (innovations), what saves the cost of production or services and increases productivity. In parallel, occurs an opportunity to implement new management innovations such as: customer relationship management (CRM) systems, local interconnect network (LIN) and etc. (Davidaviciene, 2008). It accelerates the enterprise's processes, increasing customer satisfaction and leads to growth of value added by increasing volume of sales and decreasing production costs. The implementation of technological and management innovations relates to knowledge diffusion because advanced technologies and software packages service require specific knowledge. These processes provide growth demand of new ICT technologies and services as follow return effect on ICT producing and service sector.

Governments using ICT innovations (technological and management) ensure faster delivery and better quality public service (including public health and education services). Furthermore, they improve the institutional environment. This leads to the improvement of business environment and economic growth.

Individuals using ICT technologies improve their knowledge level and it utilises in business and government.

Although from the theoretical point of view, ICT must be treated as one of the most important sources for productivity and economic growth, results of retrospective studies are mixed. According to Dedric et al. (2003) and Rangriz and Raja (2011), the first examinations of ICT impact on productivity were conducted by Roach (1987, 1991), Loveman (1988) and Baily and Chakrabarti (1988). Their research results have denied links between ICT development and productivity at micro, mezo and macro level. This so-called productivity paradox encouraged researchers to continue empirical studies of ICT impact on productivity. Later studies conducted by Brynjolfsson (1993), Brynjolfsson and Hitt (1995, 1998), Stiroch (2001), Pilat et al. (2002), Belorgey et al. (2004), Sobhani (2008), using higher scope of data and applying the advanced research methods found a positive and significant impact of ICT development on productivity at micro and macro level. However, studies carried out by other researchers show that ICT impact on productivity is controversial (see Table 1).

Table 1 Differences of ICT impact on productivity by previous studies

Type of the impact	*Impact level or direction*	*Source, date, scope and period*
ICT contribution to GDP	High contribution	Oulton (2001) – UK, 1989–1999, Qiang et al. (2003) – ten EU countries 1990–2000; Shapiro and Mathur (2011) – USA, 1991–2009, Pilat (2004) – 17 OECD countries, 1995–2002, Vu (2013) – 0 countries (from 50) in 1990–1995 and 22 (from 50) in 1995–2000, Savulescu (2015) – 18 EU countries in 2013
	Low contribution	Oulton (2001) – UK, 1973–1979 and 1979–1989, Qiang et al. (2003) – four EU countries 1990–2000, Pilat (2004) – 17 OECD countries, 1990–1995, Vu (2013) – 50 countries in 1990–1995 and 28 (from 50) in 1995–2000, Savulescu (2015) – 10 EU countries in 2013
ICT impact on productivity	Positive	Pilat et al. (2002) – USA and Australia, 1990–1995 and 1996–2000, Qiang et al. (2003) – six EU countries 1990–2000, Sobhani (2008) – Iran, 1997–2007, Belorgey et al. (2004) – 25 industrialised countries, 1991–2009, Hodrob and Awad (2016) – Qatar, 1995–2013
	Negative	Pilat et al. (2002) – 17 OECD (except USA and Australia), 1990–1995 and 1996–2000
	No impact	Khan and Santos (2002) – Canada, 1988–2000, Qiang et al. (2003) – eight EU countries 1990–2000, Acharya (2016) – 16 OECD countries, 24 industries for 32 years period

Source: Concluded by authors

As Maciulytė-Sniukienė and Gaile-Sarkane (2014) revealed, the identified impact by the research may depend on the country's ICT infrastructure literacy and usage level; amount of ICT production and international trade; and on the level of productivity. Furthermore, research results can depend on applied methods. Some authors, in order to evaluate ICT impact on productivity and economic growth, analyse the contribution of ICT manufacturing and service sectors to GDP. Naturally, if the country develops ICT production and service sector that have positive influence on the country's GDP, it is the main indicator of productivity and economic performance. There is only difference in the level of this contribution (see Table 1). In Table 1 we indicated two levels of ICT contribution to GDP: high and low, according to contribution average. Low contribution coefficient is up to 0.04 and high over 0.04.

Another possible cause of ICT impact differences on productivity is research period. Different effects of ICT development can occur in the short and long term. This was revealed by the recent studies (see Table 2).

Table 2 Main results of retrospective investigation of ICT impact on productivity

Authors	*Sample and period*	*Main research object*	*Main results*
Mamun and Wickremassinghe (2016)	South Asian countries, 1995–2012	Impact of diffusion of ICT on labour productivity	The results suggest that when the diffusion of ICT increases by 1%, labour productivity increases by about 0.09% in the long-run, and 0.11% in short-run.
Chen et al. (2015)	10 European countries, industry level, 1995–2007	ICT and intangible capital investment impact on labour productivity	Both intangible and ICT capital contributes to labour productivity growth, but greater impact leads to intangible capital deepening. Moreover, greater effect manifested when intangible capital is complemented by ICT investment.
Cette et al. (2015)	US, Canada, Euro zone, UK, 1970–2013	ICT diffusion and the contribution to GDP and labour productivity	After a long period of sustained growth, ICT diffusion has stabilised since 2000 in all four areas. In all four jurisdictions, the contribution of ICT to labour productivity growth rose significantly in 1994–2004 compared to 1974–1994. Since 2004, the contribution of ICT to labour productivity growth has fallen considerably.
Hanclova et al. (2015)	EU-14 and EU-7 countries, 1994–2000 and 2001–2008	ICT and non-ICT capital, labour and TFP productivity impact on economic growth	Both non-ICT and ICT capital positively affected EU-14 and EU-7 countries economic growth, but higher influence was established by non-ICT capital. Growth elasticity by ICT capital was higher in EU-7 group. Growth elasticity by non-ICT capital growth was higher in EU-14 group.
Shahiduzzaman et al. (2015)	Australia, 1965–2013	ICT capital deepening impact on labour productivity	ICT capital has significant positive impact on productivity in long-run, but lower comparing with non-ICT capital. In short-run results indicate negative effects of ICT capital and positive effects of non-ICT capital.
Skorupinska and Torrent-Sellens (2015)	21 Eastern European countries, 1993–2011	Impact ICT on productivity	ICT use and investment is ICT impact on productivity complementarities. Change of productivity sources during the years of crisis and significance of trade openness.

Source: Concluded by authors

Table 2 Main results of retrospective investigation of ICT impact on productivity (continued)

Authors	*Sample and period*	*Main research object*	*Main results*
Albiman and Sulong (2016)	45 Sub Sahara African (SSA) countries, 1990–2014	Long run impact of ICT on economic growth	Positive direct impact of ICT infrastructure development on economic growth was examined. The results indicated that (except for financial development) the human capital, institutional quality and domestic investment were the main growth enhancing transmission channels of ICTs use in the economy.
Erumban and Das, 2016	India, 1986–2011	ICT investment impact on productivity (labour and TFP) growth in ICT using and ICT producing sectors	ICT investment and non-ICT capital played an important role on India productivity growth, but effect varied by time (1986–1990; 1991–1995; 1996–2000; 2001–2005; 2006–2011). ICT contribution to productivity is growing, but non-ICT capital still determines the key role.
Hofman et al. (2016)	Latin America (18 countries at macro level and five in mezo), 1990–2013	ICT capital and ICT investment impact on GDP per capita, labour productivity, KLEMS	The role of ICT capital on labour productivity is very low comparing with non-ICT capital contribution. But analysis at sectoral level shows that ICT investment is one of the main sources of industry growth.
Kumar et al. (2016)	China, 1980–2013	Impact of five ICT indicators on output per worker (productivity)	All ICT indicators have a positive and statistically significant elasticity coefficient in long-run, but have negative or positive but not significant elasticity in short-run.

Source: Concluded by authors

Moreover, ICT impact on productivity can depend on ICT development measuring methods. Some authors proxy ICT development using ICT infrastructure indicators, ICT literacy indicators, ICT usage indicators and/or ICT investment or expenditure indicators. Therefore, it is important to select ICT development indicators that is in line with research aim.

3 Research methodology and data

Research methodology was developed assuming that the impact of ICT development on productivity:

1 depends on country’s productivity level

2 effect of this impact could occur with a time lag.

Above-mentioned assumptions determine steps of the research. In the first step EU member states (except Luxembourg and Croatia) were assigned to clusters characterised by relatively high (RHP) and relatively low (RLP) productivity. Referring to Everitt et al. (2001), for this assignment we used cluster analysis. We assigned countries in a way that differences in terms of productivity among them would be smaller within the cluster than between the clusters.

Table 3 EU member states by productivity level (results of cluster analysis)

RHP cluster	Ireland, Austria, Belgium, Denmark, Spain, Finland, France, UK, Italy, Netherlands, Sweden and Germany.
RLP cluster	Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Latvia, Lithuania, Poland, Malta, Portugal, Romania, Slovakia, Slovenia and Hungary.

In the second step, we aim to identify when, if any, the impact of ICT development on productivity occurs and for how long it lasts. Here we are testing the first hypothesis:

H1 Development of ICT positively affects productivity in countries with relatively low, as well as with relatively high level of productivity, but it takes time for this effect to occur.

In order to research the relationship between ICT development and productivity growth, we augment the standard Cobb-Douglas production function particularly focusing on ICT development: $F = AF(K/L, ICT, X)$, where A is technological progress; K/L is capital to labour ratio; ICT is development of ICT and X represents other sources of productivity growth, such as economic structure, openness, FDI, R&D and investment in human capital. The main difference between our augmented equation and the traditional Cobb-Douglas production function is the incorporation of ICT variable, as well as other variables that affect the productivity. This approach of augmentation is grounded and already widely used in the empirical literature, because, in reality, there are many factors that may affect productivity. Because of that, the traditional Cobb-Douglas production function, which mainly focuses on capital to labour ratio as an input, might be too plain.

Based on the augmented Cobb-Douglas production function explained above, our econometric equation for testing H1 can be specified as follows:

$$P_{it} = \beta_0 + \beta_1 P_{i,t-1} + \beta_2 KL_{i,t} + \beta_3 ICT_{i,t} + \beta_4 X_{i,t} + \eta_t + \mu_i + \varepsilon_{i,t} \quad (1)$$

where the subscripts i and t represent, respectively, country and time period; $P_{i,t}$ denotes productivity; $KL_{i,t}$ denotes capital to labour ratio; matrix X denotes a set of control variables. η_t and μ_i denote, respectively, the time and country-specific effects; and $\varepsilon_{i,t}$ is the error term. We are interested here in testing whether the marginal impact of ICT development on productivity growth, β_3, is statistically significant and positive.

Based on previous literature review and analysis of ICT level and its development in countries that are characterised by different productivity, as well as initial analysis of nexus between them, we formulate the second hypothesis:

H2 Higher, in magnitude, impact of ICT development on productivity occurs in countries with relatively low productivity level compared with countries that are characterised by relatively high productivity level.

In the *third step* we assume that ICT development has diminishing effect on productivity and development of ICT has little effect when productivity is already high. Rejecting our hypothesis would give evidence that development of ICT follows pattern of increasing return and bigger effect is observed where productivity is high, what potentially might lead to better use of ICT.

To test that, we explore the impact of ICT development on productivity growth through productivity level. Here we are testing hypothesis that the country's productivity level shapes the impact of ICT development on productivity growth. In order to achieve this, we include the interaction between the variables of ICT development and dummy variable that is equal to one if country belongs to relatively low productivity cluster in the equation and test the significance of the interacted coefficient. The regression to be estimated is the following:

$$P_{it} = \beta_0 + \beta_1 P_{i,t-1} + \beta_2 KL_{i,t} + \beta_3 ICT_{i,t} + \beta_4 X_{i,t} + \beta_5 ICT_{i,t} \cdot RLP_i + \eta_t + \mu_i + \varepsilon_{i,t} \quad (2)$$

where RLP_i is dummy variable equal to 1 if country's productivity level is relatively low.

A positive coefficient of interaction term, i.e., β_5 would indicate that ICT development is more efficient in promoting productivity growth in less productive countries.

Equations (1) and (2) are commonly used dynamic panel equations. Because the lag term of the dependent variable ($P_{i,t-1}$) might correlate with the error term (i.e., cov ($P_{i,t-1}$, $\varepsilon_{i,t}$) $\neq 0$), even if there is no autocorrelation in $\varepsilon_{i,t}$, the usual or restricted ordinary least squares estimation will be biased. Although μ_i, the country-specific effects, are excluded from the intra-group data, using deviations from individual means, the fixed effects estimator will be inconsistent if there still exists a correlation between $P_{i,t-1} - \overline{P_{i,t-1}}$ and $\varepsilon_{i,t-1} - \overline{\varepsilon_{i,t-1}}$. Generalised least squares estimator, using the random effects equation with quasi-demeaned variables, will also be biased if there exists correlation between $P_{i,t-1} - \theta \overline{P_{i,t-1}}$ and $\varepsilon_{i,t-1} - \theta \overline{\varepsilon_{i,t-1}}$. In our research to solve these problems for the estimation of the equations (1) and (2) we will employ the generalised method of moments (GMM) proposed by Arellano and Bond (1991). The GMM panel estimators allow us to fix the abovementioned problems of inconsistency and baseness using lags of right-hand side variables as instruments for themselves. As doing so, we can more robustly examine the impact of the exogenous ICT development on productivity growth.

According to the GMM technique, equations (1) and (2) must be differentiated, next, lagged observations of the first difference of the independent variables are used as instruments for estimation. The first difference equations can be expressed as follows:

$$\Delta P_{it} = \beta_0 + \beta_1 \Delta P_{i,t-1} + \beta_2 \Delta KL_{i,t} + \beta_3 \Delta ICT_{i,t} + \beta_4 \Delta X_{i,t} + \eta_t + \Delta\varepsilon_{i,t} \quad (3)$$

$$\Delta P_{it} = \beta_0 + \beta_1 \Delta P_{i,t-1} + \beta_2 \Delta KL_{i,t} + \beta_3 \Delta ICT_{i,t} + \beta_4 \Delta X_{i,t} + \beta_5 \Delta ICT_{i,t} \cdot RLP_i + \eta_t + \Delta\varepsilon_{i,t} \quad (4)$$

There are two commonly used types of GMM estimations: the one, discussed above, and the system GMM (sys-GMM) estimators. The first one is usually used under the assumptions that the idiosyncratic error term is not auto-correlated and the independent variables are weakly exogenous. But, as suggested by Alonso-Borrego and Arellano (1999) and Blundell and Bond (1998), the instruments available for the first-difference equation are weak when the independent variables are almost constant over time and that may lead to serious finite sample biases. To overcome that problem, Arellano and Bover (1995) proposed additional moment conditions for an equation expressed in levels. When combining equation in differences with equation in levels into one system, the estimators are called sys-GMM estimators. As Bond et al. (2001) and Hauk and Wacziarg (2009) pointed out, the sys-GMM estimators should be used for panel data regressions to estimate more consistent and efficient parameters. Based on the above considerations, the sys-GMM estimator is used to estimate equations (1) and (2).

To examine the overall validity of the sys-GMM estimation, following Arellano and Bond (1991) and Blundell and Bond (1998), two tests are to be carried out:

1 the Sargan test which tests the null hypothesis that the instruments are valid

2 the AR (2) test which tests null hypothesis that there is no second-order auto-correlation.

The sys-GMM estimation results are valid only after passing the above two tests.

Table 4 Definition of variables and data sources

Variable		*Definition*	*Source*
Dependent variable	P	Productivity growth rate, value added per employee growth (annual %)	World Bank
Core independent variables	ICTt	ICT development growth rate, total amount of investment in ICT (as % of GDP) annual growth	ECONSTAT, ITU
	ICTpc	ICT development growth rate, investment in ICT per capita growth (% annual)	
Control variables	KL	Capital to labour ratio, expenditures on gross capital formation per employee growth (% annual)	World Bank
	OPN	Trade openness (import plus export as % of GDP)	
	IND	Industry, value added (% of GDP)	
	SER	Services, value added (% of GDP)	
	FDI	FDI inflow stock per capita growth rate (% annual)	UNCTAD
	R&D	Investment in R&D per capita growth rate (% annual)	World Bank
	HK	Expenditures on health care per capita (% annual)	

In order to evaluate impact of ICT development on productivity, we should use variable that proxy investment in ICT. As Van Ark et al. (2003) state, country's ICT infrastructure, as well as an ability to use it should depend on investment in ICT. Investment in ICT as a proxy for development of country's ICT was also used by many authors: Mahmood and Mann (2000), Oliner and Sichel (2000), Oulton (2001), Colecchia and Schreyer (2002), Jorgenson et al. (2005), Zwick (2003) Crespi et al. (2007) Kamel et al. (2009), Spieza (2012), Khayyat et al. (2014) Miller and Atkinson (2014) and others. In our research, to ensure robustness of the estimated results, we will use two alternative proxies for ICT development: total amount of investment in ICT to GDP ratio and investment per capita.

To measure productivity we will use value added per employee.

The final samples used in the econometric analysis of this study include the panel data of 26 EU member states for the period of 1995–2015. The definition and the data sources of each of the regression variables in the econometric analysis of this study are shown in Table 4. The descriptive statistics of the variables are shown in Table 5.

Table 5 Summary statistics of the variables

Variable	*Definition*	*Observations*	*Mean*	*SD*	*Min*	*Max*
P	Value added per employee (USD)	536	45425	29091	2810	118350
	Growth rate (% annual)		5.52	10.20	–22.34	41.52
ICTt	Total amount of investment in ICT (as % of GDP)	534	0.91	0.82	0.04	6.81
	Growth rate (% annual)		11.34	72.84	–96.32	667.27
ICTpc	Investment in ICT per capita (USD)	534	190.77	252.19	1.69	2972.40
	Growth rate (% annual)		17.53	73.94	–96.03	738.44
KL	Expenditures on gross capital formation per employee (USD)	536	11171	7045	170	35142
	Growth rate (% annual)		5.76	16.15	–72.98	104.62
OPN	Trade openness (import plus export as % of GDP)	536	96.85	37.78	37.03	190.78
IND	Industry, value added (% of GDP)	536	29.30	5.89	12.70	51.00
SER	Services, value added (% of GDP)	536	67.13	7.05	36.00	84.60
FDI	FDI inflow stock per capita (USD)	535	11200	14543	36	89623
	Growth rate (% annual)		17.62	22.56	–34.99	174.65
R&D	Investment in R&D per capita (USD)	523	959.38	998.55	12.52	4235.00
	Growth rate (% annual)		8.49	14.58	–33.38	136.72
HC	Expenditures on health care per capita (USD)	536	1980	1581	53	6521
	Growth rate (% annual)		7.49	12.39	–32.93	56.94

4 Estimation results and discussion

As explained above, the sys-GMM estimation was used to estimate equations (1) and (2). The results in Table 6 and 7 show that the correlation between the current productivity level ($P_{i,t}$) and one-year lagged productivity ($P_{i,t-1}$) is positive and statistically significant. This finding strongly supports the suggestions of Lokshin et al. (2008), Niebel et al. (2017) and others, that the relationship between productivity and its sources should be investigated in a dynamic framework. It means that past country's productivity level should be considered an important factor to control the potential effects of unobserved historical background on current productivity level. This is in line with Wooldridge (2010), who suggests to include a lagged dependent variable as a proxy for omitted variables to account for historical factors that affect current changes in the dependent variable. This also implies that commonly used fixed or random effects estimators that ignore the dynamic nature of the relationship between productivity and its sources may be biased (Blundell and Bond, 2000).

Table 6 Estimation results of equation (1) for testing H1

	1	*2*	*3*	*4*
Const.	2.293***	2.318***	2.505***	2.554***
P (–1)	0.586***	0.583***	0.583***	0.568***
ICTpc	–0.001	–0.002	–0.005	–0.005
(–1)		0.001	–0.001	0.002
(–2)			0.007**	0.006**
(–3)				0.000
KL	0.177***	0.178***	0.177***	0.192***
OPN	–0.024***	–0.024***	–0.019***	–0.019***
IND	–0.082***	–0.083***	–0.102***	–0.097***
SER	–0.083*	–0.084*	–0.127	–0.133*
FDI	0.020***	0.020***	0.018***	0.014***
R&D	0.025***	0.025***	0.026***	0.023***
HC	0.123***	0.124***	0.123***	0.132***
N	500	499	475	451
AR(2) test	–1.550	–0.504	1.208	–0.037
p-value	0.121	0.614	0.227	0.971
Sargan test χ^2	66.044	29.571	65.389	13.291
p-value	0.345	0.673	0.670	0.891
	5	*6*	*7*	*8*
Const.	2.208***	2.206***	2.331***	2.365***
P (–1)	0.588***	0.592***	0.593***	0.581***
ICTt	–0.006	–0.008	–0.011	–0.011
(–1)		0.001	0.002	0.001
(–2)			0.006**	0.005**
(–3)				–0.001
KL	0.178***	0.176***	0.173***	0.187***
OPN	–0.024***	–0.024***	–0.019***	–0.019***
IND	–0.076***	–0.077***	–0.90***	–0.084***
SER	–0.069	–0.072	–0.103*	–0.109*
FDI	0.020***	0.020***	0.018***	0.014***
R&D	0.024***	0.024***	0.025***	0.022***
HC	0.119***	0.118***	0.119***	0.126***
N	500	499	475	451
AR(2) test	0.724	0.393	–1.490	0.907
p-value	0.469	0.695	0.128	0.364
Sargan test χ^2	27.281	32.846	45.465	72.413
p-value	0.715	0.802	0.740	0.220

Notes: All equations estimated using dynamic panel model and 1-step sys-GMM including equations in levels with variables in log form. All estimations include time dummies. Robust (Windmeijer-corrected) standard errors were used. *Indicates significance at the 10% level. **Indicates significance at the 5% level. ***Indicates significance at the 1% level.

Table 7 Estimation results of equation (2) for testing H2

	9		*10*
Const.	2.320***	Const.	2.557***
P(–1)	0.582***	P(–1)	0.581***
ICTpc (–2)	0.014***	ICTt (–2)	0.013***
ICTpc (–2)•RLP	–0.008**	ICTt (–2)•RLP	–0.007**
KL	0.183***	KL	0.180***
OPN	–0.019***	OPN	–0.020***
IND	–0.090***	IND	–0.102***
SER	–0.100*	SER	–0.140*
FDI	0.017***	FDI	0.016***
R&D	0.020**	R&D	0.023***
HC	0.124***	HC	0.128***
N	475	N	475
AR(2) test	–1.504	AR(2) test	0.233
p-value	0.133	p-value	0.816
Sargan test χ^2	53.522	Sargan test χ^2	42.670
p-value	0.091	p-value	0.184

Notes: All equations estimated using dynamic panel model and 1-step sys-GMM including equations in levels with variables in log form. All estimations include time dummies. Robust (Windmeijer-corrected) standard errors were used. *Indicates significance at the 10% level. **Indicates significance at the 5% level. ***Indicates significance at the 1% level.

Estimation results in Table 6 are used to examine when ICT development has an impact, if any, on productivity. Estimations [1] – [4] correspond to estimations [5] – [8]. The only difference between them is the variable used to proxy ICT development. Estimations [1] and [5] examine the impact of ICT development on productivity during current period, while others include lagged effects of ICT development up to one, two and three years to examine that it takes time, respectively, for this effect on productivity to occur.

Estimation results are in line to proof our first hypothesis, because we observed that investment in ICT, i.e., ICT development has an effect on productivity after two years. It is not surprising, that it takes time for investment in infrastructure to transit into higher productivity (see estimations [3] and [7] in Table 6). What is surprising here that ICT development has no long-run effect on productivity, i.e., we do not observe additional increase in productivity during the following years (see estimations [4] and [8] in Table 6). Our results regarding effect in long-run are in contrast with results of Shahiduzzaman et al. (2015) and Kumar et al. (2016).

In consistence with earlier studies on productivity growth, we also find that higher capital to labour ratio, investment in research and development, inflows of foreign direct investment and human capital positively correlate with productivity. Openness of the economy and relatively bigger industry sector negatively affect productivity growth, whereas size of service sector does not significantly correlate with productivity.

Estimation results provided in Table 7 can be used for testing our second hypothesis. We interacted ICTpc (–2) and ICTt (–2) with dummy variable RLP to compare impact of

ICT development on productivity in countries with relatively low productivity level with impact in countries with relatively high productivity level (see estimations [9] and [10] in Table 4). In case of both estimations we clearly see that impact of ICT development on productivity is about two times bigger in countries with relatively high productivity level compared with countries that have relatively low productivity level. This evidence contradicts to our hypothesis and is in line with a view that investment in ICT has higher return and bigger effect where productivity is high. This allows us to claim that high level of ICT infrastructure, usage and literacy in the countries with high productivity increase the potential of ICT development as a source of productivity, i.e., this potential has not been exhausted yet. Our estimations using International Telecommunication Union (ITU) data (ITU, 2016) shows that low productivity countries have reached a high ICT infrastructure, usage and ICT skills level. We estimated that in 2015 mobile-cellular subscriptions per 100 inhabitants in low productivity countries were on average 123.5, while in high productivity countries – 124.1, i.e., very similar. Meanwhile, the level of ICT investment in high productivity countries was much higher. It can be noted that the differences of ICT skills indicators between low and high productivity countries are also small. Average of gross enrolment ratio (tertiary) in low productivity countries in 2015 was 67.3 while in high productivity countries – 72.5. Mean years of schooling in low productivity countries was 11.5 and in high productivity countries – 11.6.

5 Conclusions

According to theoretical approaches and previous research, the development of ICT directly contributes to countries' value added and GDP through ICT manufacturing and ICT service sectors and thus the growth of ICT sector leads to country's economic growth.

The development of ICT and its usage by business, governments and individuals can influence productivity and economic growth mainly through four channels: capital deepening, implementation of technological innovations, implementation of management innovations and knowledge diffusion sequentially at firm, industry and country levels.

Although from the theoretical point of view, ICT must be treated as one of the most important productivity and economic growth sources, retrospective studies of ICT impact on productivity are not unambiguous. Research results can depend on country's productivity and ICT development level, indicator used to proxy ICT development and methods applied, as well as research period. Different effects of ICT development can occur in the short and over the long run.

Results of examining the impact of ICT development on EU member states productivity revealed positive and significant impact of investment in ICT, but this effect occurs with a two years lag. It was also found that impact of ICT development on productivity is about two times bigger in countries with relatively high productivity level compared with countries that have relatively low productivity level. This allow us to claim that high levels of ICT infrastructure, usage and literacy in high productivity countries have bigger potential to use ICT development as a source of the productivity growth, i.e., this potential has not been exhausted yet.

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