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The Role of ICT in the Productivity of Central and Eastern European Countries: Cross-country Comparison [1]

El papel de las TIC en la productividad de los países del centro y este de Europa (CEE): comparación internacional

Aleksandra Skorupinska
Universitat Oberta de Catalunya (UOC)
askorupinska@uoc.edu

Joan Torrent-Sellens
Universitat Oberta de Catalunya (UOC)
jtorrent@uoc.edu

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Abstract

This paper analyses stage of transition to knowledge economy in CEE countries and reveals a considerable gap between CEE and EU countries in human capital level, infrastructure, innovation capacity and quality of institutions. Results of a panel data model for 21 countries over the period of 1993-2011 confirm the importance of complementarities to ICT use and investment in explaining productivity levels. Another conclusion is a change of productivity sources during the years of crisis and significance of trade openness. Analysis of this area bridges the gap of insufficient academic research about CEE countries and enriches the existing research on ICT usage and its impact.

Keywords: Information and Communication Technologies (ICT); Co-innovation; Aggregate Productivity; Labour Productivity; Cross-country analysis.

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Resumen

El trabajo analiza el proceso de transición hacia la economía del conocimiento en los países del Centro y Este de Europa (CEE). La investigación revela una considerable brecha entre los países de la CEE y la UE en su nivel del capital humano, infraestructuras, capacidad de innovación y calidad de las instituciones. Los resultados del modelo de panel para los 21 países de la muestra en el período 1993-2011 confirman la importancia de las complementariedades de la inversión y los usos de las TIC en la explicación de los niveles de productividad. Otro resultado importante obtenido es el cambio de las fuentes de la productividad durante los recientes años de crisis económica y la creciente importancia de la apertura internacional. El análisis realizado mejora el conocimiento sobre las fuentes de productividad en los países CEE y amplía las investigaciones existentes sobre el uso de las TIC y su impacto económico.

Palabras clave: Tecnologías de la Información y la Comunicación (TIC); Coinnovación; Productividad agregada; Productividad del Trabajo; Análisis internacional.

Clasificación JEL: J24, O33, O47.

1. Introduction

The widespread use of Information and Communication Technologies (ICT) is one of the main distinguishing features of today's economic activity (Jovanovic and Rousseau, 2005; Jorgenson and Vu, 2007). The reason for this is twofold: first, their direct contribution to increased productivity and economic growth (Sainz *et al.*, 2005) and second, their indirect contribution resulting from the generation of complementary innovations that improve economy's Total Factor Productivity (TFP) (Pilat, 2006; Jorgenson *et al.*, 2011). From the perspective of the impact analysis of ICT investment on aggregate productivity and economic growth, empirical evidence shows that: 1) the rates of return on digital investment are relatively much higher than those on investment in other physical components; 2) the reason for this is that digital investment and use often go hand in hand with other endeavours, usually human capital improvement and organisational and institutional change (Bresnahan *et al.*, 2002; Arvanitis, 2005). Indeed, the transformative impact of digital investment and use on the productivity and economic growth becomes more evident through co-innovation processes. The transition countries of Central and Eastern Europe (CEE) face considerable challenges in adapting their economies to compete effectively in regional and global markets. It is a key issue to find a path to increase their productivity, adapt the structure of their economy to global-knowledge competition, to promote co-innovation and develop new goods and services that respond to changing domestic and international demand. Thus, the impact of digital technological change and their co-innovation processes on productivity is an important aspect for the region's economic performance.

Main motivation behind this study is to evaluate what is the stage of transition of Central and Eastern European countries (CEE) towards a knowledge economy from the perspective of ICT relation to complementary productivity sources. The main questions behind this study are: 1) What is the stage of transition of CEE towards a knowledge economy? 2) What is the role of complementarities to ICT investment in productivity growth in CEE?

2. Literature Review

Much effort was put into research to understand the so called Solow Paradox concerning the limited evidence of a positive productivity impact of the ICT (Jorgenson and Stiroh, 1999). The importance of ICT is a much debated question with extensive literature focused on explaining and understanding their

role in economic growth, productivity and efficiency. Significant progress has been noted since 1990 in the analysis of ICT and productivity. Most empirical studies have been performed at the microeconomic firm and industry level examining their relationship with economic growth and productivity. At macroeconomic level fewer studies have been conducted because of a shortage of datasets related especially to ICT investment and usage and other relevant national characteristics.

Research conducted by Colecchia and Schreyer (2002) compares the contribution of ICT capital to economic growth in nine OECD countries up until year 2000. Time periods are different between countries depending on data availability. They present results based on the analysis of official statistics covering ICT investment in equipment, including software as ICT asset, and the role played by ICT in overall capital accumulation. There is evidence that driving forces of growth derived from ICT require particular frame to give larger benefits. Their conclusions are that despite the fact that ICT investments in every country have been increasing, significant differences still remain between particular countries. Other conclusion is a remarkable productivity acceleration in the US since 1990s related to ICT use and investment, which affirmed previous studies (Oliner and Sichel, 2000; Jorgenson and Stiroh, 2000). However, no similar acceleration has been demonstrated in Europe, as confirmed by further research (Van Ark *et al.*, 2008).

The following study of Jorgenson and Vu (2010) analyses the impact of ICT equipment and software on the resurgence of world economic growth in 122 economies, distinguishing seven regions and 14 major world economies, analysing the time period of 1989-2008. They contributed to previous research, showing that contributions of the ICT investment to productivity have increased in all regions, but especially in the industrialized economies and the Developing Asia which followed the trends similar of those of the developed countries. Countries from Eastern Europe experienced a steep decline in output during 1989-1995 after the transition from socialism to market economy. During 1995-2000 the output of Eastern Europe began to rise, while both capital and labour inputs declined and productivity rose.

The transition of Central and Eastern European economies is a recent phenomenon. Those countries have much less experience in evaluating the effect of ICT. Publications on ICT in most transition economies are sparse. Following Roztocki and Weistroffer (2008) there are several explanations of this scarcity of published research. Firstly, lack of funding for this type of research. Much of the published research dealing with ICT in transition economies has therefore been carried out by researchers employed at institutions in developed countries. Secondly, in the communist period research was directed to other disciplines than ICT, such as physics and chemistry. Moreover, the effect of many administrative structures and procedures that were instituted in the past still remain. Furthermore, reforms have been concentrated on economic changes rather than academics, with existing structures at many higher universities still inhibiting research productivity.

First publications concerning Central and Eastern European countries evaluated the impact of ICT on growth at the aggregate level. Van Ark and Piatkowski (2004) compare productivity performance of CEE-10 and EU-15 countries during 1990s examining productivity and income convergence hypothesis. Their investigation gives more support to the convergence hypothesis. Besides, they show that ICT capital in the CEE countries has contributed as much to labour productivity growth as in the EU-15 countries and that ICT capital depending on itself has not been an important source of convergence. They emphasize the importance of consistent progress in economic, institutional and regulatory environment, the creation of modern institutions, implementation of market oriented policy reforms, increase in innovation and improvements in the quality of human capital.

Most of the firm-level studies were focused on highly-developed countries. The empirical study for the Unites States (Bresnahan *et al.*, 2002) formulated and confirmed new theory of skill-biased technical change. The authors have shown the evidence of positive correlation of ICT use and investment, workplace organization and skilled labour which have affected productivity. Moreover, it concluded that with growing spread and access to ICT, the investment in complementarities is crucial, particularly in skilled labour. Furthermore taking the Unites States into consideration, there are studies from Black and Lynch (2001; 2004) showing that productivity growth during 1990s has a source in workplace organization changes and innovations (employee involvement, team work, incentive pay and decision-making autonomy) along with diffusion of computers.

Investigations conducted in other countries followed the path of analysis initiated in the Unites States. Analysis of panel data from for British and French firms (Caroli and Van Reenen, 2001) revealed that skilled workers adapt more easily to changes in organization. Having the above in mind, the authors presented empirical evidence of relationship between workplace innovation and human capital, and its influence on productivity. Another comparative study of Swiss and Greek firms (Arvanitis and Loukis, 2009) shows positive effects of physical capital, ICT, human capital and new organizational practices on labour productivity. However, Swiss firms are more efficient in combining and implementing those factors, while in the Greeks firms physical capital still plays crucial role in relation to labour productivity. Research for the Catalan firms (Torrent-Sellens and Ficapal-Cusi, 2010) confirmed role of new co-innovative sources in technology and knowledge-intensive firms. Among the remaining 80% of firms no evidence was found to show any impact of those sources.

There are some pioneers as Stare *et al.* (2006) who explored a link between ICT and the performance of service firms in Slovenia. They confirmed positive impact of ICT use on productivity, however due to absence of data on complementary expenditures for training and organizational change the results might overestimate the impact of ICT.

Table 1 summarises the main results for a broad set of studies. Most of international empirical evidence has confirmed the complementarities of new

co-innovative firm productivity sources: ICT investment and usage, human capital and new forms of work organization, however more empirical studies are still needed in this field.

TABLE 1. LITERATURE REVIEW SUMMARY

Authors	Region	Time period	Key results
Macroeconomic literature			
Oliner & Sichel (2000)	United States	1972-1999	ICT capital is 1.1% of the 4.8% output growth rate during 1996-1999.
Jorgenson & Stiroh (2000)	United States	1959-1999	Remarkable productivity acceleration in US during 1990s due to ICT.
Colecchia & Schreyer (2002)	9 OECD countries	Different time periods, till 2000	Significant differences between countries. Requirement of particular frame to take advantage from ICT. Productivity acceleration in US during 1990s.
Van Ark & Piatkowski (2004)	CEE-10 & EU-15	1989-2002	Support of convergence hypothesis. Emphasis on complementarities to ICT investment.
Van Ark & O'Mahoney & Timmer (2008)	EU-15	1950-2006	European productivity slowdown as a result of slower emergence of knowledge economy.
Jorgenson & Vu (2010)	122 countries	1989-2003	ICT investment as the most important source of growth. Eastern Europe growth decline after transition and recovery from 1995.
Microeconomic (firm-level) literature			
Caroli & Van Reenen (2001)	United Kingdom & France	1984,1990, 1992, 1996	Skilled workers more easily adapt to changes in organization. Evidence of relationship between workplace innovation and human capital and their influence on productivity.
Bresnahan & Brynjolfsson & Hitt (2002)	Unites States	1987-1994	Positive correlation of ICT, workplace organization and skilled labour which have affected productivity.
Black & Lynch (2004)	Unites States	1987-1993, 1997	ICT together with workplace organization have significant and positive impact on productivity.
Stare & Jaklic & Kotnik (2006)	Slovenia	1996-2002	Positive impact of ICT use on productivity.
Arvanitis & Loukis (2009)	Switzerland & Greece	2005	Positive effects of physical capital, ICT, human capital and new organizational practices on labour productivity.
Torrent-Sellens & Ficapal (2010)	Spain (Catalonia)	2003	No relevant impact of ICT use in 80 % of firms. Significant delay in the implementation of co-innovative productivity sources in Catalonia.

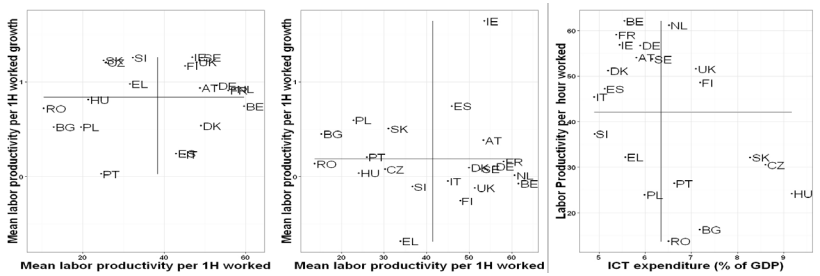
Source: Own elaboration.

3. ICT Complementarities

Initial development conditions matter for transformation to knowledge economy. It is because when one country is better developed than another, it has higher chances for taking advantage of the innovation and technological spillovers.

Comparing levels of productivity from 1993 and 2011 CEE countries experienced strong productivity improvement. Romania and Slovak Republic gained most and doubled initial productivity levels. Juxtaposition of Figures 1a and 1b shows significant slowdown in productivity growth after the economic crisis and then following years of recession.

Figure 1. Labour productivity and ICT expenditure in European Countries in 2000-2011



Note: (a) and (b) relation between labour productivity growth and labour productivity between 2000-2006 and 2007-2011; (c) ICT expenditure as % of GDP.

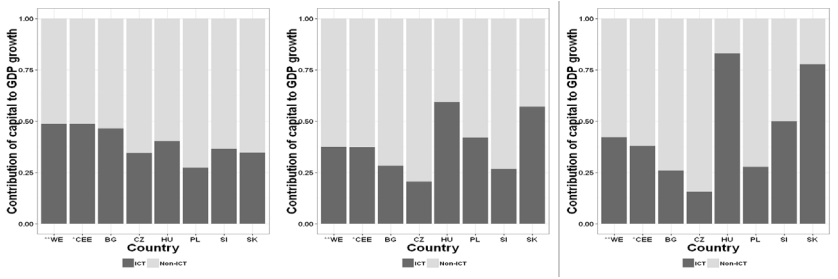
Source: Own elaboration. Data for (a) and (b) are from Total Economy Database, and (c) from WITSA.

Mean labour productivity growth for recession period after the crisis in 2007 is above average in Poland, Bulgaria, Czech and Slovak Republic. However, productivity levels in all CEE countries are still much lower than in other European economies. Apart from CEE only Portugal and Greece stay below EU average. The productivity patterns in CEE countries resemble those of advanced market economies and are mainly driven by efficiency gains within individual firms. Rapid microeconomic progress in adoption of ICT innovations proves the potential of technological revolution for transition countries (Van Ark and Piatkowski, 2004). CEE countries have been steadily increasing share of ICT expenditure to GDP. In 2003 the mean for those countries exceeded average spending of remaining countries. In 2011 CEE (except Poland and Slovenia) spent more than average (Figure 1c). Czech Republic, Hungary and Slovak Republic invested more than 8% of GDP in ICT.

Figure 2 shows that in 1990s the contribution of ICT to GDP growth was below EU-14 level and exceeded EU-14 level in the period of 2007-2011. This relatively high contribution from ICT capital in CEE countries is due to a rapid

acceleration in real quality-adjusted ICT investments (Van Ark and Piatkowski, 2004). Moreover, falling prices of ICT products and services encouraged firms to substitute Non-ICT for ICT capital. CEE countries under the socialist system suffered from restrictions on imports of technology and the level of ICT investment was low. There was large demand for ICT infrastructure catch-up.

FIGURE 2. CONTRIBUTION OF ICT AND NON-ICT CAPITAL SERVICES TO GDP GROWTH IN CENTRAL AND EASTERN EUROPEAN COUNTRIES BETWEEN 1993-2011



(a) 1993-1999 (b) 2000-2007 (c) 2008-2011

Note: Romania was excluded from analysis because of negative contribution values.
Source: Own elaboration. Data are from Total Economy Database.

Despite considerable improvement, it seems that much more time is needed for microeconomic progress to make a tangible impact on people's well-being. Nowadays, when transition is over, productivity improvements should be searched in the knowledge economy components: ICT usage and knowledge, human capital development, workplace organization and research and innovation (Bresnahan *et al.*, 2002; Arvanitis and Loukis, 2009).

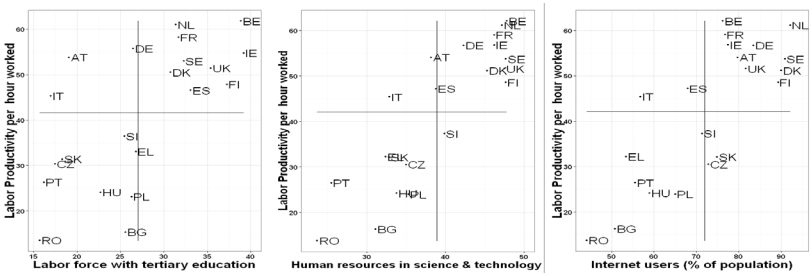
3.1. ADAPTIVE CAPACITY OF TECHNOLOGY: HUMAN CAPITAL AND WORKPLACE ORGANIZATION

Presently the importance of human capital is much higher in knowledge economy than in industrial economy. Better quality human capital can help countries to develop their technologies as well as increase country's ability to absorb high technology knowledge from abroad (Pohjola, 2000; Caselli and Coleman, 2001). Countries with greater human capital innovate more. Education acquisition, especially tertiary education, provides higher level knowledge and skills which is the key to technology use and support within organizations (firms, governments, schools). Moreover, human resources in science and technology are one of the key resources for economic growth, competitiveness, and more general social, economic and environmental improvement.

Human capital derived from university education, but also from training and accumulated through learning by action, can increase the efficiency of labour and also enhance TFP (Black and Lynch, 2001; Arvanitis, 2005). Moreover, the human resource management inside companies, organizations and institutions is an important factor in knowledge economy and one of determining elements, which enable the increase of competitiveness and improve the individual and aggregated productivity (Brynjolfsson and Hitt, 2003). Increased availability of digital equipment and more advanced ICT usage development require an increase of competences from the workforce. Workers need to be better educated and qualified, with initiative and innovative abilities, high work capacity and technical knowledge. Therefore, the crucial areas of development are continuous training and learning processes, more extensive professional and on the job training for directors, managers and workers. Moreover, the additional courses and training will bring an improvement of the quality of human capital and develop new ICT competences and skills. It is important at the board of directors level to be innovative, flexible and open for the new rapidly changing economic environment. Entrepreneurs should use their accumulated knowledge and learn how to take advantages from flows of information and knowledge. Crucial aspects are reformulation of the organizational architecture and new forms of work organization. ICT implementation brings innovation to the work place, changes of distribution channels and production processes. To take advantage from the opportunities offered by ICT it is important to change the organization structure and adapt working processes. The other important human factor are actions, which increase workers' commitment and motivate them to be more efficient and productive, such as decrease in hierarchical structures, increased autonomy and decision making capacity, working time flexibility or innovative remuneration strategies (Caroli and Van Reenen, 2001). One of the characteristics of organizational change is greater flow of communication, sharing and exchange of information between workers.

One of the indicators of human capital is the share of labour force with tertiary education (Figure 3a). CEE countries lag behind most of Western European (WE) countries, but apart from that there is a visible divide within those countries. In this region there is a relative shortage of engineers and well qualified workers (Figure 3b), which slows down economic growth. This is connected to shortcomings in education system and emigration of skilled-workers (Alam *et al.*, 2008). In addition, one of the main information society indicators (Dewan *et al.*, 2010): level of internet usage, shows a significant gap between most advanced European countries and CEE (Figure 3c). Regarding CEE, ICT-skill oriented education level is not sufficient. Moreover, inhabitants of CEE countries should change their attitudes toward the adoption of technology. Young people will adopt technology faster, however similarly to the rest of Europe, society is ageing which can further hinder the progress.

FIGURE 3. ADAPTIVE CAPACITY OF TECHNOLOGY AND LABOUR PRODUCTIVITY IN EUROPEAN COUNTRIES IN 2010-2011



a) Education 2010 (b) HRST 2011 (c) Internet 2011

Source: Own elaboration. Data for (a) and (c) are from World Bank, and (b) from Eurostat.

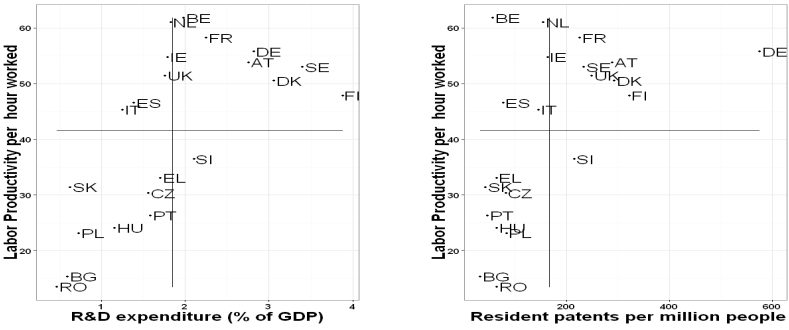
3.2. KNOWLEDGE, TECHNOLOGY CREATION AND INNOVATION CAPABILITY

Nowadays, knowledge is the resource and the commodity of knowledge economy, which explains the progress in productivity (Castells, 2011). The knowledge generation is a dynamic process created on the basis of interactions between individuals, groups, organizations and societies (Torrent-Sellens, 2009). Regarding knowledge, it seems important to emphasize a distinction between information and knowledge. The knowledge arises from interpreting and rethinking information. Economic activity covers four types of knowledge: know-what, know-why, know-how and know-who (Lundvall and Johnson, 1994). First two types of knowledge are called observable knowledge and are easily reproducible. Know-what refers to a knowledge about facts, in this sense knowledge is synonymous with information, for example hardware, software and telecommunications. Know-why refers to scientific knowledge and it is very important for technological development, for example scientific knowledge, patents, research and development (R&D). The other two types of knowledge are called tactical knowledge and can be mainly gained from practical experience. Know-how can be characterized as a combination of skills and talents, precisely development of person's capabilities, abilities and attitudes. It can be obtained mainly from education and professional development. An example can be found in digital competences or Internet job sites. Lastly, know-who refers to the concept of knowledge networks and how to use them, for example business and social network. Intensive use of ICT has resulted in an increase in supply of observable knowledge and also the transformation of tactical knowledge into observable knowledge. Moreover, ICT usage increased the know-how knowledge by development of new abilities within the workforce. Knowledge gained new attributes: ease of transmission and became a commodity, which can be traded and exchanged on the markets.

There is empirical evidence that investment in research, development and innovation affects TFP (Jorgenson and Vu, 2005). Domestic research and development is needed for understanding and absorption of knowledge developed internationality, for improvement of local R&D skills and active participation in international R&D networks. Countries where ease business arrangements and quality of tertiary education are relatively high tend to benefit more from R&D efforts and from international R&D spillovers. Profitable application of the newly created knowledge is crucial. In addition, strong patent protection is associated with higher levels of total factor productivity. Patents can be used as a measure of the output of innovation.

Figures 4a and 4b express innovation factors: R&D expenditure share to GDP and resident patents per million people. In both cases these indicators of innovation for CEE countries are below whole sample average. Only Slovenia situates above average and is an innovation leader in CEE region. This gap is another legacy of the communism. Under the centrally planned economic system there were no incentives to innovate. Flow of the knowledge between science and industry is weak and there are difficulties in diffusion of existing results to business use. It is mostly due to the heritage of socialist times when all applications of R&D were controlled by state and due to insufficient financial support.

Figure 4. Technology creation and labour productivity in European countries in 2010



(a) R&D 2010 (b) Patents 2010

Source: Own elaboration. Data for (a) are from UNESCO, and (b) from World Bank.

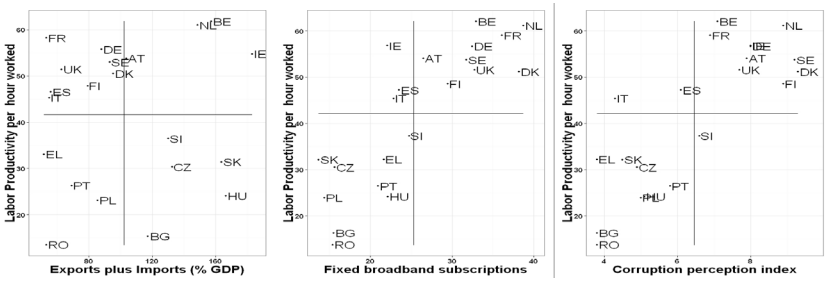
3.3. Institutions

The quality of institutions explains differences across countries in productivity and economic growth to a large extent. Institutions are deeply rooted in the social, political, ethical, economical and cultural processes of a particular country and place constraints on social interaction (North, 1990; Rodrik *et al.*, 2004).

Level of institutional infrastructure depends on many factors such as quality of regulations and contract enforcement, infrastructure, trade openness, development of financial markets, R&D spending, quality of human capital, labour and product market flexibility, entrepreneurship, macroeconomic stability, political freedom, stability and culture (Piatkowski, 2002). Trade openness and quality of infrastructure are especially important for technology diffusion.

The liberalized exports and imports are positively influencing productivity and economic growth. It is particularly important for diffusion of knowledge and innovation. Open borders allow for international spillover effect, contribution to economic growth in developing countries and enhancement of their catching-up process through adaptation of advanced foreign technologies. Moreover, under an open trade regime there is greater competition and hence a greater incentive to invest in R&D and innovation in order to remain competitive. Openness to import makes different varieties of capital goods more accessible, which increase efficiency (Caselli and Coleman, 2001; Barro and Sala-i-Martin, 2004). In the examination of trade openness (Figure 5a) 5 CEE countries (except Romania and Poland) have a sum of exports and imports share in GDP above average. This is a positive indicator, however those economies have modest share in European trade.

FIGURE 5. INSTITUTIONAL DIMENSIONS AND LABOUR PRODUCTIVITY IN EUROPEAN COUNTRIES IN 2010-2011



(a) Openness 2010 (b) Broadband 2011 (c) CPI 2011

Source: Own elaboration. Data for (a) and (b) are from World Bank, and (c) from Transparency International.

Infrastructure improvement is required to benefit from network effect as one needs to exceed certain point in development of the network. Communications and Internet infrastructure are wonders of the new economy facilitating rapid catch-up with developed countries (Kauffman and Techatassanasoontorn, 2009). Transition economies made a big step in upgrading their networks. For example the number of cellular phones is similar between all EU countries. However, CEE countries lag behind in quality of telecommunication infrastruc-

tures. In Bulgaria, Czech Republic, Poland, Romania and Slovakia an average of less than 15% of inhabitants have high-speed Internet access which is about 50% less than in Scandinavian countries (Figure 5b).

Lastly, economic environment is negatively affected by corruption. In particular, the impact of bribery for individual firms appears to vary depending on overall institutional quality. In countries where corruption is more prevalent and the legal framework is weaker, bribery is more harmful for firm-level productivity (De Rosa *et al.*, 2010). Figure 5c compares Corruption Perception Index which is a complex measure that captures opinions about economic environment as expressed by analysts, businesspeople and experts. CEE and Mediterranean countries have high perceived corruption level which also has negative influence on economic performance.

4. Empirical Model

4.1. Methodology

Methodology is based in well-established growth and productivity measurement approach, based on Solow growth model (Solow, 1957) and its extension by Jorgenson and Griliches (1967). Aggregate production function takes form:

$$Y_{ti} = A_{ti} K_{ti}^{\alpha} L_{ti}^{1-\alpha} \tag{1}$$

Where, at any given time t, for given country i, Y is gross domestic product; A is total factor productivity (TFP); K is input of physical capital; L is input of labour. After decomposition of capital and labour, equation 1 can be expressed in following form:

$$Y_{ti} = A_{ti} f\left(K_{ti}^{NOICT}, K_{ti}^{ICT}, L_{ti}^{U}, L_{ti}^{S}\right) \tag{2}$$

Where, K is decomposed to K^{NOICT} Non-ICT capital and K^{ICT} ICT capital; and L to L^{S} Skilled Labour and L^{U} Unskilled Labour. Total Factor Productivity takes the following functional form:

$$A_{ti} = \exp(\delta_0 Trade.Openness + \delta_1 Edu + \delta_2 INTuse + \delta_3 Patents + \delta_4 RDS + \delta_5 HRST) \tag{3}$$

After logarithm transformation of some variables the final model takes form:

$$\ln LP = \beta_1 \ln GFCF + \beta_2 \ln EduS + \beta_3 \ln RDS + \beta_4 \ln ICTS + \beta_5 \ln Trade.Openness + \beta_6 Edu + \beta_7 INTuse + \beta_8 \ln Patents + \beta_9 HRST \tag{4}$$

4.2. DATA AND VARIABLES

Panel data analysis has been conducted for 21 European Union member countries for a time period of 1993-2011. Table 2 presents list of countries under analysis and Table 3 variables included in the model.

TABLE 2. LIST OF COUNTRIES IN ANALYSIS

7 Central and Eastern European (CEE)	Bulgaria(BG), Czech Republic(CZ), Hungary(HU), Poland(PL), Romania(RO), Slovak Republic(SK), Slovenia(SI)
3 Scandinavian	Denmark(DK), Finland(FI), Sweden(SE)
2 Anglo-Saxon	Ireland(IE), United Kingdom(UK)
5 Continental	Austria(AT), Belgium(BE), France(FR), Germany(DE), Netherlands(NL)
4 Mediterranean	Greece(EL), Italy(IT), Portugal(PT), Spain(ES)

Note: Cyprus, Estonia, Latvia, Lithuania, Luxembourg and Malta were excluded from analysis due to a lack of data on ICT capital.

Source: Own elaboration.

TABLE 3. VARIABLES AND INDICATORS OF ANALYSIS

Name	Description	Source	Indicator
LP	Labour productivity per hour worked in 2012 US (converted to 2012 price level with updated 2005 EKS PPPs)	Total Economy Database	Productivity
GFCF	Gross fixed capital formation as a percentage of GDP	World Bank (WDI)	Non-ICT capital
ICTS	Total ICT spending (computer hardware, software and services, and communications) as a percentage of GDP	WITSA Digital Planet	ICT capital
EduS	Total public expenditure on education per total annual hours worked	World Bank (WDI)/ Total Economy Database	Human Capital
RDS	Research and development expenditure as a percentage of GDP	World Bank (WDI)	Innovation capability
Trade. Openness	Sum of exports and imports as a percentage of GDP	World Bank (WDI)	Technology diffusion
Edu	Gross enrolment ratio	UNESCO UIS database	Adaptive capacity of technology
HRST	Human resources in science and technology percentage of active population from 15-74 years old	Eurostat	Adaptive capacity of technology

INTuse	Internet users per 100 people	World Bank (WDI)	Adaptive capacity of technology
Patents	Resident patents per 1000000 people	World Bank (WDI)	Technology creation

Source: Own elaboration.

4.3. Results

The results are obtained by estimation of fixed effects models using least squares dummy variable (LSDV) regression. Results for time period 1993-2011 for all countries and with sample division for 7 CEE and 14 remaining countries are presented in Table 4. Spending on ICT has been significant in explaining variations in the labour productivity during time period 1993-2011. Another explanatory variable - number of Internet users - affirmed the fact that ICT usage is considered to be important determinant of productivity. Furthermore, gross enrolment ratio is a meaningful factor in explaining variations in productivity. RDS which represents R&D expenditure has negative sign and is only significant for the whole sample. Patents as another indicator of technology creation are significant but surprisingly have negative sign. Both human capital represented by total public expenditure on education per total annual hours worked and human resources in science and technology appear to be significant for the whole sample and WE countries, although there is no identical tendency for CEE.

Table 4. Influence of ICT and complementarities on labour productivity in European countries 1993-2011

	21 Countries	7 CEE Countries	14 WE Countries
log(EduS)	0.039***	−0.016	0.060***
	(0.011)	(0.013)	(0.014)
log(GFCF)	0.074**	0.115**	0.039
	(0.026)	(0.036)	(0.034)
log(RDS)	-0.024·	0.008	-0.064***
	(0.012)	(0.015)	(0.016)
log(ICTS)	0.192***	0.150***	0.058*
	(0.015)	(0.020)	(0.026)
log(Trade.Openness)	0.021	−0.031	0.116**
	(0.031)	(0.038)	(0.040)
Edu	0.001*	0.004**	0.000

	(0.001)	(0.001)	(0.001)
INTuse	0.003***	0.005***	0.002***
	(0.000)	(0.001)	(0.000)
log(Patents)	-0.041***	– 0.002	-0.021*
	(0.007)	(0.010)	(0.008)
HRST	0.005***	0.003	0.004**
	(0.001)	(0.002)	(0.001)
R2	0.839	0.941	0.780
Adj. R2	0.776	0.828	0.712
Num. obs.	399	133	266
P-value	0.000	0.000	0.000
Note: ***p < 0.001, **p < 0.01, *p < 0.05. Standard errors are in parenthesis.			

Source: Own elaboration.

Furthermore, we divided sample into three time periods (Table 5). The first period runs from 1993-1999, so first stage of transition of CEE to market economy. Second time period 2000-2007 includes the recession of early 2000s, which affected the European Union, and first three years after the accession of 5 CEE into the EU on 1st of May 2004 (Bulgaria and Romania joined on 1st of January 2007). The last period 2008-2011 captures financial crisis and global recession. For CEE countries in first period only physical capital and R&D expenditures are significant. For the following period ICT spending, education level, Internet usage and human resources in science and technology become significant and positively affect labour productivity. Estimated models clearly show the recession period 2008-2011. With the crisis, the sources of productivity have changed. Unsurprisingly previous explanatory variables for productivity become insignificant and even some coefficients obtained negative signs. Explanatory power for that period dropped to 30%. In CEE countries openness to trade, which has been significant in WE countries in all periods, gained importance during the crisis. So, it is important for Eastern and Central Europe in today's globalized world to liberalize export and import and open market for foreign investment.

Table 5. Influence of ICT and complementarities on labour productivity in European countries 1993-2011

	Central and Eastern Europe			Western Europe		
	1993-1999	2000-2007	2008-2011	1993-1999	2000-2007	2008-2011
log(EduS)	0.008	0.034	– 0.008	0.007	0.073***	0.019
	(0.016)	(0.027)	(0.022)	(0.010)	(0.020)	(0.014)
log(GFCF)	0.311***	0.192***	0.008	0.352***	0.047	-0.096*
	(0.079)	(0.044)	(0.061)	(0.058)	(0.040)	(0.039)
log(RDS)	0.046	0.043	0.029	0.001	– 0.002	-0.041**
	(0.025)	(0.052)	(0.019)	(0.012)	(0.028)	(0.015)
log(ICTS)	0.045	0.117***	0.017	0.003	-0.038	– 0.141
	(0.055)	(0.023)	(0.141)	(0.035)	(0.019)	(0.093)
log(Trade.	– 0.069	0.021	0.123*	0.317***	0.098**	0.196***
Openness)	(0.071)	(0.067)	(0.046)	(0.048)	(0.037)	(0.038)
Edu	– 0.001	0.013***	– 0.001	0.000	– 0.001	0.000
	(0.003)	(0.002)	(0.003)	(0.001)	(0.000)	(0.001)
INTuse	0.011	0.003***	– 0.001	0.002**	0.002***	0.001
	(0.006)	(0.001)	(0.002)	(0.001)	(0.000)	(0.001)
log(Patents)	0.044	0.010	0.015	– 0.009	– 0.002	-0.012*
	(0.029)	(0.011)	(0.013)	(0.014)	(0.012)	(0.005)
HRST	0.004	0.012**	0.006	-0.003*	0.004*	0.003
	(0.003)	(0.004)	(0.008)	(0.001)	(0.002)	(0.002)
R2	0.739	0.950	0.679	0.845	0.808	0.669
Adj. R2	0.497	0.678	0.291	0.647	0.642	0.394
Num. obs.	49	56	28	98	112	56
P-value	0.000	0.000	0.048	0.000	0.000	0.000

Note: ***p < 0.001, **p < 0.01, *p < 0.05. Standard errors are in parenthesis.
Source: Own elaboration.

5. Conclusion

CEE countries after transition made a huge step to restructure and are steadily striding towards a knowledge economy. Moreover, CEE countries are continuing the path of convergence to Western Europe, which was affected by the crisis in a larger degree. This region, as much as Western Europe, has

access to global technological and social development and hence may have a wide range of benefits. However, between CEE and WE countries a significant gap in economic development still abides and a notable digital divide still exists. Therefore, notwithstanding the recent gains, significant challenges remain in sustaining productivity growth.

Both descriptive analysis and panel model results have shown importance of complementarities to ICT investment. As expected, physical and ICT capital have significant and positive impact on productivity. However, in models with divided time period ICT capital is only significant in CEE for 2000-2007. It is important to note that ICT do not act alone in impacting productivity, but require other factors such as human capital, work organization, knowledge and technology creation and institutions. In the line with previous research (Caselli and Coleman, 2001; Pohjola, 2003) education and ICT skills are important for adoption of technology. Trade openness appears to be insignificant for CEE countries for 1993-2007, although the result was expected to be positive (Coe *et al.*, 1997; Yanikkaya, 2003; De la Cruz and Núñez, 2006). We found that R&D spending is positive and significant for CEE during 1990s and after the crisis, which confirms previous results (Ulku, 2004; Abdih and Joutz, 2006). However, patents as the indicators of technology creation have negative coefficient which is opposite to expected output. Important finding is that in CEE countries in the last years liberalization of trade gained significance. It is necessary to open market for foreign investors, export and increase firms' presence on international markets.

The main limitation of this research is relatively small sample of countries included in estimation. On the other hand this study tries to extend existing analysis adding other variables that affect TFP. The results have some policy implications. Policy makers should support ICT use, reduce digital divide and avoid inhibiting policies such as taxes or charges. In addition, it is important to improve quality of education and encourage more people to enrol on technical and mathematical studies in order to restructure labour force.

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