The role of information and telecommunication technologies in the productivity of the Central and Eastern European countries

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Abstract

The role of information and telecommunication technologies (ICT) in the labour productivity levels and growth is a topic thoroughly investigated by research community. In spite of this, the analysis of the effect of ICT on the economies and companies of Central and Eastern Europe (CEE) is very scarce. This thesis extends the geographical scope of research on the sources of productivity by providing a new evidence from the countries of CEE. Research provides the results on both macroeconomic and microeconomic level.

The macroeconomic part of the thesis analyses the stage of transition to knowledge economy in CEE countries and reveals a considerable gap between CEE and Western European countries, especially in terms of human capital, infrastructure, innovation capacity and quality of institutions. The results of a panel data model for 21 countries conducted in 1993-2011 confirm the importance of complementarities to the use of and investment in ICT (education, ICT skills, trade openness and research and development (R&D) spending) in explaining productivity levels. Another important conclusion is change of the productivity sources during crisis and the increasing significance of openness of trade.

The microeconomic part of the thesis evaluates the relationships among ICT, management practices, innovation and human capital based on a sample of companies in CEE region. The first study is based on data from the Management, Organisation and Innovation Survey 2009 using a representative sample of 444 manufacturing companies in Bulgaria, Poland, Romania, Serbia and Ukraine. Using the original methodology of structural equation modelling (SEM), the direct and indirect determinants of labour productivity are examined. The principal finding that emerged from the study is that wage of employees was the main direct determinant of labour productivity. Moreover, the complementarity relationships between ICT usage and infrastructure, management quality, innovation activities, education and productivity has been established indirectly. In addition, comparative analysis between German and Polish manufacturing companies delivers that productivity is higher in German sample, despite of similarities in internationalisation and innovative activities of the companies. The second study is

based on data from the Polish companies survey conducted in 2015 for a representative sample of 805 companies. The principal finding that emerged from the study is that the presence of the ICT innovation was the main determinant of labour productivity. Moreover, other variables: operating on the international markets, education of the employees and executives and presence of the separate research and development department positively influence productivity.

To conclude, the results of investigation bridge the gap in insufficient academic research about the countries of Central and Eastern European, extend the existing research on the aggregated-level and company-level labour productivity determinants and enable international comparison with other geographical areas and business environments.

Keywords: Information and communication technologies (ICT); Labour productivity; Complementarities; Central and Eastern European countries (CEE)

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To the Reader

Because the dissertation is published as articles, the files herein are in PDF format created from the original publication. As a result, the dissertation including the table of contents has been arranged as seven short chapters. The page number at the beginning of each chapter corresponds to the page number of the dissertation. The page numbers within the chapters correspond to the page number of the volume in which the article was originally published.

Contents

Chapter 1

Introduction

1.1 Introduction

Information and communication technologies (ICT) are linked to knowledge, innovation and ongoing technological changes (Castells, 2002). ICT usage can determine the way economies and societies benefit from the globalisation process. From a regional perspective, it is important to know whether these changes have an impact in terms of economic development and differences in innovation dynamics across regions. International findings suggest that there is evidence of a positive impact of ICT investment and usage on economic growth and productivity in highly developed countries (Bassanini and Scarpetta, 2002; Jorgenson and Vu, 2005; Pilat, 2006). However, ICT does not give rise to generalised productivity improvements until companies and their workers have achieved the required technological, educational/training, strategic, organisational, labour and cultural competencies. In this context, the effects of ICT on company productivity are indirect. Complementary relationships (co-innovation) are established with other components, in particular with human capital and workplace innovations. These spillovers are widely demonstrated in research using company data (Cardona et al., 2013; Díaz-Chao et al., 2015). Transitioning countries of Central and Eastern Europe face considerable challenges in adapting their economies to effectively compete in regional and global markets. For them, a key issue is to find a way to increase their productivity and adapt their economies' structure to global-knowledge competition, promote co-innovation and develop new goods and services that respond to the changing domestic and international demands. Thus, the impact of digital technological changes and their co-innovation processes on productivity is an important aspect in the region's economic performance.

Productivity has long been regarded as the key to economic growth and improvement in the standard of living. One of the possible definitions of productivity is that of Paul Krugman, winner of the Nobel Prize for Economics:

> "Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker."
>
> Krugman 1997

Productivity refers to the efficiency with which a specific economy employs resources (inputs) to produce economic outputs (goods and services). At the national level, productivity is the main determinant of the national standards of living, economic performance and the well-being of its citizens. Productivity improvement is important, because it contributes to the reduction of poverty, increases in leisure opportunities and the country's ability to finance education, public health and social and environmental programs (Baumol and Blinder, 2011). At a company or industry level, benefits of productivity growth enable the company to invest in new technologies, develop new products, expand markets or hire more workers. Moreover, it means that the company can meet its obligations to workers, shareholders and governments and still remain competitive or even improve its competitiveness in the market place. Productivity patterns in the countries of Central and Eastern Europe resemble those of advanced market economies and are mainly driven by efficiency gains within individual companies. Nowadays, with the transition completed, productivity improvements should be searched for in other areas, such as research and innovative effort, the development of human capital through education and incentives from stronger competition (Alam et al., 2008). Companies face rapid environmental changes caused by globalisation, the emergence of new competitors and diversification of demand. Therefore, the priority is to maintain and improve the ability of companies to innovate and compete. For companies to remain competitive on the market, they must develop new organisational strategies. ICT enables the development of new business processes and new work practices, which lead to cost reductions, improved output and productivity gains. Moreover, ICT provides new possibilities of doing business (B2B) and new ways of producing goods and services.

The importance of ICT is a much-debated question, with extensive literature examples focusing on explaining and understanding their role in labour productivity growth. Most empirical studies have been performed at the microeconomic level of company and industry and have been focused on highly developed countries. At the macroeconomic level, fewer studies have been conducted because of a shortage of datasets specifically related to the ICT investment and usage and other relevant national characteristics. Although the transition of Central and Eastern European economies from centrally planned economies to market-driven systems occurred more than two decades ago and those countries now actively participate in the global economic community, publications on ICT in transition economies are sparse (Roztocki and Weistroffer, 2011).

1.2 Research objectives and questions

The main objective of the presented research is to provide one of the first evidence of the relation between information and communication technologies (ICT) and productivity in the countries of Central and Eastern Europe (CEE). This was achieved by descriptive analysis and econometric modelling of the data from the countries of Central and Eastern Europe both the macroeconomic (country-level) and microeconomic (company-level) levels.

1. In order to reach the research objective at the aggregated level, I have published two macroeconomic articles where I have stated research questions:

   (a) **What is the stage of transition of the countries of Central and Eastern Europe towards a knowledge economy?**

   (b) **What is the role of complementarities to ICT investment in productivity growth in the CEE?**

2. In order to achieve the research objective at the company-level, I have published three microeconomic articles. The following are the main research questions:

   (a) **Does the existence of new co-innovative productivity sources (the usage of ICT, workplace organisation and human capital) affect the performance of manufacturing companies in Central and Eastern European countries?**

   (b) **What are the interrelationships in these complementary factors?**

   (c) **What are the differences in the relationships of complementarity (co-innovation) as the sources of productivity in Central and Eastern European manufacturing companies?**

   (d) **What are the differences between German and Polish manufacturing companies?**

   (e) **How huge is the gap in main productivity drivers (innovation, internationalization and human capital) between German and Polish companies?**

   (f) **Does the existence of new co-innovative productivity sources affect the performance of Polish companies?**

1.3 Compendium of publications

The following dissertation builds upon the role of information and communication technologies in the productivity of the countries of Central and Eastern Europe. The dissertation brings together a compendium of papers. Five papers have already been published in peer-reviewed journals, which are indexed in international databases. The papers are arranged in a specific order, starting with two papers at a macroeconomic level and followed by three papers at a microeconomic level. Both level publications are arranged in order of the highest prestige and influence of the journal.

The first paper titled, "The role of ICT in the productivity of Central and Eastern European countries: cross-country comparison" was published in the Revista de Economía Mundial (Journal of World Economy) in journal number 39, 2015. Revista de Economía Mundial was established in 1999 and is currently published through the Publications Services at the University of Huelva, Spain. Revista de Economía Mundial publishes mainly articles related to global economics, international economics and foreign sector of national economy. The journal is indexed in Journal Citation Reports (JCR) - Social Sciences Citation Index created by Thomson Reuters (Impact factor (IF) in 2012 - 0.29, 2013 - 0.21, 2014 - 0.24, 2015 - 0.16). Revista de Economía Mundial has an international prestige and is indexed in the most important international databases, including Social Sciences Citation Index (SSCI-Journal Citation Report), Scopus, EBSCO Publishing, DOAJ, EconLit, Latindex, Ulrich's, CINDOC, Dialnet, Redalyc and Repec. In the paper published in Revista de Economía Mundial, we evaluate the stage of transition of Central and Eastern European countries towards a knowledge economy from the perspective of ICT relation to complementary productivity sources. We further build upon Solow growth model (Solow, 1957) and its extension by Jorgenson and Griliches (1967), which is the panel model for the 21 European Countries. The major result of the analysis is proof of existence of a considerable gap between CEE and Western European countries in terms of productivity levels, human capital level, infrastructure, innovation capacity and quality of institutions. The article confirms a slow convergence of Central and Eastern European countries to Western European countries.

The second paper titled, "Labour productivity, ICT and complementary factors in the CEE region" was published in the Olsztyn Economic Journal, Volume 11, Issue 4, 2016. The first issue of the Olsztyn Economic Journal was published in 2006. It is published by the Faculty of Economic Sciences of the University of Warmia and Mazury in Olsztyn, Poland. It publishes scientific papers of methodical, review and empirical nature in economic sciences. The Olsztyn Economic Journal is indexed in

the following reference databases: BazEcon, BazHum, Index Copernicus Master List (Index Copernicus value (ICV) in 2012 - 5.27 pts, 2013 - 5.92 pts, 2015 - 74.19 pts) and The Central European Journal of Social Sciences and Humanities (CEJSH). In this publication, we look upon the importance of ICT effect on the productivity developments in CEE countries. The paper emphasises a developmental leap-frog in terms of ICT of these economies as well as the importance of total factor productivity in explaining the gains in productivity throughout the region, especially during the immediate EU pre-accession phase.

The third paper tiled, "ICT, Innovation and Productivity: Evidence Based on Eastern European Manufacturing Companies" was published online in the Journal of the Knowledge Economy in January 2017 and in not yet assigned to an issue. The journal was established in 2010 and it is published by the Springer (Springer Science+Business Media), New York. The Journal of the Knowledge Economy is the first journal to focus on the dynamics of the knowledge-based economy, with an emphasis on the role of knowledge creation, diffusion, and application across the spectrum of organisations, industries, nations and regions. The journal is indexed in Scopus SCImago Journal Rank (SJR) and it ranks the second quartile in the category of "Economics and Econometrics" (SJR in 2012 - 0.17, in 2013 - 0.33, in 2014 - 0.35, in 2015 - 0.42). The Journal of the Knowledge Economy is also indexed in the Citations in Economics: CitEc (IF in 2012 - 0.1, 2013 - 0.21, 2014 - 0.22, 2015 - 0.16, 2016 - 0.32). Moreover the journal is indexed in Scopus, EconLit, Google Scholar, ProQuest, Academic OneFile, ECONIS, Expanded Academic, OCLC, Research Papers in Economics (RePEc) and Summon by ProQuest. In this publication we evaluate relationships among co-innovative productivity sources in the Central and Eastern European manufacturing companies. We employed original methodology - structural equation modelling (SEM) techniques to find direct and indirect determinants of labour productivity. The preliminary analysis for this article was published as an Internet Interdisciplinary Institute (IN3) Working Paper titled, "ICT, Innovation and Productivity: Evidence from Eastern European Manufacturing Firms." However, research presentation in the article published in Journal of the Knowledge Economy has been improved by introducing newer literature sources, adding explanation of the skill-biased and routinisation-biased technical change theories and analysing the existing empirical literature on causal relationship between labour productivity and wages of workers. Moreover, we added detailed definition of the co-innovation productivity sources and a comparative analysis of the results with publication based on analysis of the sample of the Catalan companies.

The fourth paper titled, "Drivers of Manufacturing Firms Productivity in Germany and Poland: Evidence from Survey Data" was published in the Review of Applied Socio-Economic Research, Volume 7, Issue 1, 2014. The Review of Applied Socio-Economic Research was established in 2011 and is published by Pro Global Science Association, Romania. The Review covers areas of economics, social sciences and humanities. The Review of Applied Socio-Economic Research is indexed in the Citations in Economics: CitEc (IF in 2012 - 0.03, 2013 - 0.01, 2014 - 0.13, 2015 - 0.04, 2016 - 0.02). The journal is also indexed in RePEc, EconLit, EBSCO, Index Copernicus Journals Master List (ICV in 2011 - 5.09 pts, 2012 and 2013 - 5.84 pts, 2014 - 66.57 pts), NewJour (Georgetown University Library), EconBiz, Genamics JournalSeek, WorldCat, Electronic Journals Library - Universitat Regensburg and ERIH PLUS. In this publication, we analyse drivers of labour productivity: innovation, internationalisation and human capital in manufacturing companies in Germany and Poland. We present empirical results as a comparative study in the representative sample of companies using data from the Management, Organisation and Innovation (MOI) Survey 2009.

The fifth paper titled, "ICT, Innovation and Productivity: Evidence Based on Polish Companies" will be published in the Review of Applied Socio-Economic Research, Volume 13, Issue 1, 2017. This paper is providing one of the first evidence of the relationships among information and communication technologies (ICT), organisational practices, internationalization, innovation and human capital in a sample of Polish companies. The study is based on the recent data from the Polish companies survey conducted in 2015 for a representative sample of 805 companies.

1.4 Justification of the thematic unity

In my thesis I took a novel approach to combine macroeconomic and microeconomic research in one dissertation. As justified in the introduction, the empirical evidence from the Central and Eastern European countries, the role of ICT in the labour productivity is scarce in the literature at the both aggregate and company-level.

Firstly, geographical scope of the research in publications is similar. At the macroeconomic level, as CEE countries we consider: Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovak Republic and Slovenia. Although the group is not homogeneous, nevertheless, these economies share common characteristics all of which relate to their past development throughout the second half of the 20th Century, a period which left them with a "historic development gap" to be translated into a "productivity gap".

For comparative purposes, the analysis is extended to 14 Western European countries. In the company-level research, due to the data availability, the focus is shifted more on the Eastern European economies: Bulgaria, Romania, Serbia and Ukraine. Poland is the only one Central European country in the company-level study. The comparative study at the company-level presents results from Poland and Germany. Moreover, the analysis of the Polish companies using the recent representative data sample.

Secondly, the methodology to estimate company co-innovative sources and aggregated productivity is an extension of the well-established traditional growth and productivity-accounting approach, based on Solow growth model (Solow, 1957) and its subsequent elaboration by Jorgenson and Griliches (1967). The co-innovative productivity sources are incorporated in the efficiency component (Total Factor Productivity, TFP). This is an important contribution in the analysis of determinants of company-level and aggregate-level productivity because this methodology allows us to incorporate several variables simultaneously (e.g. ICT use, work organisation or human capital). This allows the use of explanatory elements that go beyond pure investment, which contemplate the management and effective transformation of business activity.

Thirdly, in all the publications we analyse relations among the new co-innovative productivity sources (the usage of ICT, workplace organisation and human capital) and their influence on labour productivity. However, due to the characteristics of the data, the approximation of variables differs between the macro and micro levels. For example, the dependent variable at the macroeconomic level is Labour productivity per hour worked in 2012 in the US (converted to 2012 price level with updated 2005 EKS PPPs), while at the microeconomic level it is the logarithm of operating revenue in 2008 in thousands of USD, divided by the number of full-time employees.

To sum up, this three characteristics present in the publications justify the thematic unity of the dissertation. Moreover, my research provides the reader with a broad evidence of the ICT and productivity in the Central and Eastern European countries.

1.5 Summary of dissertation

As can be seen from the explanation above, all five papers in the following dissertation deal with the issue of information and telecommunication technologies and productivity in the Central and Eastern European countries. Two papers deal with macroeconomic analysis and comparison of the CEE and Western European countries. Two papers analyse co-innovative productivity sources in the CEE countries and in Poland and one

paper presents a comparative study of Polish and German companies. The five papers are summarised in the table below:

Title	Journal	Publisher	Issue
1. The role of ICT in the productivity of Central and Eastern European countries: cross-country comparison	Revista de Economía Mundial	Publications Services at the University of Huelva	Journal number 39, 2015
2. Labour productivity, ICT and complementary factors in the CEE region	Olsztyn Economic Journal	Faculty of Economic Sciences of the University of Warmia and Mazury	Volume 11, Issue 4, 2016
3. ICT, Innovation and Productivity: Evidence Based on Eastern European Manufacturing Companies	Journal of the Knowledge Economy	Springer (Springer Science+Business Media)	Not yet assigned to an issue, 2017
4. Drivers of Manufacturing Firms Productivity in Germany and Poland: Evidence from Survey Data	Review of Applied Socio-Economic Research	Pro Global Science Association	Volume 7, Issue 1, 2014
5. ICT, Innovation and Productivity: Evidence Based on Polish Companies	Review of Applied Socio-Economic Research	Pro Global Science Association	Volume 13, Issue 1, 2017

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Chapter 2

Article 1: The role of ICT in the productivity of Central and Eastern European countries: cross-country comparison

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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

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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.

[1] This paper was presented at the XV World Economy Meeting in Santander, June 5-7, 2013. We would like to thank reviewers and participants for helpful comments.

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.

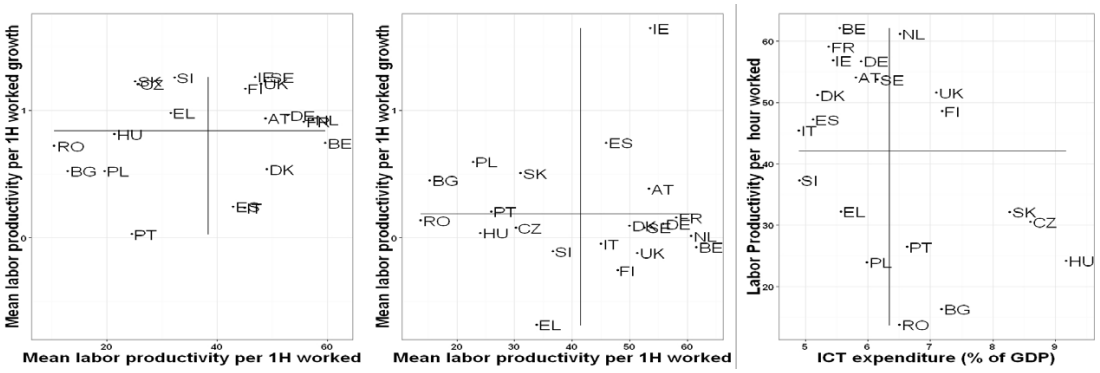
Source: Own elaboration.

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



(a) 2000-2007 (b) 2008-2011 (c) ICT 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.

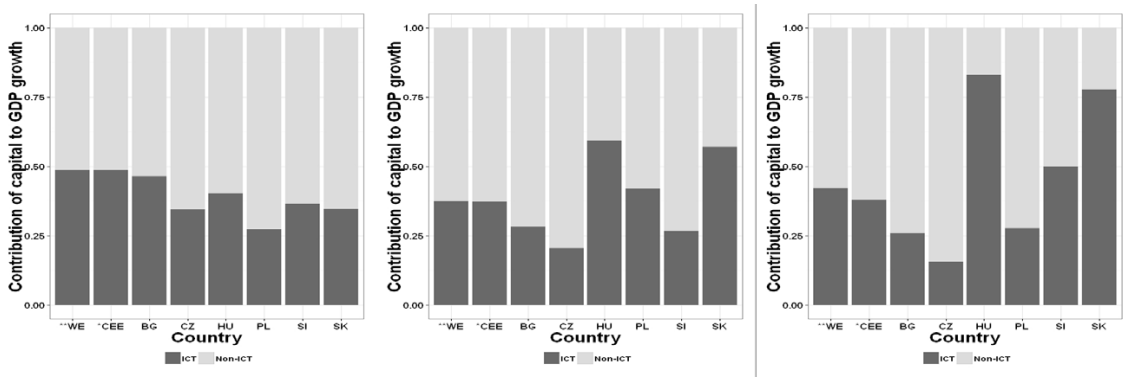
Source: Own elaboration. Data for (a) and (b) are from Total Economy Database, and (c) from WITSA.

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).

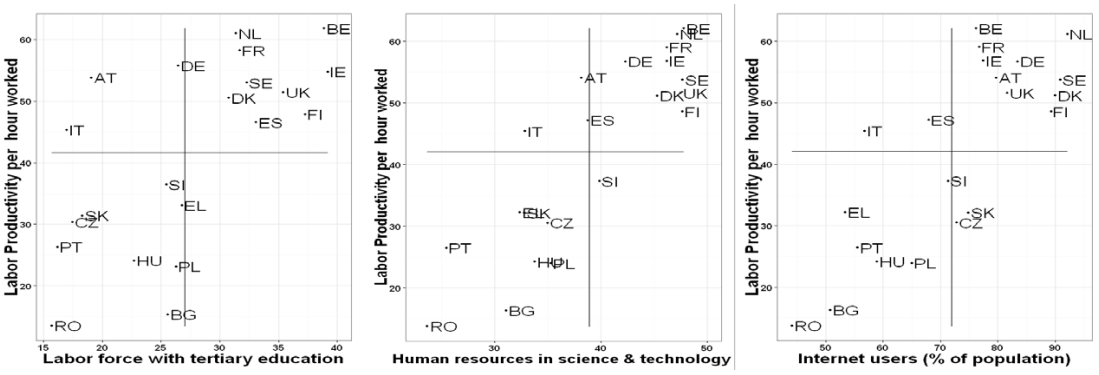
3.1. ADAPTIVE CAPACITY OF TECHNOLOGY: HUMAN CAPITAL AND WORKPLACE ORGANIZATION

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.

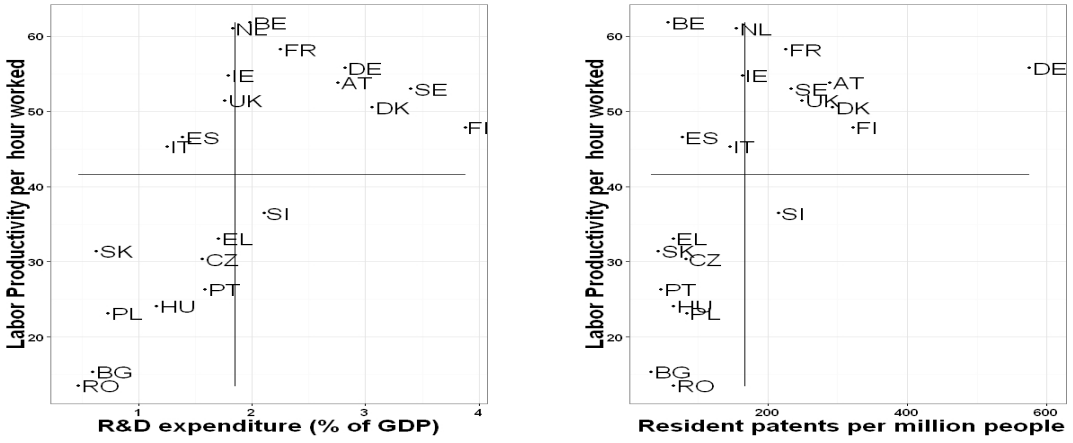
3.2. KNOWLEDGE, TECHNOLOGY CREATION AND INNOVATION CAPABILITY

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.

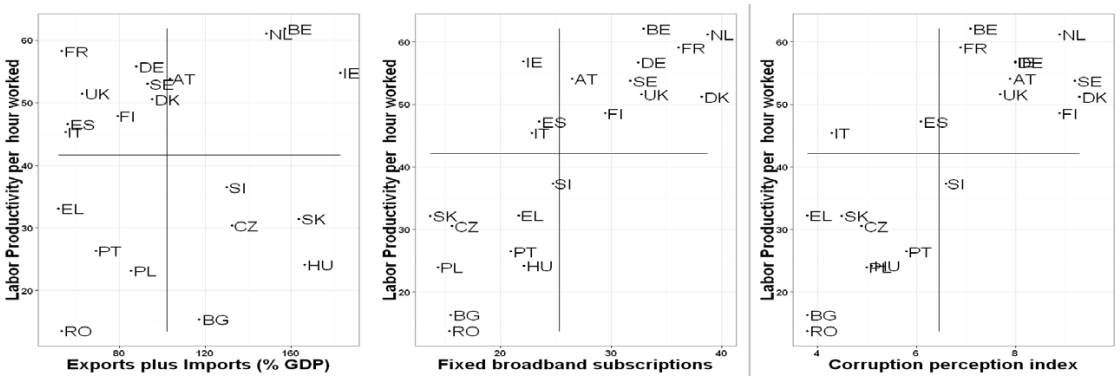
3.3. Institutions

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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Chapter 3

Article 2: Labour productivity, ICT and complementary factors in the CEE region

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LABOUR PRODUCTIVITY, ICT AND COMPLEMENTARY FACTORS IN THE CEE REGION[1]

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K e y w o r d s: labour productivity, ICT, complementarities, CEE countries.

A b s t r a c t

The paper discusses the role of Information and Communication Technologies for labour productivity in the Central and Eastern European countries, taking into account the consequences of the latest global economic crisis. It focuses on the factors (ICT complementarities) influencing the ICT diffusion trajectories, and thus having impact on labour productivity. The fixed effects models and least squares dummy variable (LSDV) regression was implemented with the use of panel data for 21 European Union member countries. The analysis revealed that only some complementary factors to ICT investments appeared significant to affect labour productivity in the CEE Region. It also showed that sources of labour productivity are sensitive to cyclical changes in the economy.

WYDAJNOŚĆ PRACY, TIK I CZYNNIKI KOMPLEMENTARNE W KRAJACH EUROPY ŚRODKOWO-WSCHODNIEJ

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S ł o w a k l u c z o w e: wydajność pracy, TIK, czynniki komplementarne, kraje Europy Środkowo-Wschodniej.

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Abstrakt

W artykule przeanalizowano wpływ technologii informacyjnych i komunikacyjnych (TIK) na wydajność pracy w krajach Europy Środkowej i Wschodniej (EŚW), z uwzględnieniem skutków ostatniego globalnego kryzysu gospodarczego. Szczególną uwagę poświęcono czynnikom komplementarnym wobec TIK, które oddziałują na ich procesy dyfuzji, mając tym samym wpływ na wydajność pracy. Analizę ilościową przeprowadzono z wykorzystaniem estymacji modeli z efektami stałymi za pomocą metody najmniejszych kwadratów ze zmiennymi sztucznymi (LSDV), dla danych panelowych dla 21 państw członkowskich Unii Europejskiej. Wyniki analiz wykazały, że jedynie niektóre czynniki komplementarne wobec TIK miały istotny statystycznie wpływ na wydajność pracy w krajach EŚW. Okazało się również, że źródła wydajności pracy są wrażliwe na zmiany koniunktury gospodarczej.

Introduction

The role of Information and Communication Technologies (ICT) concerning economic growth and productivity has been widely discussed since Solow (1987) stated "You can see the computer age everywhere but in the productivity statistics". Nowadays, there is a broad consensus among researchers that ICT are of key importance for productivity performance. Although recent research studies point towards a positive relationship between ICT investments and productivity, even in developing (or emerging) economies, there are still a lot of questions that remain unanswered. The most important are related to the hypothesis of the leapfrogging effect and the factors influencing the ICT diffusion trajectories (ICT complementarities), which have an impact on labour productivity. Both questions are crucial; however, we will focus on the latter in this paper. Our goal is to identify which complementarities to ICT investments have been significant to labour productivity growth in Central and Eastern European (CEE) countries since the second half of 1990s. A macroeconometric analysis has been conducted for three periods: 1995–1999, 2000–2007 and 2008–2011, describing different stages of transition of CEE countries to a market economy, the last period including the effects of the world financial crisis. Thusly, we were able to assess whether economic cycles influence the impact of ICT complementarities on labour productivity.

Towards ICT complementarities – a synthetic literature review

The ICT influence on economy can be described by two types of effects (JUNG, MERCENIER 2014). The first-order effect captures the impact of investments in ICT infrastructure on the stock of capital. The growth of ICT capital, as models of economic growth predict, positively influences GDP growth and labour productivity. The second-order effect (spillover effect) is a result of

complementary changes that are induced by ICT investments. This refers to outcomes of theoretical and empirical studies that were focused on "solving" the productivity paradox puzzle. The most accepted explanations include: mismeasurement of inputs and outputs related to ICT (BRYNJOLFSSON, SAUNDERS 2010, HALTIWANGER, JARMIN 2002, MOULTON 2002, YANG, BRYNJOLFSSON 2001), lags – ICT investments may not have an immediate impact on a company's productivity, as this requires a learning-by-doing form of experience (DAVID 1990, 2002, KLING, LAMB 2002), and finally the complementarity hypothesis, which argues that utilisation of the full potential of new technologies (including ICT) requires complementary changes (investments) related to work organisation, human capital or changes in business processes within companies (BRYNJOLFSSON 2005, MILGROM, ROBERTS 1990, 1995, MILGROM et al. 1991). These complementary changes affect Total Factor Productivity (TFP) and, as a result, productivity and economic growth. Literature provides many examples of adoption of organisational changes, new human resource management practices and the growing importance of human capital, which are treated as complementary factors.

BRESNAHAN et al. (2002) have shown evidence of a positive correlation between ICT use and workplace organisation and skilled labour that have affected productivity in the United States. They concluded that with the growing spread and access to ICT, investment in complementarities is crucial, particularly in skilled labour. BLACK and LYNCH (2001, 2004) showed, also for the US, that productivity growth during the 1990s had its source in changes in workplace organisation and innovations (employee involvement, team work, incentive pay and decision-making autonomy) along with the dissemination of computers. BRYNJOLFSSON (2005) described seven pillars of digital organisation, which in fact are ICT complementarities that enhance productivity and the market value of a company.

Research studies in other developed countries followed the path of analysis initiated in the Unites States. Analysis of panel data for British and French firms (CAROLI, VAN REENEN 2001) revealed that skilled workers adapt more easily to changes in organisation. Having this in mind, the authors presented empirical evidence of the relationship between workplace innovation and human capital, as well as its influence on productivity. Another comparative study of Swiss and Greek firms (ARVANITIS, LOUKIS 2009) shows the positive effects of physical capital, ICT, human capital and new organisational practices on labour productivity. It appeared that Swiss firms were more efficient in combining and implementing these factors, while in the Greeks firms, physical capital played a crucial role in relation to labour productivity.

The role of ICT complementarities has also been emphasised in macro-level research studies conducted in developing countries. PIATKOWSKI (2004) and

VAN ARK and PIATKOWSKI (2004) showed that ICT noticeably contributed to GDP and labour productivity growth in the CEE region in the second half of 1990. DEDRICK et al. (2013) found that in developed countries, ICT complementarities encompass foreign investments and cellular penetration, while in developing countries, these were the quality of human capital, foreign investments and the cost of communication services. NIEBEL'S (2014) analysis also indicates the existence of spillover effects and complementarities related to ICT investments in developed as well as in developing countries.

The interaction between ICT and complementary factors is a complex one. Access to technology is determined by the trade openness of an economy, which influences the transfer of know-how. The ability of a company to implement a given technology depends on whether it already possess adequately trained employees or is able to recruit them from the labour market. In order to bring about the expected results (e.g. increase in labour productivity), it also requires the introduction of changes in work organisation in connection with the redefinition of business processes that were performed with the use of previous-generation technology. Concurrently, the pace and scope of these changes are dependent largely upon the human capital of employees. Moreover, the institutional milieu plays an important role – it may support or hinder the implementation of this comprehensive process of changes in the organisation (e.g. more restrictive labour code regulations could hamper the introduction of changes in work organisation, while higher labour market flexibility should encourage greater openness to change among employees).

It should be emphasised that factors complementary to ICT are also reliant upon each other – changes in work organisation require access to modern technologies and suitably qualified human resources, while innovativeness and the scale of foreign investments are conditioned by the dissemination of technology and the quality of human capital.

ICT – driven productivity in the CEE countries

Statistical data shows that since 2000, the first- and second-order effects of ICT implementation have been more evident in the CEE region[2] than in the EU-15 countries. ICT capital grew 17.9% between 2000 and 2014 in the seven CEE countries, while in the EU-14, it reached 10.75%. As a result, the average contribution of ICT capital to GDP growth in the CEE region was above that of the EU-14, especially in Hungary, Bulgaria and Slovakia. TFP also played an

[2] Due to a lack of data on ICT capital in the Conference Board 2015 database for Estonia, Latvia, Lithuania, Croatia and Luxembourg, there is no possibility to assess the magnitude of the first-order effect.

important role, especially in the CEE region, where its contribution to economic growth was, on average, positive[3] (Tab. 1).

However, there were perceptible differences between individual countries. In Romania, Poland and Slovakia, TFP was the main driver of GDP growth. A smaller, but still positive, TFP contribution was recorded in Estonia, Lithuania, Latvia, Czech Republic and Slovenia. At the same time, Bulgaria, Croatia and Hungary witnessed a negative TFP contribution to GDP growth – unfortunately, it is not possible to estimate to what extent this effect was caused by ICT, though it seems that other factors played a primary role.

Table 1

Sources of GDP growth in EU-15 and CEE countries in 2000–2014

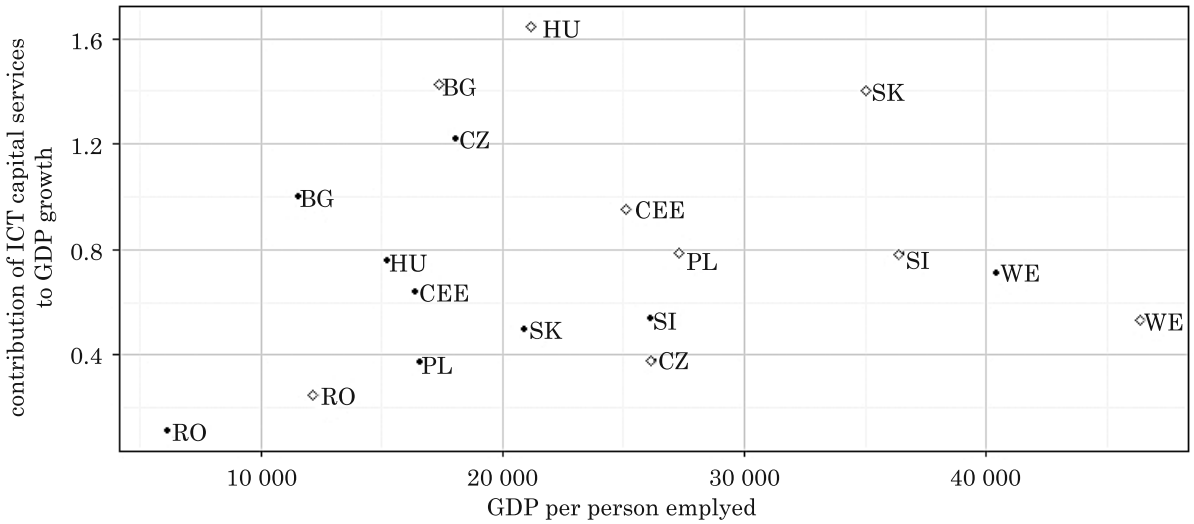
Country	Labour Quality	Labour Quantity	ICT capital services	Non-ICT capital services	TFP growth
EU-15	0.24	0.18	0.50*	0.74	-0.26
CEE (11)	0.24	-0.20	–	1.59	0.91
CEE (7)	0.28	-0.20	0.92	1.19	0.78
Bulgaria	0.34	0.01	1.40	3.06	-1.44
Croatia	0.22	0.17	–	1.41	-0.73
Czech Republic	0.22	-0.09	0.41	1.41	0.58
Estonia	0.17	-0.03	–	1.91	1.86
Hungary	0.33	-0.4	1.53	0.72	-0.22
Latvia	0.14	-0.70	–	3.22	1.38
Lithuania	0.16	-0.19	–	2.13	2.07
Poland	0.21	0.09	0.71	1.20	1.40
Romania	0.25	-1.11	0.47	0.23	3.67
Slovak Republic	0.13	0.11	1.30	0.83	1.40
Slovenia	0.48	-0.02	0.61	0.86	0.06

* Average for EU-14 excluding Luxembourg.
Source: own elaboration based on the Total Economy Database. Average for 2000–2014.

In spite of rapid labour productivity growth, the gap in the level of productivity between CEE and EU-15 (Western European – WE) countries is still quite large. Comparing average levels of productivity for the periods between 2000 and 2014, it is clear that CEE countries experienced strong productivity improvement. Productivity in the CEE region increased, on average, by 48.4%, while in WE countries, it was only 7.7%. As a result, the labour productivity gap between the two regions was reduced by 25.5%.

[3] It should be emphasised that the contribution of TFP to GDP growth in 2000–2014 in the EU-15 countries was negative.

Romania and Lithuania gained most – the increase in productivity levels in 2000–2014 accounted for 105% and 92%, respectively. However, productivity levels in all CEE countries are still much lower than in other European economies. Taking as a reference the year 2014, only Slovenia and the Slovak Republic had higher labour productivity levels when compared to the least performing EU-15 country – Portugal. The gap within the CEE region is significant, e.g. labour productivity in Bulgaria in 2014 was 35% lower than the average for the region. 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 the technological revolution for transition countries (VAN ARK, PIATKOWSKI 2004). Figure 1 shows that in 2008–2014, CEE countries, apart from Romania and the Czech Republic, have higher levels of ICT capital contribution to GDP growth on average. However, in the case of Romania, there is no clear relation between these two variables – Romania is characterised by low ICT capital contribution and low GDP per employee. Nevertheless, all countries improved labour productivity. It is evident that CEE countries made a huge step after transition to restructure their economies and have entered a convergence path towards that of Western Europe. However, the convergence processes have been affected by the crisis to a larger degree.



• – 1995-1999 average
◊ – 2008-2014 average

Fig. 1. Contribution of ICT capital services to GDP growth and GDP per person employed: 1995–1999 and 2008–2014

Source: own elaboration based on the Total Economy Database.

Identification of ICT complementarities

Macroeconometric modelling, used for quantitative analysis, is based on the Solow growth model (SOLOW 1957) and its extension by Jorgenson and GRILICHES (1967). This approach enabled us to measure the impact of ICT complementarities on labour productivity and to assess whether the role of these complementarities changed over time. The econometric analysis encompassed the years 1995–2011 due to the unavailability of more recent data.

The aggregate production function takes the form:

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

where at any given time t, for a 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 as:

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

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 can be presented in 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, the final model takes the following form:

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

Equation (4) describes four sources of labour productivity: non-ICT capital (GFCF), ICT capital (ICTS), human capital (EduS) and Total Factor Productivity, represented by different variables (Tab. 2). These variables were selected taking into account the findings discussed in literature on productivity. It has been argued that productivity improvements in transition countries should be linked to the components of knowledge economy: ICT usage and knowledge, human capital development, workplace organisation and research and innovation (ARVANITIS, LOUKIS 2009, BRESNAHAN et al. 2002). There is also empirical evidence that investment in research, development and innovation affects TFP (JORGENSON, VU 2005). Domestic research and development is

needed for understanding and absorption of knowledge developed internationality, for improvement of local research and development (R&D) skills and active participation in international R&D networks.

A better quality of human capital can help countries to develop their technologies, as well as increase a country's ability to absorb high technology knowledge from abroad (CASELLI, COLEMAN 2001, POHJOLA 2000). Human capital derived from university education, but also from training and accumulated through learning by doing, can increase the efficiency of labour and also enhance TFP (ARVANITIS 2005, BLACK, LYNCH 2001). Moreover, human resource management within companies, organisations and institutions is an important factor in knowledge economy and one of the determining elements which enable the increase of competitiveness and improve individual and aggregated productivity (BRYNJOLFSSON, HITT 2003).

Finally, liberalised trade positively influences productivity and economic growth. This is particularly important for dissemination of knowledge and

Table 2

Variables and indicators used in econometric analysis

Name	Description	Source	Indicator
LP	Labour productivity per hour worked in 2012 USD (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	Net export 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 25–64 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.

innovation. Open borders allow for international spillover effects, contributing to economic growth in developing countries and enhancing their catching-up process through adaptation of advanced foreign technologies. Openness to import makes different varieties of capital goods more accessible, which increases efficiency (BARRO, SALA-I-MARTIN 2004).

The econometric analysis was based on panel data for 21 European Union member countries divided into two groups: CEE countries (7 economies)[4] and WE countries (14 economies). We treat WE countries as a point of reference.

Equation (4) was estimated with the use of fixed effects models and least squares dummy variable (LSDV) regression. The results clearly indicate changes in the sources of labour productivity and the impact of ICT complementarities in CEE countries, as well as the influence of the economic crisis on changes in the relationship between ICT and productivity (Tab. 3).

Table 3

Influence of ICT and complementarities on labour productivity in CEE and WE countries in 1995–2011

Specification	Central and Eastern Europe			Western Europe		
	1995–1999	2000–2007	2008–2011	1995–1999	2000–2007	2008–2011
log(EduS)	0.000 (0.013)	0.050 (0.028)	-0.006 (0.017)	0.015 (0.010)	**0.077***** (0.019)	0.019 (0.015)
log(GFCF)	**0.333***** (0.073)	**0.160**** (0.046)	-0.017 (0.053)	**0.378***** (0.074)	0.021 (0.042)	**-0.093*** (0.044)
log(RDS)	-0.072 (0.051)	0.011 (0.026)	0.012 (0.016)	-0.007 (0.014)	0.003 (0.027)	**-0.041**** (0.015)
log(ICTS)	-0.183 (0.051)	**0.125***** (0.026)	-0.051 (0.127)	-0.083 (0.084)	**-0.038*** (0.019)	-0.169 (0.099)
log(Trade.Openness)	-0.183 (0.109)	0.021 (0.070)	**0.119**** (0.035)	0.167 (0.094)	**0.120**** (0.036)	**0.180***** (0.045)
Edu	-0.003 (0.003)	**0.012***** (0.002)	0.000 (0.002)	-0.001 (0.001)	0.000 (0.000)	0.000 (0.001)
INTuse	**0.017**** (0.006)	**0.003***** (0.001)	0.002 (0.002)	**0.002*** (0.001)	**0.002***** (0.000)	0.000 (0.001)
log(Patents)	0.049 (0.053)	0.063 (0.044)	0.038 (0.058)	0.009 (0.044)	-0.023 (0.020)	-0.042 (0.034)
HRST	0.005 (0.003)	**0.013**** (0.004)	0.004 (0.007)	0.001 (0.002)	**0.005*** (0.002)	0.003 (0.002)
R^2	0.838	0.947	0.757	0.753	0.823	0.622
Adj. R^2	0.455	0.676	0.324	0.506	0.654	0.367
Num. obs.	35	56	28	98	112	56
P-value	0.000	0.000	0.0125	0.000	0.000	0.000

Source: own elaboration.

[4] Countries for which data on ICT capital is available in the Total Economy Database.

In the first sub-period (1995–1999), only gross fixed capital formation (β=0.333, p<0.001) and Internet usage (β=0.017, p<0.01) appeared to be significant and positively affected labour productivity in CEE and WE countries. In the years 2000–2007, ICT spending (β=0.125, p<0.001), gross enrolment ratio (β=0.012, p<0.001) and human resources in science and technology (β=0.013, p<0.01) also become significant in explaining the growth of labour productivity in Central and Eastern European countries. In WE countries, at that time, two other complementarities – human capital, measured by total public expenditure on education per total annual hours worked (β=0.077, p<0.001) and trade openness (β=0.12, p<0.01), along with human resources in science and technology (β=0.005, p<0.01) and Internet usage (β=0.002, p<0.001), positively influenced productivity. Interestingly, ICT capital had a significant but negative impact on labour productivity in Western European countries (generally, in all analysed sub-periods, the relationship between ICT spending and labour productivity in WE countries was negative). This may imply that new ICT investments in WE countries were too low to positively affect productivity. In contrast, it appears that CEE countries took advantage of the favourable economic situation in order to catch up to West European countries by investing in ICT capital. Unfortunately, the economic crisis reversed this trend – the impact of ICT capital on labour productivity in CEE countries in 2008–2011 became insignificant and negative.

Estimated models clearly show that in the recession period (2008–2011), explanatory power dropped significantly (to 32% in the case of CEE countries, and to 37% in the case of WE countries). Variables that previously explained changes of labour productivity became insignificant, and even some coefficients acquired negative numbers. The only significant variable (ICT complementarity), explaining labour productivity in CEE countries, was trade openness (β=0.119, p<0.01). This variable was also significant for WE countries (β=0.18, p<0.001), along with non-ICT capital and R&D expenditures (but in this case, the coefficients had negative numbers).

This leads to the conclusion that the relationship between ICT and productivity, and the importance of given ICT complementarities, are strongly dependent upon the economic situation and the phase of the economic cycle. Macroeconomic stability seems to be a crucial factor enhancing labour productivity through the use of Information and Communication Technologies in Western and Central and Eastern European countries. Thus, the convergence processes between CEE and WE countries are hampered during economic slowdown, not only because of a decrease of capital investments (in non-ICT and ICT capital), but also due to the diminished influence of ICT complementarities.

Conclusions

It has been widely acknowledged that Information and Communication Technologies play a crucial role concerning economic growth and productivity performance, not only in highly developed countries, but also in developing or emerging economies – e.g. CEE countries. Theoretical and empirical research studies on the relationship between ICT and labour productivity and TFP growth emphasises the importance of complementary factors enhancing the measurable effects of ICT implementation. The analysis presented in this paper focuses on identifying these complementarities in CEE and Western European countries.

Empirical research at the macroeconomic level, based on the Solow growth model, showed that ICT complementarities played an important role in enhancing labour productivity in CEE (and WE) countries, especially in the years 2000–2007. It also revealed that the global economic crisis had a significant and unfavourable impact on the relationship between ICT complementarities and labour productivity. The following conclusions, stemming from the analysis, seem exceptionally interesting.

Firstly, although there are a couple of potential ICT complementarities at the macro level, econometric modelling revealed that only some complementary factors to ICT investments appeared significant to affect labour productivity in CEE countries – almost all of them are related to human capital (gross enrolment ratio, human resources in science and technology and Internet usage determined by the digital skills of the users). At the same time, variables used as indicators of innovativeness turned out to be statistically insignificant.

Secondly, sources of labour productivity (including ICT complementarities) proved to be sensitive to cyclical changes in the economy. These are significant in explaining productivity when the economic situation is relatively stable, but during a recession, the relationship becomes insignificant. Obviously, this issue requires further examination. This conclusion is quite important, taking into account that CEE countries are still attempting to converge to the performance levels of the more developed Western European countries, and ICT seem to be an important factor in this process.

Thirdly, ICT contribution to labour productivity in CEE countries was significant only in 2000–2007 – a period when the economic situation was relatively good and stable in these countries. If companies invest in ICT mainly in times of promising financial prospects, the role of ICT complementarities shall be even more important when enhancing ICT-driven productivity.

Fourthly, trade liberalisation and openness to foreign investment appears to be an important factor determining the implementation of new technologies

and dissemination of knowledge and innovation to all European economies in times of crisis. Open borders allow for an international spillover effect that contributes to economic growth in developing countries and enhancement of their catching-up process through adaptation of advanced foreign technologies.

The obvious limitation of this research study is the relatively small sample of countries included in the estimation. We also keep in mind the existing disparities in labour productivity caused by heterogeneity across the analysed countries. Although there are more factors influencing labour productivity, we could not take all of them into consideration. Regarding the importance of this topic, especially for transition economies, there is a need to conduct further research studies in this area. This includes macro-level analyses (with more countries, improved indicators and more reliable longitudinal data taken into account), as well as micro-level studies. This company-level approach (requiring collection of primary data from small, medium and large enterprises) seems especially promising, as CARDONA et al. (2013) argue that differences between countries concerning ICT effects are much less significant at the micro-level than at the macro and sectoral level.

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Chapter 4

Article 3: ICT, Innovation and Productivity: Evidence Based on Eastern European Manufacturing Companies

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Chapter 5

Article 4: Drivers of Manufacturing Firms Productivity in Germany and Poland: Evidence from Survey Data

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Drivers of manufacturing firm's productivity in Germany and Poland: evidence from survey data

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Abstract. *The main motivation behind this study is to analyse drivers of labour productivity: innovation, internationalization and human capital in manufacturing enterprises. Using data from the Management, Organisation and Innovation (MOI) Survey 2009 for a representative sample of 218 firms from Germany and 103 firms from Poland we present empirical results as a comparative study. The principal finding that emerged from the study is that patterns in internationalization and firm innovative activities are similar in both countries. However, output of innovation and productivity are significantly higher in German sample. The results of the investigation extend publications on firm-level productivity and innovation European countries based on survey data.*

Keywords: innovation, productivity, German and Polish manufacturing industries

JEL Codes: L60, O31.

1. Introduction

Nowadays, firms face rapid changes of environment caused by globalization, appearance of new competitors and diversification of demand. It is a key issue to find a path to increase their productivity and to compete effectively in regional and global markets, adapt the structure to global-knowledge competition and develop new goods and services that respond to changing domestic and international demand. Though, the priority is to maintain and improve ability of firms to innovate and compete. Firms to remain competitive on the market have a need to improve research and innovative effort, the development of human capital through education, and develop new organizational strategies.

Although the transition of Eastern European countries from centrally planned economy to market driven system occurred more than two decades ago and now those countries participates in the global economic community, publications on firm-level innovation in transition economies based on survey data are sparse (Roztocki and Weistroffer, 2011). The closed economies blocked international linkages that impact on innovation, including knowledge spillovers and technology adoption. The characteristic of the command economic system resulted in low competitiveness and technological obsolescence (Winiecki, 2004). Consequently, 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 anti-innovation bias from the command economy system when all applications of research and development (R&D) were controlled by

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state and due to insufficient financial support. For Eastern European countries one of the main issues of productivity improvement and competitiveness is innovativeness. Innovations stimulate the economic growth of countries and thus enable to catch up with developed market economies. However, in response to the introduction of market institutions and market rules in the 1990s, firms faced increased competition, had to modify their innovation behaviour and also new economic networks among firms developed rapidly.

Therefore, in this paper we provide preliminary analysis of manufacturing enterprises in Poland and Germany, as a benchmark of more advanced economy. Poland is the most important country from former communist states with rapidly growing economy and the increasing influence in the European Union. Poland managed to maintain positive growth during the crisis, so as being the only EU country not to have experienced a recession in the last twenty years. The main motivation behind this study is to compare German and Polish manufacturing enterprises: Firstly, to characterize German and Polish manufacturing enterprises including their economic performance. Secondly, to analyse differences in drivers of productivity: innovation, internationalization and human capital. The main questions underpinning the research are: 1) What are the differences between German and Polish manufacturing enterprises? 2) How huge is the gap in main productivity drivers (innovation, internationalization and human capital) between German and Polish firms?

The reminder of this paper is organised as follows. Section 2 presents data and sample design. Section 3 describes general characteristics of the firms and their performance. Section 4 reports the empirical findings on firm productivity drivers, and section 4 provides conclusions and policy implications based on those findings.

2. Data

This paper's empirical descriptive analysis is based on data from Management, Organisation and Innovation (MOI) Survey 2009, a joint initiative of the European Bank for Reconstruction and Development (EBRD) and the World Bank Group (the World Bank). The MOI survey was undertaken for the first time in 2008-2009, covering 1870 manufacturing establishments with between 50 and 5000 employees from 10 Eastern European countries: Belarus, Bulgaria, Kazakhstan, Lithuania, Poland, Romania, Russia, Serbia, Ukraine, Uzbekistan, and Germany as a developed country benchmark and India as a developing country benchmark. MOI interviews were conducted face-to-face with interviewers recruited by local survey companies and took place between October 2008 and April 2010. The interviews were conducted with managers and endured on average 50 minutes. The response rate was 44 percent. The questionnaire comprised seven sections organised by topic. Initially questions were posed about the characteristics of the firm, such as legal status, ownership and number of years in operation. This was followed by sections on management practices, organisation of the firm, innovation and R&D, degree of competition and labour. The MOI questionnaire was developed and tested in two pilot surveys prior to its implementation in the field. Two main objectives of the sample is measure and compare management practices across the countries and to conduct firm performance analysis focusing on determining how management practises affect productivity and job creation in manufacturing. MOI survey was used to determine if quality of management practices is positively associated with various measures of firm performance in Eastern European countries (Bloom et al., 2012; Schweiger and Friebel, 2013). The Survey uses a standardized survey instrument and a uniform sampling methodology to minimize measurement error and generate a sample representative of the manufacturing sectors in each country. Data are comparable across the countries and the sample seize is large enough to conduct statistically robust analysis with levels of precision at minimum 7.5% precision for 90% confidence intervals (EBRD and World Bank, 2008).

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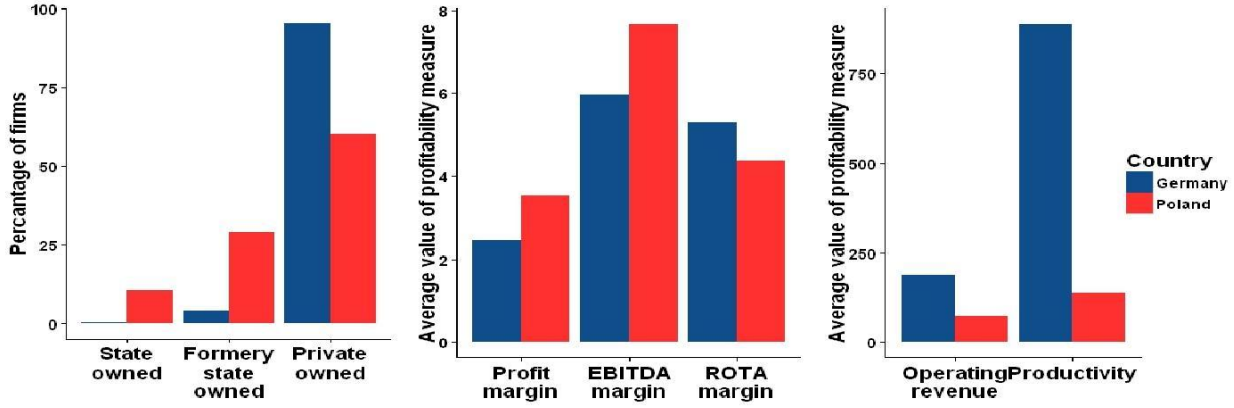
Data from the MOI survey was complemented by firm performance data (balance sheets and income and loss statement) from Bureau van Dijk's Orbis database. Given that the output variables from Bureau van Dijk's Orbis database are not available for all countries and also for all firms in the country, we run the risk that results are driven by the specific country. Performance data: the operating revenue, profit margin, EBITDA margin, ROTA margin and spending on research and development activities are winsored at 1% to limit the impact of outliers on the result (this means that all the data below the 0.5th percentile are set to the 0.5th percentile and all the data above the 99.5th percentile are set to the 99.5th percentile as in Bloom et al. (2012)).

3. Empirical findings

3.1. General characteristics and firm performance

For the present study, we have included 218 firms from Germany and 103 firms from Poland. In Polish and German sample we observe similar distribution of enterprises regarding the technology intensity of industry in which firms operate. Those firms operate mainly in low technology industries 34% of firms in both countries mainly producing wood, pulp, paper, printing and publishing industries and in food products, beverages and tobacco. Furthermore, 25% of German and 30% of Polish firms operate in medium-low technology industries, mainly producing basic metals and fabricated metal products. In Germany more firms are medium-high technology intensive 32% and in Poland 27% in both countries producing mainly machinery and equipment. Lastly, 9% of companies in both sub-samples operate in high technology industries in Poland mainly producing pharmaceuticals and in Germany manufacturing medical, precision and optical instruments.



(a) Ownership (b) Performance (c) Productivity

Fig. 1: General characteristics and firm performance. Source: Own elaboration. Orbis database and MOI survey.

Regarding the size of firms based on the number of employees, firms form the sample in Germany and in Poland slightly differ. In Poland 47% of firms are large, 50% medium-sized (between 50 and 250 employees), 3% are small firms and have on average 399 workers. In Germany there are more medium-sized firms 62%, 36%large firms, 2% of small firms and have on average 310 workers. Those companies are mainly firms on they own 66% and 57% in Poland and in Germany respectively. The remaining firms are a part of a bigger firm. Comparing distribution of the firms by the legal status in both countries, firms are mainly share-holding companies, with distinction for those which are traded in the stock market 20% and 12% and with shares traded privately 68% and 76% in Poland and in Germany respectively. Firm ownership

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is presented on figure 1a. In Poland 11% of the firms are still state owned, 29% were state owned in the past and 60% were not state owned. In Germany 95% were not owned by state. The ownership of the single largest block in the firm differs. In Germany 44% of firms are family owned, followed by individual ownership 21%, where in Poland most popular is that firm have multiple owners 32% and than individual ownership 26%. Taking into consideration full-time top and middle managers we observe gender gap. In Poland only 32% of managers are female and in Germany 42% of managers.

In addition, we have compared firm performance indicators profit margin, EBITDA margin, ROTA margin (figure 1b), operating revenue and productivity (figure 1c). Profit margin is a ratio of profitability calculated as operating and financial profit divided by total operating revenue. Profit margin is very useful when comparing companies in similar industries. Polish firms on average have a higher profit margin, what indicates that have better control over its costs compared to German firms. EBITDA margin is a measurement of a company's operating profitability. It is equal to earnings before interest, tax, depreciation and amortization (EBITDA) divided by total revenue. EBITDA margin can provide an investor with a cleaner view of a company's core profitability. On average Polish firms have higher EBITDA margin scores. Moreover, ROTA margin defined as earnings before interest and taxes (EBIT) over total assets indicates how efficiently the company is using its assets to generate earnings before contractual obligations must be paid. German firms have greater a company's earnings in proportion to its assets, that means they are using assets more effectively than Polish enterprises. Lastly, we compared operating revenue, which is income derived from sources related to a company's everyday business operations. The operating revenue in 2008 expressed in millions of dollars on average is more than two times higher in German than Polish manufacturing enterprises form the sample (figure 1c). In addition, we compared firm productivity which is approximated by the operating revenue in 2008 divided by the number of full-time employees (figure 1c). The MOI survey data show that Polish companies have more than six times lower firm productivity than German.

3.2. Innovation

Nowadays, knowledge is the resource and the commodity of knowledge economy, which explains the progress in productivity (Castells, 2011). In-house 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. Innovation begins with firm's formal and informal R&D effects. There is empirical evidence that knowledge and subsequently innovation lead to improvement of firm productivity. Innovation can boost productivity in two ways, by firms investing in R&D themselves and reaping the benefits from new or improved products and processes, or by spillovers from creators of knowledge to other firms to compete. Studies have shown that both these processes – R&D investment and the use of external knowledge – influence the ability of firms to innovate (Criscuolo et al., 2010). International sales and innovation have been shown to be associated with superior productivity (Harris and Li, 2009). R&D activity is generally conceptualized as an input to the innovation process and can have substantial influence on the innovation performance of firms. In addition, R&D and ICT are both strongly associated with innovation and productivity, with ICT investment being more important for productivity (Hall et al., 2013). Moreover, management of innovation includes the use of available resources to generate novel methods to address organizational and marketing aspects of firm's activities (Birkinshaw et al., 2008). Hence innovation comprises both technological and non-technological aspects which are not mutually exclusive. Some other aspects are interconnected with innovation, for example: changes of work training, improvement of human capital, organizational change in business practices in workplace or in external relations.

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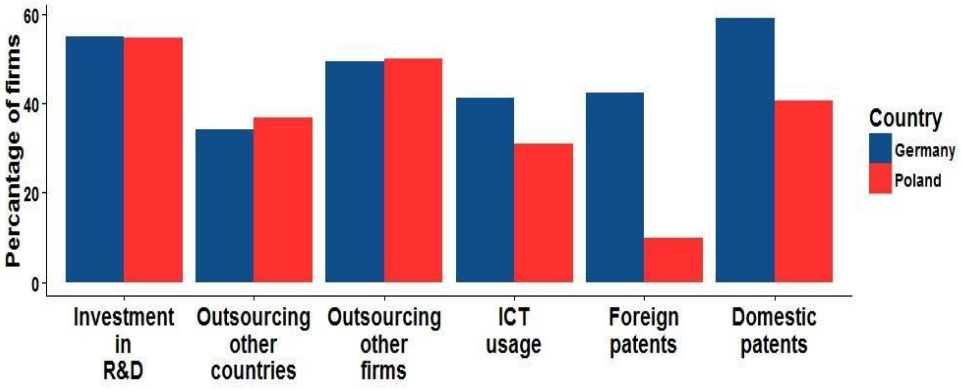

Fig. 2: Aspects of innovation. Source: Own elaboration. MOI survey.

Figure 2 presents comparison of aspects of innovation considered in the MOI survey. Firstly, 55% of German and Polish companies have invested in R&D activities, either in-house or contracted with other companies (outsourced). However, on average German manufacturing firms had almost three times higher R&D expenditures (3.36 millions of dollars compared to 1.2 millions of dollars in Poland). Furthermore, outsourcing is a possible way of acquiring better quality inputs or parts than firms which produce on their own. In both countries half of firms outsourced production to other companies and 37% of Polish firms and 34% of German firms outsourced production to other countries. Moreover, profitable application of the newly created knowledge is crucial. Development of new products or services is a prime source for gaining position in the market and competitive pressure is an incentive for firms to innovate and raise productivity. Around 82% of Polish and German establishment have introduced new product or services three years. Those new products or services have generated 27% and 22% of sales in Poland and in Germany respectively. Regarding information and communication technologies (ICT) indicator in German manufacturing firms on average 41% of employees regularly uses personal computers for their job, when in Poland it is 31%. Lastly, we compared patents as a measure of the output of innovation, which is associated with higher levels of productivity. Germany have better output 42% of companies registered patents abroad, when in Poland only 10% of companies. Domestic patents registered 59% of German firms and 41% of Polish firms.

3.3. Internationalization

Foreign presence of the companies is particularly important for diffusion of knowledge and innovation. Openness allows for international spillover effect, enhancement of their catching-up process through adaptation of advanced foreign technologies and improving their productivity. Moreover, firms operating on international markets face greater competition and hence a greater incentive to invest in R&D and innovation in order to remain competitive. Internationalization makes different varieties of capital goods more accessible, which increase efficiency (Caselli and Coleman II, 2001; Barro and Sala-i-Martin, 2004). Competition raises levels and growth of productivity, enable more productive firms to grow at the expense of others and gives firm's a clear incentive to improve performance (Disney et al., 2003). There is also considerable evidence that businesses that are able to compete internationally, as multinationals in global markets, are able to reap productivity benefits and able to grow as well as survive better in their domestic markets. To become internationally competitive, firms must be market oriented and offer products and

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services of international quality (Criscuolo and Martin, 2009). Moreover, studies have shown that competition is positively associated with innovation by firms (Aghion et al., 2005).

German companies are more present on international markets, then Polish. 85% of German manufacturing enterprises from the sample have establishments abroad, for Poland it is 66% of firms. In the case of 42% of German firms the main product is sold on international market, 45% on national and 13% local market. Polish firms mainly sold product across the country (59%), 37% on international market, 4% locally. This data grasp if firm has any foreign affiliation, but not the importance of the outward orientation, we do not dispose of information about the sales generated in each foreign establishment and amount of sales on foreign market. Furthermore, external consultants can be seen as a source of providing tactic technological know-how in improving management and adopting new, imported technology. 41% of Polish and 71% German firms have ever hired an external consultant to improve its area of management. In Germany and in Poland manufacturing enterprises have a similar business environment to compete. In both countries, 90% of companies admitted that compete with multinational firms and 75% with imports from abroad on their main product market. Moreover, there is huge number of competitors on establishments' main product market. 53% and 68% of companies pointed that they face more than five competitors on its main product market, in Germany and in Poland respectively.

3.4. Human capital

Presently the importance of human capital is much higher in knowledge economy than in industrial economy. Better quality human capital can help companies to develop their innovation activities as well as increase ability to absorb high technology knowledge from abroad. Greater human capital is complementarity for innovation and ICT use, also positively affects firm productivity (Brynjolfsson and Hitt, 2003; Iranzo et al., 2008; Arvanitis and Loukis, 2009). In addition, innovation abilities are strongly connected with human capital. Wide range of skills needed for innovation, including technical skills, academic skills, generic skills, creativity, soft skills, and management and entrepreneurial skills (Brown et al., 2001). In Poland on average in manufacturing enterprises share of workers with university degree is higher than in Germany. In Poland 10% of the full-time production workers, and 39% of the full-time non-production workers graduated from university. In Germany those rates are lower: 4% and 20% respectively. On contrary, in Poland on average only 3% of full-time top and middle managers have Master of Business Administration (MBA), where in Germany 23%. Lastly, top managers have on average 18 and 24 years of experience, in Poland and in Germany respectively.

4. Conclusions

We have shown empirical analysis of drivers of productivity based on the survey data from representative sample of manufacturing enterprises from Germany and Poland. Moreover, we have characterized German and Polish manufacturing enterprises including their economic performance. We aim to extend publications on firm-level productivity and innovation in European countries, presented as a comparative study based on survey data.

The following conclusions can be drawn from the present study. Firstly, in Poland huge percentage of companies is or were state-owned firms in the past. It can be a potential explanation of worse productivity performance and be factor that slows down innovative activities and improvement of efficiency. Secondly, manufacturing companies in both countries have similar patterns in internationalization and firm innovative activities. However, output of innovation approximated by patents and labour productivity are significantly higher in German sample. To sum up, Poland after transition made a huge step to restructure economy and Polish firms as much as Western European, have access to global technological and social development and

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hence may have a wide range of benefits. Therefore, notwithstanding the recent gains, significant challenges remain in sustaining firm productivity growth and compete on international markets.

The obtained results have some policy implications. Policy makers should adopt a mix of policies to foster innovation, for instance by easing access to finance, allowing firms to cooperate with other firms and technological institutions and increasing the amount of skilled personnel. Besides, the business environment of innovation is affected by government policy, provision of infrastructure, education, industrial relations, legal institutions and research funding. The main limitation of this research is relatively small sample of enterprises included in the MOI survey database and high number of missing financial data. We have in mind existing disparities caused by firm heterogeneity across Poland and Germany and across industries. Regarding importance of this topic especially for transition economies there is a need for more data including: more countries, improving indicators, collecting data from service enterprises and small and medium enterprises and longitudinal data. The results of the investigation extend publications on firm-level productivity and innovation in European countries based on survey data.

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Chapter 6

Article 5: ICT, Innovation and Productivity: Evidence Based on Polish Companies

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ICT, Innovation and Productivity: Evidence Based on Polish Companies

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Abstract. *The main motivation behind this study is to evaluate the relationships among information and communication technologies (ICT), organisational practices, internationalization, innovation and human capital in a sample of Polish companies. To examine that we used the data from the Polish companies survey conducted in 2015 for a representative sample of 805 companies. Using ordinary least squares modeling, we examined determinants of labour productivity. Our study is a one of the first empirical studies using this methodology for Polish companies. The principal finding that emerged from the study is that the presence of the ICT innovation was the main determinant of labour productivity. Moreover, other variables: operating on the international markets, education of the employees and executives and presence of the separate research and development department positively influence productivity. The results of the investigation bridge the gap in insufficient academic research about Central European countries and extend existing research on the company-level labour productivity determinants.*

Keywords: productivity, ICT, Polish companies

JEL Codes: L25, O33

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 ICT have a positive influence on the productivity growth. Moreover, they contribute indirectly by the generation of complementary innovations that improve the economy's Total Factor Productivity (TFP) (Pilat 2006; Jorgenson et al. 2011; Ceccobelli et al. 2012). However, ICT do not give rise to generalised productivity improvements until companies and their workers have achieved the required technological, educational/training, strategic, organisational, labour and cultural competencies. In this context, the effects of ICT on company productivity are indirect. The link between innovation and ICT has been identified in literature as a set of internal knowledge externalities to explain company productivity (Venturini, 2015). Complementary relationships (co-innovation) are established with other components, in particular with human capital and workplace innovations. These spillovers are widely demonstrated in research using company data (Cardona et al., 2013; Díaz-Chao et al., 2015).

Although the transition of Poland from centrally planned economy to market-driven system occurred more than two decades ago, the country still faces considerable challenges in adapting economy to effectively compete in regional and global markets. The key issue is to find a way to increase productivity and adapt Polish economies' structure to global-knowledge competition, promote co-innovation and develop new goods and services that respond to the changing domestic and international demands. Thus, the impact

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of digital technological changes and their co-innovation processes on productivity is an important aspect in the Polish economic performance.

The main objective of the presented research is to provide one of the first evidence of the relation between information and communication technologies, co-innovation productivity factors and productivity in Polish companies. The following is the main question underpinning the research: Does the existence of new co-innovative productivity sources (the ICT investment, workplace organisation and human capital) affect the performance of Polish companies?

The remainder of this paper is organised as follows: The data section describes the dataset from the survey in Polish companies. The empirical results section reports the results of the ordinary least squares (OLS) model and the empirical findings. Finally, the conclusion provides a summary, main limitations and recommendations based on those findings.

2. Data

The empirical descriptive and econometric analysis presented in this paper is based on data collected using structured questionnaire interviews conducted in Polish companies. The data was collected within the framework of the research project titled "Impact of Information and Communication Technologies on productivity – macro and micro analysis", financed by the National Science Centre Poland at the Department of Economic Policy, University of Lodz, Poland. The survey was undertaken in 2015, covering 1007 Polish companies. The companies were chosen using the stratified random sampling and covered the companies form the whole country. The questionnaire was developed and tested in pilot surveys prior to its implementation in the field. The topic of the project underlined, that the main requirement of the field-research was to include only those companies, which use information and communication technologies. As a result, questionnaire interviews were conducted only in those companies that had computers and benefit from ICT in at least two of the nine business areas of management in: administration, accounting, human resources, production, supply, customer relationship, enterprise resource planning, computer aided design or manufacturing, control of machines and production lines. The questionnaire comprised of 55 questions organised by topic. Initially, questions were posed about the areas of the usage of the ICT in the company's activities. This was followed by sections on company management practices, organisation, innovation and research and development (R&D). Furthermore followed the questions about level of the education of employees and training activities. Last section covers characteristics of the company, among others as legal status, ownership and number of years in operation. The interviews were conducted face-to-face with interviewers using the Pencil and Paper Interview (PAPI) survey method. The interviews were conducted with managers, precisely owners, co-owners, directors, CEOs, board members of the companies. The companies operate in different industries among others agriculture, industry, construction and trade.

3. Empirical results

In this research methodology is based on the Solow growth model (Solow 1957) and its subsequent elaboration by Jorgenson and Griliches (1967). This well-established traditional growth and productivity-accounting approach is used for the estimation of co-innovative sources of company productivity. As presented below, the efficiency component - Total Factor Productivity (TFP) incorporates the co-innovative productivity sources, which are the important growth factors complementing physical capital and labour. In the empirical analysis we use explanatory elements among others ICT investment, work organisation or human capital and they complete the analysis. Similar approach has been used in the company-level research

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in the United States (Bresnahan et al., 2002) or in the comparative study of Swiss and Greek companies (Arvanitis, Loukis, 2009).

The company production function of the Cobb-Douglas type takes the form:

$$Y_i = A_i f(K_i, L_i)$$

where, for any given company i, Y is the average gross salary of full-time employees in the company; A is the production efficiency (Total Factor Productivity); K is the input of physical capital; L is the input of labour.

The innovative sources of productivity are incorporated into the production efficiency indicator. This element shows the effects of company innovation that are not associated directly with factors of production. Thus, the indicator of efficiency A_i takes the following functional form:

$$A_i = \exp(\delta_0 INT + \delta_1 \mathrm{RD} + \delta_2 ORG + \delta_3 EDU + \delta_4 ICT)$$

Finally, the labour productivity function of the Polish companies, which would be estimated by the ordinary least squares (OLS) method, takes the following form:

$$\ln\mathrm{SALARY} = \beta_0 + \beta_1 \mathrm{INT} + \beta_2 \mathrm{RD} + \beta_3 \mathrm{ORG} + \beta_4 \mathrm{EDU} + \beta_5 \mathrm{ICT} + \beta_6 \ln\mathrm{SIZE} + \beta_7 \mathrm{SECTOR} + \varepsilon_i$$

where, β_0 (constant), β_i for i=1…7 represents the elasticities (coefficients) of the explanatory components of company productivity and εi is the estimation error.

The data collected through primary research is a rich source information on the Polish companies ICT usage, innovation activities and organization practices. However, the survey does not include the details of the financial situation in the companies. Despite ensured anonymity of the survey, the data on the balance sheet, profit and loss account, net turnover or the amount of the investment in the information and communication technologies were not collected. Usually the attempts to obtain such information result in the refusal to answer. Therefore, after the pilot survey it was decided not to incorporate in the questionnaire questions about the so-called 'sensitive data'. Despite of this limitation the microeconometric analysis has been performed. As a proxy of the productivity and the dependant variable we use the logarithm of average gross salary of full-time employees (SALARY). Salary is an approximation of the labour efficiency. In line with the neoclassical approach salary is a marginal productivity of labour. The salary used to determine the relationship from the salary structure to company productivity was used in the recent empirical evidence (Lallemand et al. 2009; Faggio et al. 2010; Mahy et al. 2011).

The information on the employee's salary was missing in 146 results of interviews and this companies were excluded from the analysis. Moreover, 55 companies had a missing values for the independent variables and were also excluded from the analysis. The final sample for the analysis counts 805 companies. The sample size is large enough to split the data on the subsets regarding the number of the employees of the company. The sample is split into four subsets: micro enterprises (less than 10 employees), small enterprises (10-49 employees), medium enterprises (50-249 employees) and large enterprises (more than 250 employees).

The labour input (L) from the Solow growth model is approximated by logarithm of number of full-time employees - variable SIZE. The set of independent variables is used to examine the hypothesis on the positive impact of those variables on productivity. We have included five independent variables: INT, RD,

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EDU, ORG and ICT. The estimated model includes also the control variable SECTOR, which is a industrial sector of the company.

The dummy variable INT indicator of institutional conditions, takes value 1 when the company is operating in the international market and 0 if otherwise. To show a company's innovatory dynamics, we used variable RD: innovation which takes value 1 when the company has separated R&D department and 0 if otherwise.

For the needs of the econometric modelling we created two indices ORG i EDU. ORG is a indicator of the work organisation. The create this index we used answers on questions: 1) if the implementation of the information and telecommunication technologies brought the changes in the business functions of the company (ORG1); 2) if employees can manage their own time independently (ORG2); if employees can participate in initiating or making changes in the company (ORG3).

To take into account the different scaling across organisation practices and questions regarding education. To calculate indices we followed the procedure used by Bloom et al. (2012). The scores were converted to z-scores by normalising each practice (i.e. each question) to the mean of zero and the standard deviation of one:

$$z_{p_i} = \frac{p_{i-\overline{p_i}}}{\sigma_{p_i}}$$

where: z_{pi} is a z-score for a question pi for a company *i*, p_i is an unweighted average for a question p_i for all the companies, and σ_{pi} is a standard deviation for a question pi for all the companies.

Furthermore, z-scores for each company are added:

$$M_i = z_{p_1} + z_{p_2} + z_{p_3}$$

In the last step the sum if the results is normalised by subtraction of the average for each observation and then division of the difference by the standard deviation:

$$z_i = \frac{M_i - \overline{M_i}}{\sigma_i}$$

As a result of this transformation the average for ORG indices is equal to zero. The negative values mean worse organisational practices in the company and positive values - better performance than average for all companies in the analysis.

The same method was used to create EDU variable. The index is composed by the answers on three questions regarding education level of executives (EDU1), education level of employees (EDU2) and assessment of the skill level of the employees by executives (EDU3). The negative deviation of the index from zero means lower level of the human capital, while the positive deviation means the higher level of the human capital.

Lastly, the variable ICT; has a value 1 when the company has invested in the information and communication technologies during last 24 months before the interview and 0 if otherwise.

Table 1: Variables and indicators used for the model estimation

Variable	Definition	Indicator	Values
SALARY	Average gross salary of full-time employees in the company	Productivity	Natural logarithm
SIZE	Number of employees employed on a full-time	Labour	Natural logarithm
SECTOR	Industry sector	Control variable	1. Agriculture 2. Industry

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			3. Construction 4. Trade 5. Other services 6. Production and commercial 7. Other
INT	Operating in the international market	Institutional conditions	1. Yes 0. No
RD	Presence of separated R&D department	Innovation	1. Yes 0. No
ORG1	Presence of changes in company's business functions with the implementation of ICT	Organisation	1. Yes 0. No
ORG2	Employees can manage their own time independently	Organisation	6. Always 5. Very often 4. Often 3. Rarely 2. Very rarely 1. Never
ORG3	Employees can participate in initiating or making changes in the company	Organisation	6. Always 5. Very often 4. Often 3. Rarely 2. Very rarely 1. Never
EDU1	Education level of executives	Education	3. Higher education 2. Secondary education 1. Below secondary education
EDU2	Education level of employees	Education	3. Higher education 2. Secondary education 1. Below secondary education
EDU3	Assessment of the skill level of the employees by executives	Education	1. Employees perform well all commissioned work 0. Other
ICT	Presence of the ICT investment in the last 24 months	Information and communication technologies	1. Yes 0. No

Source: Own elaboration

The results of the ordinary least squares estimation of the productivity of Polish companies are presented in Table 2. We estimated the model for all the companies and sample divisions for according to the size: micro, small, medium and large. The models include sector-fixed effects as the additional control that will affect productivity. All the models estimated are significant (p-value<0.000) and the level of adjustment (adjusted R^2) is satisfactory and varies from 20% to 36%. The set of diagnostic tests was performed to test the assumptions of the classical linear regression model: general form specification test, variance homoscedasticity, autocorrelation and normality of the distribution of the residual. The results of most of the tests confirmed that the models are valid for the interpretation.

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The results of estimation confirmed that investment in the information and communication technologies is significant variable for the whole sample ($\beta = 0{,}145$, $p < 0{,}001$) and for the other subsamples, but medium companies. In line with the stated hypothesis in all subsamples, but small companies, presence of separate R&D department leads to higher levels of the labour productivity. The causal relationship between education and productivity approximated by the index EDU is statistically significant and as expected has a positive direction. This relationship is not present in the large companies subsample. However, the hypothesis regarding the positive influence of the organisational practices has been not confirmed by the model. This variable is only significant for the medium companies ($\beta = 0{,}069$, $p < 0{,}05$). The international presence of the company positively influence the productivity levels in the all companies sample ($\beta = 0{,}054$, $p < 0{,}05$) and for the small companies ($\beta = 0{,}137$, $p < 0{,}05$).

Table 2: Influence of ICT and complementarities on labour productivity

Variable	All	Micro	Small	Medium	Large
(Intercept)	7,515***	7,358***	7,702***	7,355***	7,751***
	(0,173)	(0,275)	(0,379)	(0,366)	(0,239)
INT	0,054*	0,055	0,137*	–0,004	0,038
	(0,026)	(0,044)	(0,068)	(0,053)	(0,066)
RD	0,121***	0,179**	0,063	0,122*	0,140*
	(0,029)	(0,059)	(0,093)	(0,053)	(0,064)
ORG	0,025	0,010	–0,026	0,069*	0,068
	(0,015)	(0,023)	(0,041)	(0,032)	(0,038)
EDU	0,066***	0,053*	0,086*	0,081*	0,057
	(0,015)	(0,022)	(0,040)	(0,034)	(0,041)
ICT	0,145***	0,146***	0,223***	0,084	0,140*
	(0,023)	(0,032)	(0,061)	(0,050)	(0,066)
SIZE	0,025***	0,091**	-0,044	0,071	–0,004
	(0,007)	(0,028)	(0,060)	(0,046)	(0,037)
SECTOR	Yes	Yes	Yes	Yes	Yes
R^2	0,277	0,246	0,204	0,325	0,261
Adj. R^2	0,266	0,219	0,139	0,280	0,200
P-value	0,000	0,000	0,000	0,000	0,000
Num. obs.	805	348	146	178	133

Note: *** $p < 0{,}001$, ** $p < 0{,}01$, * $p < 0{,}05$; the standard error in brackets.
Source: Own elaboration.

4. Conclusions

The relationship between productivity and co-innovative sources of company productivity has been widely investigated, but mainly in the high developed countries. This paper provides new empirical evidence from Poland, post communist country. We use the new data collected by survey in the representative sample of Polish companies in 2015.

We verified the hypothesis about the positive influence of indices of innovation, internationalization, management practices, education and ICT investment on the productivity of the companies. The results of the ordinary least squares model were presented for the total sample and subsamples divided by the size of companies. The results differs between the samples. The ICT investment and presence of separate R&D department and human capital are the main factors influencing company's productivity. The management practices and internationalization to the lesser extend, or appeared to be insignificant. All in all, the ICT investment should go hand in hand with other determinants of productivity. Policy makers should have in

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mind the presence and importance of the joint promotion of co-innovation productivity factors to boost company's productivity.

The main limitation of this study is a missing financial data, which would be a better approximation for the company's labour productivity. Moreover, all variables are derived from the questionnaire based on the scaled data. Usage of the discrete variables instead continuous variables causes more issues in obtaining stable econometric model and may cause bias in the estimates. Moreover, we have in mind existing disparities in labour productivity caused by company heterogeneity across industries and with different size. This topic is of great importance and more country data should be collected covering especially small and medium enterprises, to identify the problems which are faced by companies.

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Chapter 7

Conclusion

7.1 Impact of the research

In this dissertation, I have attempted to show the importance of studying the role of information and telecommunication technologies in the productivity of the Central and Eastern European countries. I believe this research has had an impact on the real world, helping individuals and organisations to understand the theme better and to a greater extend. I hope that the results will be of use for academics, company management organisations and policy makers.

7.2 Research implications

In the introduction to the dissertation, I identified information about the journals in which the publications are published and the basic idea of each of the articles contained within the dissertation. In the following paragraphs, I will take this step further by going trough each dissertation paper and discussing the implications and conclusions of each article.

7.2.1 Article 1: The role of ICT in the productivity of Central and Eastern European countries: cross-country comparison

The main purpose of the publication is to evaluate the stage of transition towards the knowledge economy in the Central and Eastern countries. The first result presented in this study showed that labour productivity levels strongly increased in CEE countries when compared with the levels in the second half of the 90's. However, productivity levels in the CEE economies are still below those in the majority of other EU countries. Furthermore, analysis of the complementary factors to the ICT showed that CEE countries lag behind in economic development. The percentage of labour force in the tertiary education and technical professions is on average lower in comparison with Western European countries. Moreover, there is an existing digital divide, indicated by a lower Internet usage and insufficient ICT infrastructure such as the high-speed Internet access. Innovation indicators are also below EU averages with only Slovenia above the average. In addition, the business environment in Central and Eastern countries is negatively affected by corruption. Further conclusions from the empirical panel model analysis affirm the importance of the complementarities to ICT investment, although

the causal relationships differ between the periods and samples of the countries. To summarise the progress achieved in recent years in the Central and Eastern European economies is significant, while still showing a huge room for improvement in terms of all crucial factors for the knowledge economy.

7.2.2 Article 2: Labour productivity, ICT and complementary factors in the CEE region

Analysis presented in the paper shows that ICT capital between 2000 and 2014 grew by 18 percent and the average contribution of ICT capital to GDP growth in the Central and Eastern European region was above that in 14 Western European countries considered in the study. Moreover, the total factor productivity on average had positive contribution to the economic growth. The results of panel model indicate that variables related to human capital appeared to be significant in explaining labour productivity growth. Moreover, the sources of productivity proved to be sensitive to the cyclical changes in the economy. In addition, in the time of crisis in all European economies trade liberalisation and openness to foreign investments is a significant factor. It is crucial for the successful implementation of new technologies, boosting innovation and dissemination of knowledge.

7.2.3 Article 3: ICT, Innovation and Productivity: Evidence Based on Eastern European Manufacturing Companies

The main purpose of this paper is to provide one of the first company-level evidence on the role of the ICT and productivity from Central and Eastern Europe and present the original methodology, which is a structural equation modelling, applied in this type of research. At the beginning of the paper, we present a survey of the recent literature focused on ICT developments and its contributions to productivity as well as to the determinants of productivity in Central and Eastern Europe. The results of the ordinary least squares (OLS) model show that labour productivity is explained by physical capital represented by the wage of full-time employees. The other co-innovation productivity sources appear to be significant, depending on the country: mainly the presence of the high-speed Internet connection, level of education of the employees and management quality. Empirical analysis using the structural equation model (SEM) enabled the identification of direct and indirect relationships among ICT and its complementarities and

productivity. In line with the results of the OLS, the wage of full-time employees is the main determinant of company productivity. Moreover, the set of causal relationships is confirmed, such as ICT usage and infrastructure, innovation, education and management quality. The results stemming from the analysis confirm the importance of the co-innovation productivity sources, underlying the interdependence of different variables and their direct and indirect impact on labour productivity.

7.2.4 Article 4: Drivers of Manufacturing Firms Productivity in Germany and Poland: Evidence from Survey Data

The objective of this publications is to present results of the company-level comparative study between German and Polish manufacturing companies. The main focus are the drivers of labour productivity: innovation, internationalisation and human capital. The first finding is that in Poland a huge percentage of companies is or was state-owned in the past. This can be a possible negative effect on the productivity levels and the slow improvements in efficiency. Moreover, the innovative activities and diffusion of knowledge can be slow. Also, the patterns in internationalisation and company innovative activities are similar in both countries. However, outputs of innovation and productivity are significantly higher in the German sample.

7.2.5 Article 5: ICT, Innovation and Productivity: Evidence Based on Polish Companies

The goal of this paper is to present the first evidence of the relation between information and communication technologies, co-innovation productivity factors and productivity in Polish companies. The data used is coming from the recent survey conducted in 2015 for representative sample of Polish companies from the different branches and size. The analysis was done the ordinary least squares estimation with the sector-fixed effects. The main findings that emerged from the study is that ICT investment and presence of separate R&D department and human capital are improving the companies productivity.

7.3 Policy implications

The countries in Central and Eastern Europe have achieved a significant economic progress and substantial improvement of living standards since the times of communism. Their process of striving towards market economies was difficult, especially in terms of institutional reforms in areas such as governance, competition policy, labour markets, privatisation and enterprise restructuring. Under communism, business activity was governed by central planning, political decisions and often corruption (Roaf et al., 2014). Moreover, the university education system was heavily centralised and devoid of any economic competition resulted in high inefficiency and over-employment. The Communist Party monitored the education system, research goals and the assignment of positions. Furthermore, the financing of universities was entirely dependent on the government. To a large extent, the universities in Central and Eastern Europe had been transformed and had become autonomous, but in the post-communism period they were short of funds and sorely needed higher education reforms. Therefore, universities increasingly turned to teaching rather than to research and development of knowledge. Low academic salaries lead to many academics simultaneously teaching at public and private institutions, which were introducing fee-based curricula. This focus on teaching activities led to research occupying a subordinate place and the public losing interest in universities as knowledge-generating incubators (Kwiek 2012). In the CEE countries, the flow of knowledge between science and industry and the ability to conduct research in partnership with the enterprise sector is weak and jam-packed with difficulties when it comes to disseminating the existing results to business. The higher education and innovation are important for economic competitiveness, however, according to Porter (1990), these countries also lag behind in terms of other pillars of economic competitiveness, which are structural, extremely difficult to overcome and requiring both time and funding (Kwiek 2012). The wide gap between Eastern and Western Europe is related to many factors including tax and legal systems, quality of infrastructure, company spending on R&D, access to founding or ease of doing business (Schwab 2010). A few of the recent International Monetary Fund recommendations for the economic growth of areas of Central and Eastern Europe (Roaf et al., 2014) relevant to the topic of my research are as follows: improving the business and investment climate, which will stimulate entrepreneurship; improve productivity and create more jobs; the development of a strong and independent supervision of the banking system; the revival of credit growth and broadening of small and medium enterprises access to finance.

The results of my research brings a few policy recommendation. Policy makers should support ICT use, reduce the digital divide and avoid inhibiting policies such as taxes or charges. The public policies should promote and implement support programs that will not only provide resources for the acquisitions of new technologies, but also simultaneously provide advisory services, help with training activities within the programme and support the organisational changes needed to implement technology. Knowledge of the indirect relations between the factors affecting the labour productivity relations is useful for policy makers because it can lead to the more efficient choices and linking policy initiatives and measures. This will ensure a complex implementation of technology and maximise the benefits of the new solutions. Incomplete public policies designed to promote ICT use without considering the other determinants of the co-innovative productivity sources may not achieve their targets. In addition, public policies should strengthen the link between productivity and internationalisation by promoting programmes that facilitate knowledge spillovers. Moreover, the research showed significant digital divide between the Central and Eastern European and Western European countries. There is a need of the increase of digital literacy and further development in the human capital, especially to cover the shortage of engineers and qualified workers, which would possibly lead to an increase in labour productivity. In addition, it is important to improve quality of education and encourage more people to enrol in technical and mathematical studies in order to restructure the labour force. This could be partially achieved by scholarship programs for technical studies to promote technical professions, which faces the shortage of workers in the CEE countries.

Moreover, the acquisition of new technological solutions in the company requires a change of the managerial model of the company. Firstly, the implementation of new technology involves comprehensive processes. Beside buying a new IT equipment or software business processes should be simultaneously modified, the employees trained and the expansion plans continuously improved to accommodate the new skills. In addition, changes in the work organisation can be required e.g. flexible working hours or an increase in team work. After technology implementation, it is important to monitor the results brought by the new features and implement further changes in the company organisation structure and ensure to maintain a sufficient number of skilled and trained employees.

7.4 Research limitations and future lines of research

Presented research has certain limitations. The main limitation of macroeconomic level research is a relatively small sample of countries included in econometric estimation. Moreover, it would enrich the research if we were to cover the latest periods and more countries in the estimation and the descriptive analysis. Unfortunately, data on the ICT spending was not available for all the European Union countries and Cyprus, Estonia, Latvia, Lithuania, Luxembourg and Malta were excluded from the analysis due to the lack of data on ICT capital. In the study at the microeconomic level, the main limitation is a relatively small sample of companies included in the the Management, Organisation and Innovation (MOI) Survey 2009 dataset and the high number of missing financial data. Due to this fact, I could include only 444 companies from 6 countries in my modelling and analysis. Sample size makes the statistical significance hard to interpret. In small studies, the confidence intervals are narrower and the estimates can be less precise. Moreover, unobserved heterogeneity or simultaneity of issues can appear. In addition, there are existing disparities in labour productivity caused by company heterogeneity across countries and across industries. This implies that more factors influence labour productivity that we may not have taken into consideration. In the second microeconomic study based on the data from Polish companies as in MOI survey the main limitation is a missing financial data, which would be a better approximation for the company's labour productivity. Moreover, all variables are derived from the questionnaire based on the scaled data. Usage of the discrete variables instead continuous variables causes more issues in obtaining stable econometric model and may cause bias in the estimates. In addition, there are existing disparities in labour productivity caused by company heterogeneity across industries and with different size.

Regarding the importance of this topic, especially for transition economies, there is a real need to conduct further research studies in this area. The future lines of research are mainly connected to data availability. This includes macro-level analyses (with more countries, improved indicators and more reliable longitudinal data taken into account), as well as micro-level studies. Company-level research requires collecting primary data from small, medium and large enterprises. The usage of ICT is expanding at an accelerated pace and there is a clear need for analysis of the complementary factors mainly at the company-level, to fully take an advantage of these improvements.

7.5 General conclusions

Study of the role of information and communication technologies in the labour productivity is important to extend the existing empirical evidence presented in the literature focused on this topic. Unfortunately, there is scarcity of evidence from the Central and Eastern European countries. In this dissertation, I have attempted to bring more attention to the topic of ICT and productivity in the CEE countries by publishing my research in academic journals. I have also made an effort to spur more attention and debate of the study of ICT in the countries of Central and Eastern Europe by attending and presenting the research at various international conferences. In fact, while still a doctoral student, the research that Joan Torrent-Sellens and I had done, I presented in Santander at the XV World Economy Meeting, in Budapest at the 13th European Association of Comparative Economic Studies (EACES) biennial conference and in Cambridge at the British Association for Slavonic and East European Studies (BASEES) Annual Conference. Moreover, I was pleased to be invited by the Centre for European Policy Studies in Brussels to attend the Winter school: "New skills and occupations in Europe: Challenges and possibilities". I also was invited by Professor Knut Blind to stay for three months as a visiting scholar at the Chair for Innovation Economics at the Institute for Technology and Management of the Technical University of Berlin, where I presented my results at an open seminar and got valuable feedback from the faculty researchers.

My primary thesis proposal, thanks to Dr. Łukasz Arendt, evolved in the research project titled, "Information and Communication Technologies and productivity in Poland and Central and Eastern European countries". The proposal won the grant from the National Science Centre in Poland. This project allowed to conduct a large scale survey in Polish companies on ICT, innovation and organisational practices. The results of the project with the new empirical evidence are presented in the book "Information and Communication Technologies and productivity in Poland and Central and Eastern European countries" (in Polish) published by Lodz University Press in 2016. The book is co-authored by Arendt, Krynska, Skorupinska, Grabowski and Kukulak-Dolata. Data collected during this project has also been used for publications and conference presentations. I hope that this research will have practical implications in the business environment in Poland.

In conclusion, the purpose of this dissertations has been to stress the importance of co-innovation complementary factors to investment in information and communication technologies and their important contribution to labour productivity growth. Above all, it is crucial to invest in the human capital, implement organisational changes and

invest in innovation processes. The papers presented in my dissertation provide insight into the role of information and communication technologies and co-innovation in the productivity of the Central and Eastern European countries. The macroeconomic papers present a comparison of the countries of the European Union. The microeconomic papers show the importance of co-innovative productivity factors in the Central and Eastern European manufacturing companies. I would like to emphasise the importance of continuing investment in modern technologies for Central and Eastern European economies, openness to trade as a prerequisite for access to such technologies and a growing investment in both the quality of human resources and in research and development.

7.6 References

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