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ASSESSING THE IMPORTANCE OF ICT ADOPTION FOR PRODUCTIVTY IN ESTONIA

Master’s thesis

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Abstract

We study the effects of Information and Communication Technology (ICT) on firm productivity of Estonian enterprises combining two data sets - Innovation Technology Survey (IT) and Business Registry. The ICT solutions we study in our analysis are Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), download speed and share of employees using internet-connected computers. To investigate the relationship between ICT and productivity we use OLS and Fixed Effects (FE) estimation techniques and Propensity Score Matching (PSM). Our findings show that while looking at between firm variations, firms adopting the aforementioned digital technologies have higher productivity than those who do not adopt. However, when analyzing the within-firm effects with the FE model, we find that the adoption of ERP and CRM has no significant effect on firm productivity in the period of treatment. Meanwhile, PSM findings show a significant effect of ERP and CRM on TFP, indicating that firms adopting ERP and CRM in period t have higher productivity in period t+1. In the case of labor productivity, however, we do not see the same effects. While the impact of adoption becomes significant in the subsequent period for labor productivity, in the case of TFP, the significant effect in the first period fades away in the second.

Keywords: ICT adoption, productivity, ERP, CRM

Info-ja kommunikatsioonitehnoloogiate kasutusele võtmise tähtsus Eesti ettevõtetes

Käesolev uurimus analüüsib Eesti ettevõtetes info- ja kommunikatsioonitehnoloogiate (IKT) kasutamise seost ettevõtete tootlikkusega. Erinevatest IKT rakendustest uurime me täpsemalt ettevõtte ressursside planeerimise (enterprise resource planning, ERP), kliendisuhete juhtimise (customer relationship management, CRM), allalaadimise kiiruse, Internetti ühendatud arvuteid kasutavate töötajate osakaalu seost tootlikkusega. Analüüsis kasutatud andmestik ühendab andmeid Eesti Statistikaameti poolt läbiviidavast uuringust „Infotehnoloogia ettevõttes“ ja Eesti Äriregistrist. Andmed hõlmavad kokku 5,545 unikaalset ettevõtetet, kes osalesid aastatel 2014-2019 vähemalt korra mainitud uuringus ja kasutasid vähemalt ühte mainitud IKT lahendustest. Tootlikkuse mõjude hindamiseks kasutatakse nii tööjõu tootlikkust kui tootmistegurite kogutootlikkust, viimane on seejuures mõõdetud Levinsohni ja Petrini (2003) lähenemisega. IKT kasutamise ja tootlikkuse seoste analüüsimiseks kasutatakse tavalist vähimruutude meetodit ning ettevõtte fikseeritud efektidega mudeleid ning tõenäosuslikku sobitamist. Meie tulemuste kohaselt on ülalmainitud IKT lahenduste kasutusele võtmine ettevõttes seotud statistiliselt oluliselt kõrgema tootlikkusega vaadates andmetes varieeruvust üle ettevõtete, kuid statistiliselt ebaoluline vaadates muutusi ühe ettevõtte piires. Analüüsides seoseid eraldi tööstuse ja teenindussektori lõikes ilmnes, et analüüsitud IKT lahenduste kasutuselevõtt seondub kõrgema tööjõu tootlikkusega mõlemas sektoris. Samas, me ei leidnud tõendust, et ERP lahenduste kasutamine seonduks kõrgema tootmistegurite kogutootlikkusega tööstussektoris, samuti osutus statistiliselt ebaoluliseks IKT lahenduste ja tootlikkuse seos ettevõtete fikseeritud efektidega mudelis. Tõenäosusliku sobitamise mudeliga tehtud analüüs näitas nii ERP kui CRM lahenduste positiivset mõju tootmistegurite kogutootlikkusele kuid mitte tõõjõu tootlikkusele esimesel aastal peale vastava lahenduse kasutuselevõtmist, teisel aastal peale lahenduse kasutuselevõtmist ilmnes omakorda positiivne mõju tööjõu tootlikkusele kuid mitte tootmistegurite kogutootlikkusele. Antud tulemusi võib tingida see, et tootmistegurite kogutootlikkus arvestab ka kapitaliga, niisiis selle tootlikkuse mõõdiku kasv analüüsitud IKT lahenduste kasutuselevõtmise tulemusena eeldab täiendavate komplementaarsuste kasutamist.

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1. Introduction

In the world of digitalization the global economy is shaped by technological innovations. The intensive use of information and communication technology (ICTs) since the early 1990s has introduced a new perspective on the way firms work and their productivity.

Productivity determines the success of the economy on micro and macro levels and this is because productive countries and firms tend to have more wealth. Therefore, specifying the common drivers of productivity becomes one of the principal research areas for the researchers and policymakers. The research of productivity growth triggers has become an important topic since European firms lacked the productivity level compared to US firms during the 1990s and 2000s (Basu et al., 2003; Van Ark et al., 2002). ICT was assumed to be one of those main drivers of productivity, which was also considered as a special case of general purpose technologies that leads to further technological advancements (Basu and Fernald, 2007). Nevertheless, the benefits of ICT were not the same for all the developed countries including the EU countries, as the capital intensiveness of Europe lagged compared to the US (Cardona et al., 2013). In addition to the nation-wide results, it became obvious that ICT investments and adoption are observed to be clearly significant in firm-level results too (Cardona et al., 2013).

As ICTs become a regular part of the everyday lives of the organizations, the change in IT also shapes the way businesses operate and affects the markets. Hereby, it draws the attention of academic researchers to identify how ICT exactly affects the economy at different levels. Thus, a variety of academic work presents an influence of ICT on the production process and its efficiency growth (Castiglione and Infante, 2013; Strohmaier and Rainer, 2015; Basu and Fernald, 2007; Relich, 2017), however, different study levels give different results. Although the majority of empirical studies show a positive relationship between ICT and firm level productivity it depends on the methodology acquired during the research (Cardona et al., 2013).

This research adds to the current empirical literature by investigating the relationship between productivity of firms and ICT, particularly of Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), download speed, and share of internet-connected computer use. ERP and CRM are frequently used to replace outdated software that is often weakly connected, with the purpose to lower infrastructure support costs. Furthermore, developments in operational integration achieved by enterprise software can have a positive impact on the overall company and, as a result, firm performance (Engelstätter, 2009). Moreover, we look at the effects of download speed because faster download speed makes it easier for businesses to implement new digital technology, which can also have an effect on their performance and productivity. This study makes use of a combined data set, which merges two separate data sets, namely the Information Technology survey and the Business Registry, for research, covering 5,545 unique firms in total. As IT survey has been conducted since 2014 and Business Registry Data is not available after year 2019, we are constrained to use 2014-2019 time period to do the analysis. Using this data allows us to investigate the impact of ICT on productivity of a relatively large number of firms in recent years.

In this paper we look at how labor productivity and total factor productivity (TFP) are separately affected by ICT solutions. We used Levinsohn and Petrin (2003) methodology to calculate the total factor productivity. The research is done by executing OLS and Fixed effects (FE) estimation methods and Propensity Score Matching (PSM) technique.

To sum up, we study the effects of ICT variables, like ERP, CRM, download speed and share of internet-connected computer use on both labor and total factor productivity of Estonian firms. In our analysis of between firm variations, we report higher total factor and labor productivity for the firms who adopt ERP, CRM, higher download speed and higher share of internet-connected computer use. Nevertheless, using FE models we observe that ERP and CRM do not have significant influence on firm level productivity in the period of treatment. At the same time, matching analysis finds that enterprises adopting ERP and CRM at time t have higher total factor productivity in time t+1. However, we do not observe such an effect on labor productivity. In addition, we find that effects of ERP and CRM on labor productivity become significant in the following period, as employees acquire better skills on the field throughout the time. Meanwhile, we cannot observe the significant influence of these technologies on TFP in the next period, as we did in the previous one. The explanation for this may be that TFP also controls for capital, necessitating additional complementarities for higher productivity.

To see if the effects of ICT solutions are similar for all firms in different sectors we implemented our analysis separately on firms in services and manufacturing sectors. Firms that adopt any of the mentioned digital technologies have higher labor productivity in both sectors. However, we cannot observe the significant effect of ERP adoption while assessing its relationship with TFP of firms in the manufacturing sector. We do not observe significant effects of ERP and CRM for either of sectors while using FE and PSM methods to assess within firm effects.

This article is organized as follows. Section 2 compares evidence of ICT effects on productivity from various theoretical and empirical literature. In Section 3, we use descriptive statistics to present the sources of the data sets used in the analysis. Section 4 covers the methodology used to do the analysis throughout the paper. Section 5 presents the empirical findings from the regression analysis and propensity score matching. In the final section we conclude with the summary of the results.

2. Literature Review

Wide-spread computer age statement and "productivity paradox" by Robert Solow (1987) was the topic for debate throughout the years. Solow stated that the computer age was everywhere except for the productivity statistics, implying that as firms make more investment in information technology (IT), labor productivity may decrease rather than increase. After Brynjolfsson and Hitt (1996) provided substantial firm-level evidence indicating that the paradox had become redundant by the beginning of the 1990s and asserting the value of information and communication technologies in productivity development, the paradox no longer seemed to be valid. Subsequently, several researchers also found a significantly positive effect of ICT on firm-level productivity (O'Mahony and Vecchi, 2005; Bloom et al., 2012; Brynjolfsson and Hitt, 2003; Sanchez et al., 2006; Koellinger, 2006).

Before analyzing the effects of ICT on productivity, we would like to define the terms productivity and ICT separately. Productivity is considered to be efficiency[1] in production, which is simply an output-input ratio (Syverson, 2011). While analyzing productivity two main practices are used: single-factor productivity and total factor productivity (TFP). Single-factor productivity takes into consideration just one particular type of input. Labor productivity is considered to be the most commonly used practice of this type. (Syverson, 2011). Total factor productivity, on the other hand, is the unobservable efficiency with which the various inputs operate to produce output. Though TFP is invariant to the intensity with which observable factor inputs are employed in the production process. (Syverson, 2011).

Throughout history there have been a number of radical innovations that have altered the way economy works (Strohmaier and Rainer, 2015). This form of major technological transition can be captured by the concept of general purpose technologies (GPTs), like the steam engine, electricity etc., given its widespread usage and ability to increase the overall innovation rate (Bresnahan and Trajtenberg, 1995).

When it comes to ICT, some articles regard it as one of the types of GPT and discuss its productivity impact, while others attempt to figure out whether ICT can be considered a

[1] Here efficiency is referred to how effectively production inputs such as labor and capital are used to generate a given amount of output.

GPT or not. According to Bresnahan and Trajtenberg (1995) ICT is considered to be a new GPT if it has the features of “pervasiveness, technological dynamism and innovation complementarities”. As General Purpose Technologies progress, they extend across the economy, resulting in and encouraging generalized gains in productivity. Taking technical advancement in ICT development exogenous, Basu and Fernald (2007) used the neoclassical growth approach to evaluate the general-purpose nature of ICT in their study. Here neoclassical approach refers to the ICT using firms, which configures their organizational capital by reacting to new powerful computers and software. Thus, in this paper ICT is indeed considered as general purpose technology. Moreover, Castiglione and Infante (2013) confirmed the hypothesis that ICT is general purpose technology by observing the influence of ICT on various aspects of manufacturing firms (e.g. firms investing in ICT use fewer workers in the production process). Strohmaier and Rainer (2015) also assessed the effect of ICT on labor productivity by referring to ICT as GPT. However, Cardona et al. (2013) could not conclude on any evidence that ICT is general purpose technology.

A wide variety of research has looked into the relationship between ICT and productivity on an empirical basis. Strohmaier and Rainer (2015) provided a detailed analysis of the impact of the information and communication technology as GPT on aggregate and sectoral labor growth in Denmark from 1996 to 2007. They identified a major impact of strong ICT diffusion on growth only after 2000, as a result of technical change, substitution, and capital deepening, as well as potential relations to skill-induced wage dispersion. Despite the fact that ICT-producing and ICT-using businesses are adding more on the overall growth, it took two decades for ICT to become a significant source of productivity growth, showing the long time it takes for a GPT to develop and the economy to adapt to modern technologies. In their studies Castiglione, Infante (2013) and Basu, Fernald (2007) investigated the impact of ICT on total factor productivity as a general purpose technology and reported a positive relationship. Cardona et al. (2013) surveyed a variety of empirical research and concluded that the effect of ICT on productivity is significantly positive and increasing over the years. Hall et al. (2013) evaluated innovation and productivity in Italian manufacturing companies from 1995 to 2006, using R&D and ICT investment as the two key inputs. They emphasized the importance of R&D for innovation and ICT investment for productivity of firms by using the CDM model augmented with ICT as an enabler of innovation and organizational innovation as an indicator of innovation output.

With a growing consensus that ICT adoption has improved growth in the United States, more evidence is becoming available that Europe is clearly lagging in this regard. Labor and total factor productivity accelerated in the United States after the mid-1990s, but not in most other major economies (Basu et al., 2003). An increasing body of study has looked into the sources of the US productivity growth acceleration, with the majority of studies concluding that the acceleration is due to underlying technological advancements.

Using aggregate national accounts data from 1980 to 2000, Van Ark et al. (2002) provided a reasonably detailed comparison of the 12 European Union countries and the United States. Labor and total factor productivity grew much faster in the EU than in the US in the 1980s and the first half of the 1990s, according to the findings, though the situation reversed in the second half of the decade. Consequently, labor productivity in the United States increased 0.75 percentage point per year faster than in the European Union between 1995 and 2000. Van Ark et al. found that some of this U.S. benefit was due to a higher contribution to labor efficiency from ICT usage, and some reflected a greater contribution of ICT output to TFP growth, using more precise growth accounting. O'Mahony et al. (2005) on the other hand looked at the impact of ICT capital on real output growth in the USA and the UK using industry data for both countries. After combining data for both the USA and the UK, and analyzing it using dynamic panel data estimation technique, they discovered that ICT has a positive and significant effect on output development. Individual country findings in the United States indicate a substantial impact, while results in the United Kingdom are less definitive. As one of the reasons of higher productivity growth in the USA than in the EU, Ark et al. (2003) pointed to the higher share of employees working for ICT producing sector. Biagi and Federico (2013) concluded that ICT played a significant role in the productivity acceleration seen in the United States from 1995 to 2005. They were unable to draw precise conclusions for the EU, however, because some countries took full advantage of the opportunities provided by digital technology, while others did not. Overall, they concluded that ICT is primarily responsible for the difference in productivity directions observed between 1995 and 2005 in the United States and the European Union. Bloom et al. (2012) looked into the productivity impact on US multinationals in the EU to better understand the contrasting paths of ICT adoption in two regions. According to the authors, the United States IT productivity advantage stemmed primarily from the country's tougher human resource management policies.

In the next strand of literature, we discuss how the specific ICT solutions have an impact on productivity growth. We begin by reviewing the literature on various broadband usages and their impact on firm efficiency and later proceed with ERP and CRM. Enterprise resource planning and customer relationship management are the two major software applications that businesses use to automate core business processes. CRM lets corporations monitor the way consumers interact with their firms, while ERP enables companies to operate effective businesses by linking their financial and operating processes to a central database. Enterprise systems are built to automate everything from inventory management to sales force automation, and nearly every other data-driven management process (Hendricks et al., 2007).

A group of researchers looked into the effects of broadband connectivity on firm productivity in particular (Dalgic and Fazlioglu, 2020; Fabling et al., 2016; Haller and Lyons, 2015). These effects are primarily studied by firm-level data linking broadband availability to adoption and total factor productivity. Broadband internet access is regarded as a valuable tool for companies because it enables the use of complementary broadband software applications (e.g., virtual private network, supply chain management, customer relation management) that can greatly improve productivity and performance.

Bartelsman et al. (2019) presented one of the most recent studies capturing the impact of four types of innovations on productivity for ten European countries, including broadband internet-connected workers acting as an indicator for ICT intensity of output covering the years 2002-2010. According to the authors, there was no clear connection between organizational, marketing, and process innovations and productivity. The study highlighted a significantly positive association between the proportion of workers with broadband internet access and productivity across sectors in nine countries, with a magnitude much greater than that of product innovations. In most countries, however, they reported a positive and significant relationship between product innovations and productivity in manufacturing and service firms, albeit to a lesser extent than broadband-connected employees. Furthermore, adding the ICT intensity variable reduces the strength and importance of the innovation variables. Grimes, Ren, and Stevens (2012) studied the effect of broadband access on firm productivity by using a large micro-survey of firms covering over 7,000 firms in New Zealand in 2006. Using propensity score matching for selection effects and IV estimates for robustness, they found out that broadband adoption improves the firm’s productivity from 7% to 10%. Using data from Turkish manufacturing and service firms, Başak Dalgıç and Burcu Fazlıoğlu (2020) also used PSM and Difference-in-Differences techniques to see whether faster broadband adoption leads to higher productivity gains than normal speed broadband adoption. The empirical findings support the importance of higher-speed broadband for improving firm productivity. Respectively, broadband deployment rates in US telecommunication companies also had a significant positive impact on the firm productivity (Majumdar et al., 2010).

Despite the facts of the positive relationship between a broadband connection and firm productivity, some research results claimed no significant influence of the broadband connection on productivity. Fabling and Grimes (2016), by using Statistics New Zealand's Longitudinal Business Database (LBD) and employing the IV technique, found that the average impact of ultra-fast broadband adoption (UFB) on firm productivity was insignificantly different from zero. They also added that the findings are maintained even though the study is limited to industries where the return to UFB adoption is expected to be reasonably high. Furthermore, based on observations from around 2,200 manufacturing firms in Ireland from 2002 to 2009, Haller and Lyons (2015) found no statistically significant impact of DSL broadband adoption on productivity of firms. The authors also pointed out that even when the implementation of higher-speed DSL broadband was investigated, the findings remained the same. Furthermore, no significant impact on firm productivity was observed after the sample was divided into more homogeneous groups of firms based on size, ownership, or internet usage. Colombo et al. (2013) took a different approach while researching the impact of broadband adoption on the productivity of small and medium-sized Italian enterprises by distinguishing basic applications from the advanced ones. The data they used covered 799 firm observations covering the years from 1998 to 2004. According to the authors, it is the use of specific broadband software applications, rather than a broadband Internet connection alone, that generates productivity gains for SMEs, depending on the specific characteristics of the adopting SMEs.

ICT solutions for firm operations, especially specific systems such as ERP and CRM are also commonly acquired technologies in recent years that create a new research question of how these adoptions affect the productivity of the firm. Nurmilaakso (2009) analyzed e-Business Survey containing data of seven European countries (Germany, United Kingdom, France, Spain, Czech Republic, Poland, Italy) for the impact of different ICT solutions including ERP and CRM on labor productivity using the linear regression model. The paper concluded that enterprise resource planning systems and customer management systems have a significant positive impact on labor productivity. However, this result might change based on different aspects. According to Relich's (2017) country level analysis, the adoption of ERP, CRM, and e-commerce significantly increased labor productivity in the EU countries, whereas the impact was higher in CEE countries including Estonia than the developed ones such as old EU member countries, as CEE countries had lower productivity level and they gained more from ICT implementation. On the other hand, Gal et al. (2019) found that the adoption of ERP, CRM, cloud computing and broadband also contributes to firm-level total factor productivity in OECD countries. The findings indicated that firms with already high productivity are more likely to gain when adopting new ICT components. Moreover, according to the e-business watch data for Germany, UK, France, and Italy ERP and CRM systems have a positive influence on the labor productivity within the firm and CRM also correlates with the sectoral skill intensity or ICT intensity (Falk, 2005). Tastan and Gonel (2020) looked at the effect of ICT labor input, software investments and usage of enterprise system applications such as ERP and CRM on firm-level productivity. The authors observed a positive relationship between ICT usage and firm-level productivity. They concluded that firms investing in enterprise software applications such as ERP and CRM gain more efficiency from ICT use and this effect is more visible in SMEs and service providers.

Although most of the literature came to the conclusion that ICT adoption positively affects firm-level productivity, there are still some investigations that ended up with no significant effect of the specific ICT components on productivity. Delina and Tkac (2010) arrived at a decision that ICT adoption has no significant effect on firm productivity. They first tested for the level of correlation between ICT adoption and the firm performance. Then paper studied which of the adopted ICT solutions are considered as essential productivity driver by companies. The analysis showed that procurement support systems that include ERP and other supporting systems that contain CRM have the lowest effect on productivity improvement, whereas, ICT solutions that enable internal resource sharing through working environment and internet affects the productivity in a positive way. In addition to that, Hendricks (2007) investigated how ERP and CRM implementation contribute to the profitability level. The analysis resulted in finding a positive effect of ERP implementation on firm profitability, whereas no significant impact of CRM system on profitability.

On top of that, ICT capital also can be considered as a means leading to ICT adoption, which also may have an impact on productivity as well. In this regard, Spiezia (2012) studied effect of three types of ICT in sectoral level for 18 OECD countries using the econometric approach such as GMM. Based on the EU KLEMS Database, he found that ICT investment contributed from 0.4% to 1% to the business growth and most of this contribution was the result of computing equipment. What's more, the paper concluded that total factor productivity in ICT producing industries increases, whereas it decreases in the overall business sector. Kılıçaslan et al. (2017) used data from Turkish Statistical Institute over the period 2003-2012 at the firm level and found a positive relationship between ICT capital and labor productivity growth in Turkish manufacturing firms.

Lastly, we would like to mention some very recent works that have analyzed how specific ICT solutions affect the firm-level productivity in OECD countries, specifically in Estonia. To begin, Gal et al. (2019) looked at the ICT effect on productivity in OECD countries.

The paper examined the cross-country firm-level data to analyze the effects of five digital technologies (high-speed broadband, simple and complex cloud computing, ERP and CRM) on firm productivity for 19 EU countries and Turkey over 2010-2015. According to Gal et al. (2019) digital adoption is higher in services sector than in manufacturing. Except for high-speed broadband adoption, manufacturing firms have stronger connection between digital adoption and productivity at the sector level. On the other hand, Mosiashvili and Pareliussen (2020) discussed a very similar topic for Estonia using the Community Survey on ICT Usage and e-commerce in Enterprises in 2016 and business registry data from Statistics Estonia. The research covered high-speed broadband, ERP, CRM, computer use at work and ICT training as digital variables for 2,725 firms in the final examination. Applying the same sectoral split as Gal et al. (2019), they found that digital adoption is more common in the services sector in Estonia. The authors also concluded that the impact of these digital variables is positive on firm-level productivity especially for digitally intensive firms (intensity level determined according to Calvino et al., 2018 methodology).

In conclusion, the majority of the literature cited above suggests that the relationship between ICT and productivity is positive. However, some studies find no substantial or direct effects of ICT solutions, but rather effects outside the reach of ICT. We decided to contribute to the literature by exploring the effects of specific ICT solutions on productivity in Estonian firms because there is a shortage of research papers in this subject for Estonia. Although one of the recent OECD papers Mosiashvili and Pareliussen (2020) have looked at a very similar topic, we use data from Statistics Estonia (IT survey data and business registry data) and different methodologies to assess the effects.

3. Data and Descriptive Statistics

Our study applies firm-level analysis and is based on two main data sources from Statistics Estonia including Information Technology (IT) Survey (2014-2020) and Business Registry data (1993-2019).

IT survey is a comparably new survey provided by Statistics Estonia that gathers the information about the use of digital technologies of the firms within Estonia starting from 2014 and is conducted every year. The survey provides information about digital technologies (computers, 3D printers, robots, etc.), internet usage, software solutions (ERP, CRM, website, etc.), and IT-related training firms acquire. On the other hand, Business Registry data contains various firm-level annual financial data from company financial statements along with a number of employees and specific industry codes for firms covering the period 1993-2019. We merged data from IT survey and Business Registry to extract firm-specific characteristics and financial data for further productivity and ICT relationship analysis. We use firm indicators from Business Registry data to calculate our dependent variables, labor and total factor productivity, and control variables which are firm size, firm age, foreign ownership, year, industry, and location dummies. As we believe each of these control variables can influence the productivity level of the firm we choose them as controls to see better impact of ICT variables.

Table 1. Description of Variables

Description		Coverage	Source
Dependent Variable			
Total Factor Productivity	Calculated using Levinsohn and Petrin (2003) semi-parametric methodology	1995-2019	Business Registry data (Statistics Estonia)
Labor Productivity	Calculated as value added per employee	1995-2019	Business Registry data (Statistics Estonia)
Digital Variables			
Share of employees using computers connected to internet	Calculated as the number of employees using computers connected to internet divided by the total number of employees	2017-2020	IT Survey & Business Registry data (Statistics Estonia)
ERP dummy	The firm uses Enterprise Resource Planning software	2014-2015 2017,2019	IT Survey (Statistics Estonia)
CRM dummy	The firm uses Customer Relation Management software	2014-2015 2017,2019	IT Survey (Statistics Estonia)
Download speed	Categories of different internet download speed: the first category being below 2 Mbit/s and the last one being at least 100 Mbit/s	2017-2020	IT Survey (Statistics Estonia)
Control Variables			
Firm size	Number of employees	1995-2019	Business Registry data (Statistics Estonia)
Firm age	Calculated as a difference between the current year and registration year	1993-2019	Business Registry data (Statistics Estonia)

Description		Coverage	Source
Foreign Ownership dummy	If the firm is mostly foreign owned	2014-2017 2019-2020	Business Registry data (Statistics Estonia)
Industry dummies	Based on 2-digit NACE code	1993-2019	Business Registry data (Statistics Estonia)
Location dummy	Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located	2014-2020	Business Registry data (Statistics Estonia)

Business Registry includes 375,591 unique firm records between 2014 and 2019. The number of observations in the IT Survey between 2014 and 2019 make up 31,666 covering 5,545 unique firms. Using data from the IT Survey we extracted ICT variables like ERP, CRM, share of internet-connected computer use, and download speed to define specific effects of ICT solutions on productivity (Table 1).

Table 2. Annual digital usage

	2014	2015	2016	2017	2018	2019	Total
			ERP dummy				
0	2,133	2,275	-	1,833	-	1,970	8,211
1	637	633	-	912	-	917	3,099
			CRM dummy				
0	2,006	1,919	-	1,910	-	2,030	7,865
1	764	990	-	835	-	856	3,445
Download speed	-	-	-	2,850	3,017	2,935	8,802
Share of computer use	-	-	-	2,850	3,017	2,935	8,802

Source: Information Technology Survey (2014-2019) from Statistics Estonia

As illustrated at Table 2, ERP dummy shows if companies use an ERP software package (1 stands for yes) or not (0 stands for no) to manage their business activities. The same holds for CRM, 1 if they use this system and 0 if they don't. As can be seen from the table the values are missing for 2016 and 2018 for these 2 dummies. Download speed is a categorical variable with firms using speed of 5 categories. The categories are specified as follows: the 1st category - speed below 2 Mbit/s, the 2nd category – speed range 2-10Mbit/s, the 3rd category – speed range 10-30 Mbit/s, the 4th category – speed range 30-100 Mbit/s, the 5th category – speed higher than 100 Mbit/s. The last digital variable we use defines the share of people using computers with internet connection. The observations for these two variables cover the years 2017, 2018 and 2019; the values of rest of the years under observation are missing.

Table 3. Descriptive statistics

	Mean	Bottom decile	Top decile	Standard deviation	Observations
Dependent variable					
Labor productivity(log)	10.22	2.38	15.79	0.83	35,916
TFP(log)	9.51	2.92	17.35	1.19	29,696
Digital variables					
ERP dummy	0.27	0.00	1.00	0.45	11,310
CRM dummy	0.30	0.00	1.00	0.46	11,310
Download speed	3.54	0.00	5.00	1.21	8,802
Share of computer use	0.47	0.00	1.00	0.33	8,802
Control variables					
Firm size(log)	3.15	0.00	9.05	1.22	79,282
Firm age	11.83	1.00	30.00	7.33	89,282
FDI dummy	0.18	0.00	1.00	0.38	82,630
Industry dummies		0.00	1.00		93,955
Location dummies					94,826

Source: Estonian Business Registry data, Information Technology Survey (2014-2019) from Statistics Estonia

Analyzing Table 3, we see that approximately 27% of respondent companies reported using the ERP software package, and 30% of respondents reported using the CRM software package. As regards the download speed, firms mostly prefer using speed levels of the 3rd and 4th categories. On average, 47% of employees within the firms use computers with internet connection.

Moreover, we decided to divide the firms into sectors, as we believe that ICT adoption can have different effects at the sectoral level than it does at the overall average level, such that firms in services sectors gain more from ICT adoption (Mosiashvili and Pareliussen, 2020). Further we also divided the sectors into high-tech and low-tech groups for the manufacturing sector, knowledge-intensive and low knowledge-intensive groups for the services sector according to OECD classification (see Table 4.).

Table 4. Descriptive statistics of sector variables

	2014	2015	2016	2017	2018	2019	Total
Manufacturing sector							
High-tech	198	169	166	162	157	154	1,006
Low-tech	920	782	774	756	740	720	4,692
Services sector							
KIS	975	892	865	841	851	829	5,253
LKIS	2,015	2,249	2,239	2,203	2,170	2,147	13,023

Source: Information Technology Survey (2014-2019) from Statistics Estonia

By plotting Kernel density graphs (see Figure 1) we can demonstrate the difference of labor productivity distributions of digital solution adopting and non-adopting firms. As seen from the graphs, labor productivity of the firms that have adopted ERP, CRM and higher internet speed is relatively higher than the labor productivity of those firms who have not.

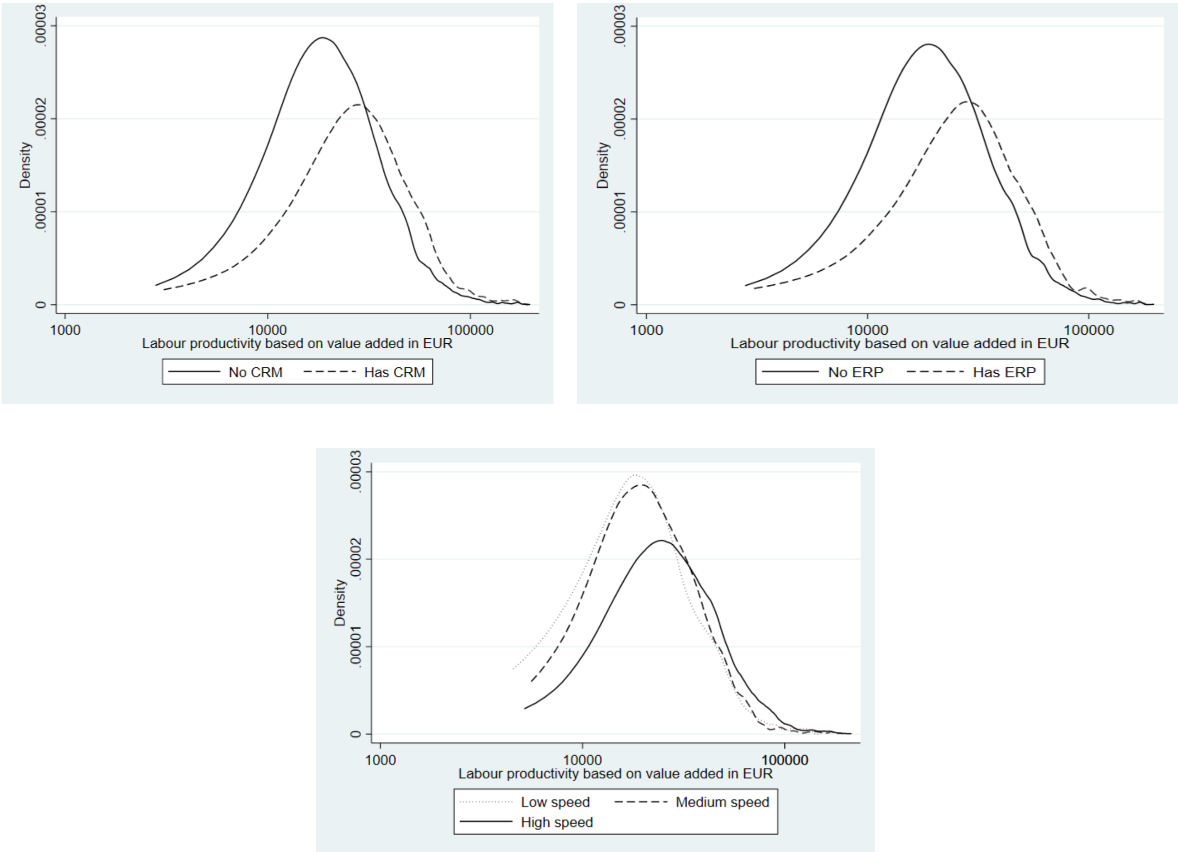

Figure 1. Kernel density plot that demonstrate distribution of labor productivity in the case of CRM, ERP adopters and non-adopters and for different download speed levels.

Kernel graphs (see Figure 2) for total factor productivity show the similar difference between the digital technology adopting and non-adopting firms. Adopters of higher download speed, ERP and CRM software packages get better results in terms of total factor productivity. Adopters of these digital technologies who are already productive are likely to gain more, as they are able to benefit from additional investments in digitalization, organizational and technical skills (Gal et al., 2019).

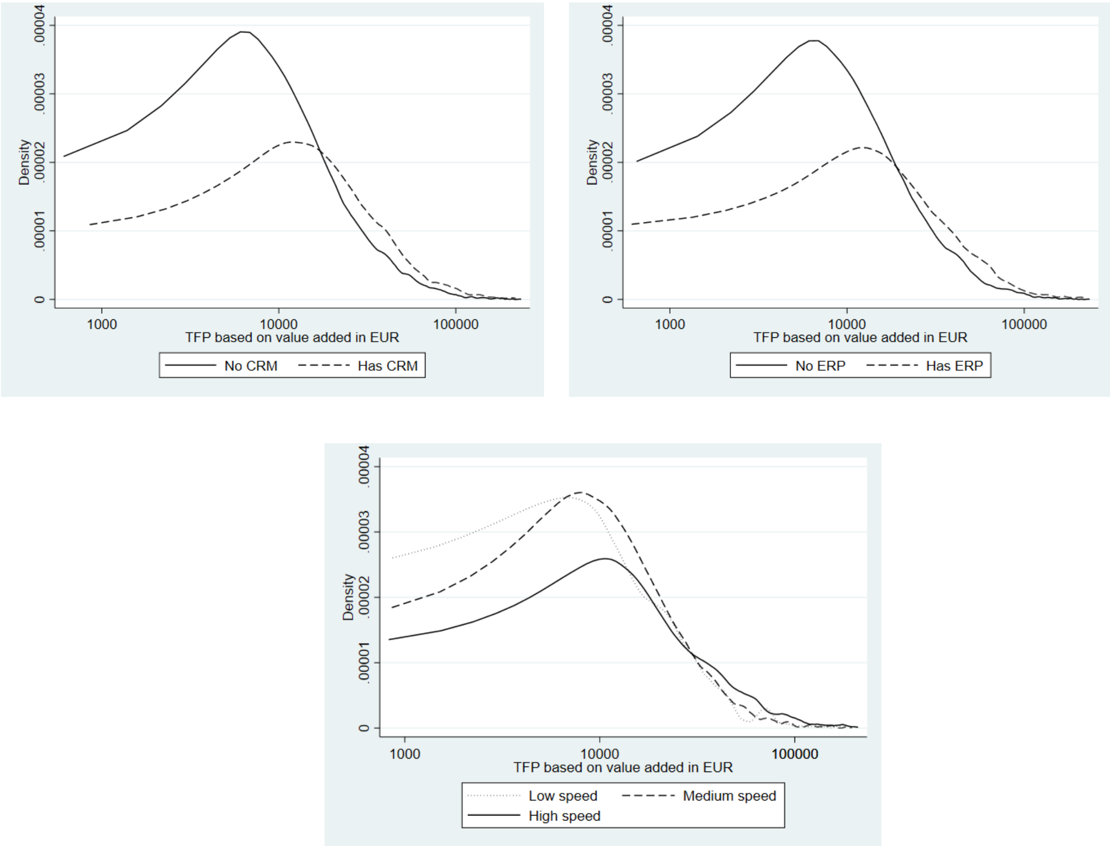

Figure 2. Kernel density plot that demonstrate distribution of total factor productivity in the case of CRM, ERP adopters and non-adopters and for different download speed levels.

Overall, firms that are using ERP, CRM and high internet speed seem to be more productive. Besides, we applied two-sample Kolmogorov-Smirnov (KS) tests to evaluate the distributions of productivity between adopters and non-adopter of ERP and CRM. In both labor and total factor productivity cases, we obtained significant p-values at 1% significance level and concluded that distributions are not equal.

4. Methodology

To estimate the relationship between productivity and ICT variables (ERP, CRM, higher download speed and share of internet-connected computer use) we do OLS regression analysis and proceed with FE regressions to measure changes within firms. In our regression analysis, we separately and together regress our dependent variables, labor and total factor productivity, on ICT variables taking firm size (log), firm age, foreign ownership dummy, year dummies, industry dummies and location dummy as controls. Labor productivity is calculated as value-added (difference between revenue and material cost) per employee.

When it comes to TFP there are several methods to measure it. The simultaneity problem, where the explanatory variables are jointly determined with the dependent variable, is the most common problem encountered in productivity estimates. That's why real productivity results cannot be captured by OLS calculations. Since it does not account for the possible correlation between input levels and unobserved firm-specific productivity shock in the calculation of production function parameters, OLS estimates of production function will produce biased estimates of productivity (Levinsohn and Petrin, 2003).

There are semiparametric methods like Olley and Pakes (1996) and Levinsohn and Petrin (2003) that account for productivity shocks. Both of them propose measures for determining the correlation between input levels and unobserved firm-specific productivity. To control for this correlation Olley and Pakes take investment proxy as the control, while Levinson and Petrin use intermediate inputs to control correlation. Taking into consideration the specifics of the aforementioned methods and our data, we calculate TFP using Levinsohn and Petrin's (2003) semiparametric methodology using cost of raw materials, materials, goods and services as a proxy. All variables were adjusted based on price indices while estimating TFP.

To assess the effects of the ICT variables we regress labor productivity and calculated TFP on digital variables along with various firm specifications such as firm size, firm age, foreign ownership dummy, location dummy and industry dummies. We regress every ICT variable (ERP, CRM, download speed, share of internet-connected computer use) separately and together while doing OLS regression analysis. Y_{it} represents firm i^{th} labor productivity (or TFP) at time t in the equation below.

$$Y_{it} = \alpha_0 + \alpha_1 ICT_{it} + \alpha_2 Size_{it} + \alpha_3 Age_{it} + \alpha_4 FDI_{it} + \alpha_5 Industry_{it} + \alpha_4 Location_{it} + \varepsilon_{it} \quad (1)$$

Despite the fact that the average results of OLS regressions showed a positive and significant relationship between productivity and ICT variables, we chose to broaden our study and look at more specific sectors. So, in the manufacturing sector, we classified firms as high-tech or low-tech, and in the service sector, we classified firms as knowledge-intensive (KIS) or less knowledge-intensive (LKIS), using OECD classification.

Since the selection of adopters and non-adopters of ICT solutions is not a random experiment, using the regression approach for panel data to find the reliable effect of digital usage on firm productivity was challenging. However, employing the Propensity Score Matching technique lowers the selection bias. Moreover, the PSM method was evaluated as the most frequently used practice to measure such effects (Khanh Duy and Thi Hoang Oan, 2015).

The PSM method assigns propensity scores for each observation based on their structural specifications and creates two groups, treatment and control groups, based on assigned propensity scores. The propensity is the probability of receiving the treatment calculated based on Rosenbaum and Rubin (1983) probit specification. In our case, the probability of adopting a CRM (or ERP) software package at period t is the dependent variable in the probit model. We define firm specifications inside the probit model which are productivity, the total number of employees, firm age, firm size, foreign ownership, year, industry, and location dummies.

Within the context of our study having the treatment refers to switching from not having ERP or CRM software package to having one. We select these two dummies to do the matching and exclude the rest two, as the download speed is a categorical and share of internet-connected computer use is a continuous variable.

We built a model to evaluate the treatment effects. The treatment group covers the companies that didn't have a CRM (or ERP) software package at period t-1 but did have it at period t. Consequently we compare the productivity levels of firms before, at time t-1, and after, at time t+1, adopting CRM (or ERP) software packages. Next we look at the model where we compare the productivity levels of firms at t-1 and t+2. The control group in the model is composed of the firms that did not use the CRM (or ERP) software package. The average treatment effect on the treated firms (ATT) is given by the following equation:

$$ATT = E(Y_{it}(1) - Y_{it}(0)|D_i=1) = E(Y_{it}(1)|D_i=1) - E(Y_{it}(0)|D_i=1) \quad (1)$$

Here Y_{it} represents the outcome variables which are labor and total factor productivities of i^{th} firm at time t. In the model, the ATT reflects the difference between the labor productivity and TFP of a firm that previously did not have CRP(or ERP) software package and switched to having one at time t ($Y_{it}(1)|Di=1$) and the potential productivity if this firm had never shifted to use a software package ($Y_{it}(0)|Di=1$).

Using the PSM method we apply nearest neighbor (NN) matching to improve the quality of the matching, as each treated observation is matched with the two controls which are the closest in terms of propensity score. All in all, we employ OLS regression in the first place and continue with FE and PSM analyses to look at the within firm effects.

5. Results

In this section we discuss the results of the analysis that show the relationship between firm-level productivity (labor productivity and TFP) and ICT adoption in Estonia. First, we performed an OLS regression analysis to determine the relationship between ICT use and the firm productivity. The results of OLS for labor productivity and TFP are shown in Table 5 and Table 6 respectively. Any ICT solution (ERP, CRM, share of internet-connected computer use, download speed) was regressed on labor productivity and TFP together and separately.

Table 5. OLS results for TFP

	All four variables	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES					
ERP dummy	0.004		0.101***		
	(0.024)		(0.017)		
CRM dummy	0.051**	0.140***			
	(0.025)	(0.016)			
Share of employee using internet connected computers	0.516***				0.553***
	(0.036)				(0.028)
Download speed	0.044***			0.071***	
	(0.009)			(0.008)	
Log Firm size	0.179***	0.182***	0.183***	0.171***	0.193***
	(0.010)	(0.007)	(0.007)	(0.008)	(0.008)
Firm age	-0.004***	-0.004***	-0.003***	-0.002**	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Foreign ownership dummy	0.148***	0.224***	0.224***	0.176***	0.140***
	(0.027)	(0.019)	(0.019)	(0.022)	(0.022)
Location dummy	0.175***	0.229***	0.234***	0.215***	0.186***

	(0.020)	(0.015)	(0.015)	(0.017)	(0.017)
Constant	8.598***	8.767***	8.751***	8.663***	8.698***
	(0.069)	(0.049)	(0.049)	(0.059)	(0.056)
Observations	3,335	6,733	6,733	5,095	5,095
R-squared	0.785	0.769	0.767	0.764	0.777

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

In our first analysis we look at average ICT effects on TFP of all Estonian firms. While looking at the effects of all variables simultaneously, as can be seen from Table 5 that except ERP, the adoption of CRM, higher download speed and higher share of internet-connected computer use is associated with higher level of TFP. Meanwhile, results show a positive and significant relationship between all ICT variables and productivity when regressing ICT variables separately. While analyzing separately, firms adopting CRM software have 15%, ERP adopters have 10.6%, higher download speed adopters have 7.3% and adopters of higher share of internet-connected computer use have 73.8% higher productivity level. Our results are consistent with the findings of previous literature as well. Accordingly, Gal et al. (2019) find that firms with digital adoption have higher total factor productivity than those who do not adopt.

Table 6. OLS results for labor productivity

	All four variables	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES					
ERP dummy	0.044*		0.145***		
	(0.026)		(0.018)		
CRM dummy	0.036	0.173***			
	(0.027)	(0.017)			

Share of employee using internet connected computers	0.622***				0.693***
	(0.038)				(0.029)
Download speed	0.071***			0.105***	
	(0.010)			(0.008)	
Log Firm size	-0.002	0.007	0.006	-0.007	0.022***
	(0.010)	(0.007)	(0.007)	(0.009)	(0.008)
Firm age	0.002	0.003***	0.003***	0.003***	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Foreign ownership dummy	0.153***	0.229***	0.227***	0.190***	0.148***
	(0.029)	(0.020)	(0.020)	(0.024)	(0.023)
Location dummy	0.150***	0.208***	0.214***	0.194***	0.158***
	(0.021)	(0.016)	(0.016)	(0.018)	(0.017)
Constant	9.442***	9.721***	9.724***	9.387***	9.458***
	(0.074)	(0.052)	(0.052)	(0.063)	(0.059)
Observations	3,927	7,939	7,939	6,033	6,033
R-squared	0.327	0.243	0.240	0.272	0.315

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

When regressing all ICT variables at the same regression on labor productivity, however, CRM adoption shows insignificant effect, while the rest variables show positive significant effects on productivity. Similar to TFP regressions, in the case of labor productivity, the relationship between ICT variables and productivity shows positive significant results, when analyzing ICT variables separately. In this case, firms that use CRM have on average 18.9% higher labor productivity, ERP 15.6%, higher download speed 11.1%, and share of internet-connected computer use 99.9%, as we see it from Table 6. Similarly to our research, Mosiashvili and Pareliussen (2020) also find that firms implementing any of these technologies have significantly higher labor productivity. Furthermore, several previous studies that looked into the effects of ERP and CRM adoption found that they had a positive impact on labor productivity (Falk, 2005; Relich, 2017).

Obtaining positive significant effects of ICT adoption on firm productivity, we divided firms into sectors to determine the impact in specific groups of industries.

Table 7. OLS results for TFP in manufacturing sector

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.045		
		(0.032)		
CRM dummy	0.070**			
	(0.033)			
Share of employee using internet connected computers				0.605***
				(0.062)
Download speed			0.068***	
			(0.015)	
Log Firm size	0.260***	0.259***	0.228***	0.260***
	(0.014)	(0.015)	(0.017)	(0.015)
Firm age	-0.004*	-0.004*	-0.002	-0.002
	(0.002)	(0.002)	(0.002)	(0.002)
Foreign ownership dummy	0.185***	0.182***	0.178***	0.140***
	(0.033)	(0.034)	(0.039)	(0.038)
Location dummy	0.220***	0.221***	0.196***	0.161***
	(0.028)	(0.028)	(0.032)	(0.031)
Constant	8.468***	8.468***	8.420***	8.388***

	(0.074)	(0.074)	(0.089)	(0.083)
Observations	1,685	1,685	1,223	1,223
R-squared	0.799	0.799	0.811	0.822

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

While dividing firms into manufacturing and services sectors, we observe in Table 7 that the firms using the majority of the digital technologies have significantly higher productivity in both sectors. However, we do not find evidence of such results for the manufacturing firms that adopt ERP. In contrast, firms in the services sector acquire 12.5% higher productivity (see Table 8). ERP implementations are extremely challenging and it needs the constant process adaptation throughout the firm (Hitt et al., 2002). This can be the case that manufacturing firms in Estonia just adopt ERP systems but do not maintain overall processes simultaneously, so significant effects of ERP cannot be observed.

Table 8. OLS results for TFP in services sector

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.118***		
		(0.020)		
CRM dummy	0.163***			
	(0.019)			
Share of employee using internet connected computers				0.550***
				(0.033)
Download speed			0.077***	
			(0.009)	

Log Firm size	0.160***	0.163***	0.158***	0.177***
	(0.008)	(0.009)	(0.010)	(0.009)
Firm age	-0.002	-0.002	-0.001	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Foreign ownership dummy	0.235***	0.239***	0.165***	0.131***
	(0.024)	(0.024)	(0.028)	(0.027)
Location dummy	0.227***	0.233***	0.228***	0.260***
	(0.019)	(0.019)	(0.022)	(0.021)
Constant	8.830***	8.846***	8.640***	8.582***
	(0.047)	(0.047)	(0.057)	(0.053)
Observations	4,420	4,420	3,417	3,417
R-squared	0.750	0.748	0.739	0.755

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

After conducting analyses separately by the groups of industries, we see insignificant results of CRM, ERP and higher download speed adoption on productivity levels of high-tech manufacturing firms (see Appendix A). On the other hand, the effect of adoption on productivity levels of low-tech firms is positive and significant for CRM and download speed at 5% significance level, whereas ERP results can be considered significant at 10% significance level (see Appendix B). There can be two main reasons behind the difference in results between these two groups. Firstly, usage of ERP, CRM software packages and download speed are relatively low in high-tech firms, as the needs of these firms may be different in terms of technological tools, which are used in their production processes. Therefore, their productivity is not associated with the use of these particular ICT solutions.

Looking at the services sector regression analyses in Appendices C and D, except ERP all ICT variables show a positive effect on knowledge intensive services firms, while all ICT solutions have positive significant effects on productivity of less knowledge-intensive firms. The effect of share of internet-connected computer use has a positive significant result both when looking at average effect and when dividing firms into categories based on industries. According to Andrew et al. (2018), certain sectors are more sensitive to adoption drivers than others. As mentioned by the author, knowledge-intensive industries are likely to be more sensitive to complementarities such as skill improvements than less knowledge-intensive industries. In the case of Estonian firms, it might be the reason that firms in KIS industries do not have enough skilled employees to redesign processes according to ERP integration. So, ERP adopters do not experience higher TFP.

Table 9. OLS results for labor productivity in services sector

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.150***		
		(0.022)		
CRM dummy	0.189***			
	(0.020)			
Share of employee using internet connected computers				0.659***
				(0.035)
Download speed			0.108***	
			(0.010)	
Log Firm size	-0.021**	-0.019**	-0.026**	-0.001
	(0.009)	(0.009)	(0.011)	(0.010)
Firm age	0.006***	0.006***	0.006***	0.005***
	(0.001)	(0.001)	(0.002)	(0.002)
Foreign ownership dummy	0.264***	0.268***	0.206***	0.168***
	(0.026)	(0.026)	(0.030)	(0.029)
Location dummy	0.200***	0.207***	0.184***	0.158***

	(0.020)	(0.020)	(0.023)	(0.022)
Constant	10.180***	10.200***	9.892***	9.863***
	(0.051)	(0.052)	(0.062)	(0.058)
Observations	5,056	5,056	3,933	3,933
R-squared	0.238	0.232	0.243	0.286

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

When we look at the effects of ICT adoption on labor productivity, we can see from Table 9 that all of our digital technologies have a positive and significant impact in both sectors unlike TFP. This difference arises from the fact that TFP also controls for capital while assessing productivity, however it is not the case in labor productivity**.** Analyzing the knowledge-intensive services firms we find 22.6% increase in labor productivity while adopting CRM, 16.8% while adopting ERP, 10.7% while using higher download speed, 55.1% while having higher share of internet-connected computer use (see Appendix G). In the case of low knowledge-intensive services firms we find positive and significant effects for CRM adopters accounting for 19.7% increase in labor productivity, ERP adopters 15.8%, higher download speed adopter 11.5% and higher share of internet-connected computer use 104.6% (see Appendix H).

Table 10. OLS results for labor productivity in manufacturing sector

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.123***		
		(0.034)		
CRM dummy	0.125***			
	(0.035)			

Share of employee using internet connected computers				0.827***
				(0.065)
Download speed			0.107***	
			(0.016)	
Log Firm size	0.062***	0.055***	0.020	0.068***
	(0.015)	(0.015)	(0.018)	(0.016)
Firm age	-0.002	-0.001	0.002	0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Foreign ownership dummy	0.141***	0.127***	0.147***	0.095**
	(0.035)	(0.036)	(0.042)	(0.040)
Location dummy	0.205***	0.203***	0.183***	0.138***
	(0.030)	(0.030)	(0.034)	(0.033)
Constant	9.770***	9.777***	9.610***	9.588***
	(0.077)	(0.077)	(0.095)	(0.088)
Observations	1,710	1,710	1,243	1,243
R-squared	0.250	0.250	0.270	0.333

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

While doing analyses separately by the groups of industries, for high-tech manufacturing firms we find insignificant effects of ERP and CRM software packages, positive significant effect of download speed at 10% significance level, and a positive significant effect of share of internet-connected computer use at 5% significance level (see Appendix E). In the case of low-tech manufacturing firms 13.9% of productivity increase is associated with CRM adoption, 14.6% with ERP adoption, 12.5% with higher download speed adoption and 146.2% with higher share of internet-connected computer use (see Appendix F). The reason for such a huge productivity increase in the case of higher share of internet-connected computer use might be due to the fact that there is small number of firms without such technology usage.

Next we have used Fixed Effects models in order to see within firm effects of the ICT adoption. We test if firms within particular groups have succeeded to improve productivity level by adopting any of the ERP, CRM, higher download speed and share of internet-connected computer use. Table 11 and Table 12 represent the regression results for FE models evaluating the effect of ICT on TFP and labor productivity respectively.

Table 11. Fixed Effects model results on TFP

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		-0.011		
		(0.012)		
CRM dummy	0.001			
	(0.012)			
Share of employee using internet connected computers				0.062*
				(0.036)
Download speed			0.011	
			(0.007)	
Log Firm size	0.005	0.006	-0.126***	-0.133***
	(0.017)	(0.017)	(0.025)	(0.025)
Firm age	0.019***	0.019***	0.015***	0.015***
	(0.002)	(0.002)	(0.004)	(0.004)
Foreign ownership dummy	-0.008	-0.008	-0.026	-0.025
	(0.024)	(0.024)	(0.025)	(0.025)
Location dummy	0.076	0.073	0.055	0.058

	(0.063)	(0.063)	(0.083)	(0.083)
Constant	9.475***	9.474***	9.875***	9.887***
	(0.117)	(0.117)	(0.129)	(0.129)
Observations	6,733	6,733	5,095	5,095
R-squared	0.678	0.678	0.018	0.018
Number of id	2,889	2,889	2,381	2,381

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Observing the results, we can clearly see that there are no significant effects of ERP and CRM on TFP. Thus, we do not get hereby any evidence on that the change of ICT adoption within the firm affect the productivity level in the period of treatment. On the other hand, while analyzing other variables, it appears that companies with higher download speed and higher share of employees using internet-connected computers are more likely to have higher productivity at 10% significance level. Short and unbalanced panel data, which prevents us from seeing longer effects of adoption, may be one of the reasons for the insignificant effects of some digital variables.

Table 12. Fixed Effects model results on labor productivity

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		-0.003		
		(0.013)		
CRM dummy	0.012			
	(0.013)			
Share of employee using internet connected computers				0.063*

				(0.036)
Download speed			0.003	
			(0.007)	
Log Firm size	-0.217***	-0.217***	-0.286***	-0.291***
	(0.017)	(0.017)	(0.024)	(0.024)
Firm age	0.019***	0.019***	0.014***	0.014***
	(0.002)	(0.002)	(0.004)	(0.004)
Foreign ownership dummy	-0.014	-0.014	-0.017	-0.017
	(0.024)	(0.024)	(0.026)	(0.026)
Location dummy	0.041	0.038	-0.359***	-0.358***
	(0.063)	(0.063)	(0.081)	(0.081)
Constant	10.620***	10.620***	11.290***	11.290***
	(0.126)	(0.126)	(0.129)	(0.128)
Observations	7,939	7,939	6,033	6,033
R-squared	0.072	0.071	0.053	0.054
Number of id	3,365	3,365	2,819	2,819

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Table 12 also highlights that adoption of ERP, CRM and higher download speed do not have a significant effect on firm-level labor productivity while analyzing within the firm variations. However, a higher share of internet-connected computer use among employees has a positive significant effect at 10% significance level.

Even after dividing firms into sectors we do not observe any significant effects of ERP and CRM on total factor productivity in both sectors. At the same time, higher download speed and higher share of internet-connected computer use have positive significant effects on TFP at 10% and 5% significance levels accordingly only in the services sector. In the case of labor productivity, the effects of ERP, CRM and higher share of internet-connected computer use are the same, while the effect of higher download speed adoption is insignificant in the services sector as in the manufacturing sector.

Looking at the results, we can clearly see that there are no significant effects of ICT adoption on labor productivity. Thus, adopting ICT solutions within the firm does not affect the labor productivity of the firm. Again, one explanation of the insignificant effects of ICT variables can be the usage of short and unbalanced panel data, in the case of which we do not see the longer effects of adoption either.

Our final analysis is Propensity Score Matching for two of our ICT variables - ERP and CRM. We evaluate the treatment effect of having one of those software packages within the firm on TFP and labor productivity.

From Appendices I-P, we see that the mean differences of treated and control groups for the variables are not significant for the matched observations, which indicates that matching is successful. To see the effect of ERP and CRM after adoption in the following years we compare productivity of firms at t-1 time with productivities at t+1 and t+2.

First we begin with an analysis of CRM effect on TFP. We see from Table 13a that firms adopting CRM in t-1 get significant and positive productivity increase at t+1 at 5% significance level, whereas we don’t find a significant effect of CRM at t+2. Additionally, firms that adopt ERP at t-1 get a positive and significant result at 10% significance level, however there is no significant effect of it at t+2.

Table 13a. PSM analysis for TFP

		CRM		
ATT				
	Treated	Control	Difference	t-stat
t+1	9.91	9.71	0.20	2.02
t+2	9.91	9.80	0.11	1.15
		ERP		
t+1	9.91	9.78	0.13	1.46
t+2	9.94	9.83	0.11	1.27

Table 13b. Number of observations

CRM			
t+1			
Treatment assignment	Common support		Total
	Off support	On support	
Untreated	0	1,356	1,356
Treated	0	247	247
Total	0	1,603	1,603
t+2			
Untreated	0	1,304	1,304
Treated	1	236	237
Total	1	1,540	1,541
ERP			
t+1			
Treated	2	316	318
Total	2	1,872	1,874
t+2			
Untreated	0	1,505	1,505
Treated	2	305	307
Total	2	1,810	1,812

Analyzing the effect of ERP and CRM on labor productivity, Table 14a shows that firms adopting these technologies at t-1 do not observe significant results at t+1 period. However, at t+2 ERP and CRM benefits labor productivity at 5% and 10% significance level respectively.

Table 14a. PSM analysis for labor productivity

	CRM				
		Treated	Control	Difference	t-stat
ATT	t+1	9.94	9.86	0.08	0.92
	t+2	9.94	9.79	0.15	1.59
	ERP				
	t+1	9.91	9.90	0.01	0.06
	t+2	9.94	9.80	0.14	1.65

Table 14b. Number of observations

Treatment assignment	Common support		Total
	Off support	On support	
CRM			
t+1			
Untreated	0	1,400	1,400
Treated	0	254	254
Total		1,654	1,654
t+2			
Untreated	0	1,350	1,350
Treated	1	243	244
Total	1	1,593	1,594
ERP			
t+1			
Untreated	0	1,608	1,608
Treated	3	319	322
Total	3	1,927	1,930
t+2			
Untreated	0	1,561	1,561
Treated	3	308	311
Total	3	1,869	1,872

Comparing the results for labor and total factor productivity, we conclude that in terms of TFP, ERP and CRM have one-time benefit from adoption, whereas labor productivity increases through the following years. As TFP controls for capital as well, we conclude that the effect of ERP and CRM is a one-time benefit and does not continue in the following years for Estonian firms. On the other hand, as employees get trained and become skilled in using the technology, their productivity increases.

To see the effect of ERP and CRM on different sectors, we also did PSM analysis for manufacturing and services sectors. Our results could not conclude any significant effect of adoption on both labor and total factor productivity in either of sectors.

6. Conclusion

In our study, we empirically investigated the relationship between ICT and productivity based on firm-level data of Estonian enterprises. Two different data sets, namely Information Technology Survey and Business Registry, have been merged and used in this study. Our paper contributes to the existing literature by examining the research in question in the context of Estonia, as there are a few studies on the topic for this country.

From our results we see that ICT adoption has a significant effect on both labor productivity and TFP while evaluating between firm variations. However, we conclude based on our Fixed Effects model that adopting ICT, specifically, ERP, CRM, higher download speed and higher share of internet-connected computer use within the firm does not show significant effect on productivity level in the period of treatment. On the other hand, we measure the treatment effect of ERP and CRM software packages using PSM nearest neighbor matching method to see if adopters have higher productivity within the firm. Consequently, we see that firms adopting of ERP and CRM get a significant productivity increase at t+1 in the case of TFP and at t+2 in the case of labor productivity while doing matching. ERP and CRM adoption may not be sufficient to drive productivity growth; complementary investments are needed. Their effect rely heavily on a company's organizational resources and management capabilities, as well as its ability to deploy complementary investments and technologies to optimize business processes (Sobre et al., 2019).

To sustain our argument, we looked at some previous studies and noticed that one of the most recent OECD papers have found that managerial efficiency, professional labor shortages, and necessary skill fit can all limit the impact of ICT adoption within the organization (Andrews et al., 2018). Furthermore, in order to achieve increased performance, managers must regularly balance strategic requirements with ICT implementations (Bayo-Morines and Lera-Lopez, 2007).

Overall, based on the findings of our analyses, it is obvious that the effect of ICT adoption has a significant positive effect while comparing between firm variations both in the case of labor and total factor productivity. Looking at the different sectors for between firm variations, we find that ERP adoption does not show a significant effect on TFP for manufacturing firms. On the other hand, according to FE analyses, adoption of ERP and CRM under observation does not influence the level of productivity if the adoption change occurs within the firms in the period of treatment. This might be because ERP and CRM adoption is a complex process that requires additional complementarities. Thus, ERP and CRM adoption alone may not be enough to drive productivity growth; additional investments, such as skilled labor and organizational changes, may be needed (Bayo-Morines and Lera-Lopez, 2007). However, we see some significant effects of the higher download speed and higher share of internet-connected computer use on firm productivity while doing sector division. Moreover, doing PSM analysis to look at within the firm changes, we find that the effects of ERP and CRM are significant at t+1 for TFP, but at t+2 for labor productivity.

For the future studies, analyses can be implemented using extended panel data to see longer effects of ICT variables on firm-level productivity. In addition, effect of complementarities can be assessed to obtain more detailed results of the relationship between ICT and firm-level productivity. Based on our results, we believe that engaging more low-skilled workers in training and encouraging improved management and organizational skills can support Estonian firms to better adopt and diffuse new technologies (Sobre et al., 2019).

7. References

1. Bartelsman, E. J., Falk, M., Hagsten, E., & Polder, · Michael. (2019). (123 C.E.). Productivity, technological innovations and broadband connectivity: firm-level evidence for ten European countries. Eurasian Business Review, *9*, 25–48.
2. Bartelsman, Eric & Gautier, Pieter A. & De Wind, Joris, 2010. "Employment Protection, Technology Choice, and Worker Allocation," IZA Discussion Papers 4895, Institute of Labor Economics (IZA).
3. Basu, S., & Fernald, J. (2007). Information and communications technology as a general-purpose technology: Evidence from US industry data. German Economic Review, 8(2), 146–173.
4. Basu, S., Fernald, J. G., Oulton, N., & Srinivasan, S. (2003). The case of the missing productivity growth, or does information technology explain why productivity accelerated in the United States but not in the United Kingdom? NBER Macroeconomics Annual, 18(2001), 9–63.
5. Biagi, Federico (2013): ICT and Productivity: A Review of the Literature, Institute for Prospective Technological Studies Digital Economy Working Paper, No. 2013/09, ISBN 978-92-79-33678-2, European Commission, Joint Research Centre (JRC), Seville
6. Bloom, N., Sadun, R., & Van Reenen, J. (2012). Americans do IT better: US multinationals and the productivity miracle. American Economic Review, 102(1), 167–201.
7. Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies "Engines of growth"? Journal of Econometrics, 65(1), 83–108.
8. Brynjolfsson, E., & Hitt, L. (1996). Paradox lost? Firm-level evidence on the returns to information systems spending. Management Science, 42(4), 541–558.
9. Brynjolfsson, E., & Hitt, L. M. (2003). Computing productivity: Firm-level evidence. Review of Economics and Statistics, 85(4), 793–808.
10. Calvino, F., et al. (2018), "A taxonomy of digital intensive sectors", OECD Science, Technology and Industry Working Papers, No. 2018/14, OECD Publishing, Paris.
11. Castiglione, C., & Infante, D. (2013). ICT as general purpose technologies: a micro-econometric investigation on Italian firms. International Journal of Trade and Global Markets, 6(3), 225

12. Cardona, M., Kretschmer, T., & Strobel, T. (2013). ICT and productivity: Conclusions from the empirical literature. Information Economics and Policy, 25(3), 109–125.
13. Colombo, M. G., Croce, A., & Grilli, L. (2013). ICT services and small businesses' productivity gains: An analysis of the adoption of broadband Internet technology. Information Economics and Policy, 25(3), 171–189.
14. Dalgıç, B., & Fazlıoğlu, B. (2020). The impact of broadband speed on productivity: findings from Turkish firms. Applied Economics Letters, 27(21), 1764–1767.
15. Delina, R., & Tkáč, M. (2010). The impacts of specific ICT solutions on productivity. IDIMT 2010: Information Technology - Human Values, Innovation and Economy - 18th Interdisciplinary Information Management Talks, 23–32.
16. Engelstätter, Benjamin (2009) : Enterprise systems and labor productivity: disentangling combination effects, ZEW Discussion Papers, No. 09-040, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim
17. Fabling, R., Grimes, A., & Grimes, A. (2016). Picking up speed: Does ultrafast broadband increase firm productivity. November.
18. Falk, M. (2005). ICT-linked firm reorganisation and productivity gains. Technovation, 25(11), 1229–1250.
19. Gal, P. et al. (2019), "Digitalisation and productivity: In search of the Holy Grail – Firm-level empirical evidence from EU countries", OECD Economics Department Working Papers, No. 1533, OECD Publishing, Paris.
20. Grimes, A., Ren, C., & Stevens, P. (2012). The need for speed: Impacts of internet connectivity on firm productivity. Journal of Productivity Analysis, 37(2), 187–201.
21. Hall, B. H., Lotti, F., & Mairesse, J. (2013). Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. Economics of Innovation and New Technology, 22(3), 300–328.
22. Haller, S. A., & Lyons, S. (2015). Broadband adoption and firm productivity: Evidence from Irish manufacturing firms. Telecommunications Policy, 39(1), 1–13.
23. Hendricks, K. B., Singhal, V. R., & Stratman, J. K. (2007). The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations. Journal of Operations Management, 25(1), 65–82.
24. Kılıçaslan, Y., Sickles, R. C., Atay Kayış, A., & Üçdoğruk Gürel, Y. (2017). Impact of ICT on the productivity of the firm: evidence from Turkish manufacturing. Journal of Productivity Analysis, 47(3), 277–289.

25. Koellinger, P. (2006). Impact of ICT on Corporate Performance, Productivity and Employment Dynamics. Management, December, 1–33.
26. Majumdar, S. K., Carare, O., & Chang, H. (2010). Broadband adoption and firm productivity: evaluating the benefits of general purpose technology. Industrial and Corporate Change, 19(3), 641–674.
27. Mosiashvili, N., & Pareliussen, J. (n.d.). (2020). Digital technology adoption, productivity gains in adopting firms and sectoral spill-overs : Firm-level evidence from Estonia. 1638, 0–19.
28. Nurmilaakso, J. M. (2009). ICT solutions and labor productivity: Evidence from firm-level data. Electronic Commerce Research, 9(3), 173–181.
29. O'Mahony, M., & Vecchi, M. (2005). Quantifying the impact of ICT capital on output growth: A heterogeneous dynamic panel approach. Economica, 72(288), 615–633.
30. Relich, M. (2017). The impact of ICT on labor productivity in the EU. Information Technology for Development, 23(4), 706–722.
31. Ruivo, P., Mestre, A., Johansson, B., & Oliveira, T. (2014). Defining the ERP and CRM Integrative Value. Procedia Technology, 16, 704–709.
32. Sánchez, J. I. L., Minguela Rata, B., Rodríguez Duarte, A., & Sandulli, F. D. (2006). Is the Internet productive? A firm-level analysis. Technovation, 26(7), 821–826.
33. Sorbe, S., et al. (2019), « Digital Dividend: Policies to Harness the Productivity Potential of Digital Technologies », OECD Economic Policy Papers, n° 26, Éditions OCDE, Paris.
34. Solow, R. (1998). Technical Change and the Aggregate Production Function. Real Business Cycles, 39(3), 543–551.
35. Spiezia, V. (2012). Measuring the contribution of ICTS to growth Vincenzo Spiezia ICT investments and productivity
36. Strohmaier, R., & Rainer, A. (2015). Studying general purpose technologies in a multi-sector framework: The case of ICT in Denmark. Structural Change and Economic Dynamics, 36, 34–49.
37. Syverson, C. (2011). What determines productivity. Journal of Economic Literature, 49(2), 326–365.
38. Van Ark, B., Melka, J., Mulder, N., Timmer, M., & Ypma, G. (2002). ICT investment and growth accounts for the European Union, 1980-2000. Brussels, European Commission, 24(January), 1–93.

Appendices

Appendix A: OLS results for TFP in high-tech manufacturing firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		-0.027		
		(0.071)		
CRM dummy	-0.012			
	(0.071)			
Share of employee using internet connected computers				0.355**
				(0.156)
Download speed			0.040	
			(0.041)	
Log Firm size	0.296***	0.299***	0.246***	0.267***
	(0.035)	(0.036)	(0.044)	(0.041)
Firm age	0.008	0.007	0.009	0.008
	(0.005)	(0.005)	(0.006)	(0.006)
Foreign ownership dummy	0.068	0.071	0.139	0.123
	(0.072)	(0.072)	(0.091)	(0.090)
Location dummy	0.250***	0.252***	0.141*	0.119
	(0.065)	(0.066)	(0.081)	(0.081)
Constant	10.210***	10.200***	10.160***	10.130***
	(0.194)	(0.196)	(0.252)	(0.243)
Observations	340	340	266	266

R-squared	0.908	0.908	0.880	0.882

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix B: OLS results for TFP in low-tech manufacturing firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.064*		
		(0.036)		
CRM dummy	0.086**			
	(0.037)			
Share of employee using internet connected computers				0.681***
				(0.065)
Download speed			0.075***	
			(0.016)	
Log Firm size	0.249***	0.246***	0.222***	0.255***
	(0.016)	(0.016)	(0.018)	(0.016)
Firm age	-0.007***	-0.007***	-0.005**	-0.005**
	(0.002)	(0.002)	(0.002)	(0.002)
Foreign ownership dummy	0.225***	0.220***	0.200***	0.152***
	(0.038)	(0.039)	(0.043)	(0.041)
Location dummy	0.219***	0.220***	0.217***	0.179***
	(0.031)	(0.031)	(0.034)	(0.033)
Constant	8.550***	8.552***	8.456***	8.414***
	(0.079)	(0.079)	(0.092)	(0.085)

Observations	1,345	1,345	957	957
R-squared	0.651	0.650	0.715	0.739

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix C: OLS results for TFP in knowledge-intensive services firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.058		
		(0.045)		
CRM dummy	0.200***			
	(0.040)			
Share of employee using internet connected computers				0.445***
				(0.081)
Download speed			0.068***	
			(0.023)	
Log Firm size	0.099***	0.111***	0.109***	0.117***
	(0.019)	(0.019)	(0.022)	(0.021)
Firm age	0.002	0.003	0.001	0.000
	(0.003)	(0.003)	(0.003)	(0.003)
Foreign ownership dummy	0.048	0.049	-0.098*	-0.077
	(0.048)	(0.049)	(0.056)	(0.055)
Location dummy	0.239***	0.258***	0.193***	0.194***
	(0.048)	(0.049)	(0.056)	(0.055)

Constant	8.296***	8.273***	8.264***	8.265***
	(0.238)	(0.241)	(0.253)	(0.247)
Observations	933	933	716	716
R-squared	0.436	0.422	0.441	0.457

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix D: OLS results for TFP in less knowledge-intensive services firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.130***		
		(0.123)		
CRM dummy	0.147***			
	(0.021)			
Share of employee using internet connected computers				0.560***
				(0.036)
Download speed			0.179***	
			(0.010)	
Log Firm size	0.178***	0.178***	0.170***	0.193***
	(0.009)	(0.010)	(0.011)	(0.010)
Firm age	-0.003**	-0.003**	-0.002	-0.002
	(0.001)	(0.001)	(0.002)	(0.002)
Foreign ownership dummy	0.308***	0.310***	0.259***	0.203***
	(0.027)	(0.027)	(0.032)	(0.031)

Location dummy	0.217***	0.219***	0.225***	0.201***
	(0.020)	(0.020)	(0.023)	(0.022)
Constant	8.802***	8.822***	8.603***	8.533***
	(0.050)	(0.050)	(0.061)	(0.056)
Observations	3,487	3,487	2,701	2,701
R-squared	0.786	0.785	0.775	0.790

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix E: OLS results for labor productivity in high-tech manufacturing firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.080		
		(0.066)		
CRM dummy	0.084			
	(0.065)			
Share of employee using internet connected computers				0.561***
				(0.138)
Download speed			0.065*	
			(0.036)	
Log Firm size	0.044	0.040	0.015	0.050
	(0.032)	(0.033)	(0.039)	(0.036)
Firm age	0.012***	0.013***	0.015***	0.013***
	(0.005)	(0.005)	(0.005)	(0.005)

Foreign ownership dummy	-0.050	-0.058	0.020	-0.007
	(0.067)	(0.067)	(0.081)	(0.080
Location dummy	0.274***	0.272***	0.194***	0.160**
	(0.060)	(0.061)	(0.073)	(0.071)
Constant	10.180***	10.200***	9.889***	9.844***
	(0.180)	(0.182)	(0.227)	(0.215)
Observations	344	344	269	269
R-squared	0.301	0.301	0.256	0.293

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix F: OLS results for labor productivity in low-tech manufacturing firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.136***		
		(0.039)		
CRM dummy	0.130***			
	(0.040)			
Share of employee using internet connected computers				0.901***
				(0.073)
Download speed			0.118***	
			(0.018)	
Log Firm size	0.065***	0.056***	0.020	0.071***
	(0.017)	(0.017)	(0.020)	(0.018)

Firm age	-0.005**	-0.005**	-0.002	-0.002
	(0.002)	(0.002)	(0.003)	(0.002)
Foreign ownership dummy	0.211***	0.195***	0.204***	0.141***
	(0.042)	(0.042)	(0.049)	(0.047)
Location dummy	0.194***	0.192***	0.186***	0.139***
	(0.034)	(0.034)	(0.039)	(0.037)
Constant	9.796***	9.805***	9.617***	9.591***
	(0.085)	(0.085)	(0.104)	(0.096)
Observations	1,366	1,366	974	974
R-squared	0.250	0.251	0.286	0.357

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix G: OLS results for labor productivity in knowledge-intensive services firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.155***		
		(0.044)		
CRM dummy	0.204***			
	(0.039)			
Share of employee using internet connected computers				0.439***
				(0.075)
Download speed			0.102***	
			(0.020)	

Log Firm size	-0.022	-0.019	-0.014	0.001
	(0.018)	(0.018)	(0.021)	(0.020)
Firm age	0.008***	0.008***	0.004	0.003
	(0.003)	(0.003)	(0.003)	(0.003)
Foreign ownership dummy	0.099*	0.103**	-0.011	0.015
	(0.051)	(0.051)	(0.059)	(0.058)
Location dummy	0.298***	0.314***	0.253***	0.251***
	(0.044)	(0.044)	(0.050)	(0.050)
Constant	11.010***	11.020***	10.910***	10.910***
	(0.216)	(0.218)	(0.215)	(0.214)
Observations	1,309	1,309	1,022	1,022
R-squared	0.274	0.265	0.313	0.318

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix H: OLS results for labor productivity in less knowledge-intensive services firms

	CRM	ERP	Download speed	Share of internet connected computer use
VARIABLES				
ERP dummy		0.147***		
		(0.026)		
CRM dummy	0.180***			
	(0.024)			
Share of employee using internet connected computers				0.716***
				(0.040)

Download speed			0.109***	
			(0.012)	
Log Firm size	-0.020*	-0.019*	-0.029**	0.002
	(0.011)	(0.011)	(0.012)	(0.011)
Firm age	0.005***	0.005***	0.006***	0.005***
	(0.002)	(0.002)	(0.002)	(0.002)
Foreign ownership dummy	0.328***	0.332***	0.284***	0.213***
	(0.030)	(0.030)	(0.035)	(0.034)
Location dummy	0.170***	0.174***	0.162***	0.130***
	(0.023)	(0.023)	(0.026)	(0.025)
Constant	10.210***	10.230***	9.902***	9.834***
	(0.056)	(0.056)	(0.068)	(0.063)
Observations	3,747	3,747	2,911	2,911
R-squared	0.228	0.223	0.220	0.277

*Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In the regression above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.*

Appendix I: Comparison of treatment and control groups of CRM at t+1, TFP analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	CRM	No CRM		CRM	No CRM	
Total factor productivity	9.790	9.708	0.79	9.790	9.541	3.12**
Firm size	3.679	3.719	-0.42	3.679	3.482	2.88**
Firm age	17.291	17.571	-0.47	17.291	17.567	-0.61
Location dummy	0.632	0.613	0.42	0.632	0.511	3.50***
Foreign ownership dummy	0.243	0.239	0.11	0.243	0.146	3.83***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix J: Comparison of treatment and control groups of ERP at t+1, TFP analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	ERP	No ERP		ERP	No ERP	
Total factor productivity	9.824	9.758	0.73	9.815	9.558	3.69***
Firm size	3.749	3.640	1.29	3.747	3.460	4.88***
Firm age	17.791	18.236	-0.86	17.786	17.638	0.37
Location dummy	0.630	0.622	0.21	0.629	0.518	3.63***
Foreign ownership dummy	0.266	0.269	-0.09	0.264	0.138	5.67***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix K: Comparison of treatment and control groups of CRM at t+2, TFP analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	CRM	No CRM		CRM	No CRM	
Total factor productivity	9.776	9.752	0.23	9.775	9.545	2.85**
Firm size	3.684	3.640	0.46	3.686	3.478	2.99**
Firm age	17.258	17.847	-0.99	17.198	17.550	-0.77
Location dummy	0.614	0.619	-0.09	0.616	0.509	3.04**
Foreign ownership dummy	0.229	0.223	0.16	0.232	0.149	3.21***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix L: Comparison of treatment and control groups of ERP at t+2, TFP analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	ERP	No ERP		ERP	No ERP	
Total factor productivity	9.827	9.764	0.70	9.818	9.561	3.68***
Firm size	3.764	3.706	0.67	3.761	3.457	5.10***
Firm age	18.020	17.482	1.03	18.013	17.630	0.95
Location dummy	0.623	0.646	-0.59	0.622	0.516	3.42***
Foreign ownership dummy	0.266	0.284	-0.50	0.264	0.139	5.48***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix M: Comparison of treatment and control groups of CRM at t+1, labor productivity analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	CRM	No CRM		CRM	No CRM	
Labor productivity	10.351	10.315	0.65	10.351	10.169	4.24***
Firm size	3.697	3.798	-1.07	3.697	3.468	3.37***
Firm age	17.189	17.272	-0.14	17.189	17.581	-0.88
Location dummy	0.634	0.634	0.00	0.634	0.509	3.67***
Foreign ownership dummy	0.244	0.282	-0.96	0.244	0.145	3.98***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix N: Comparison of treatment and control groups of ERP at t+1, labor productivity analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	ERP	No ERP		ERP	No ERP	
Labor productivity	10.365	10.369	-0.08	10.367	10.183	4.83***
Firm size	3.736	3.609	1.58	3.735	3.452	4.86***
Firm age	17.768	17.412	0.69	17.739	17.647	0.23
Location dummy	0.630	0.657	-0.70	0.630	0.516	3.76***
Foreign ownership dummy	0.260	0.277	-0.49	0.261	0.138	5.55***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix O: Comparison of treatment and control groups of CRM at t+2, labor productivity analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	CRM	No CRM		CRM	No CRM	
Labor productivity	10.327	10.292	0.60	10.326	10.168	3.66***
Firm size	3.697	3.757	-0.61	3.698	3.467	3.37***
Firm age	17.103	17.708	-1.04	17.045	17.559	-1.13
Location dummy	0.617	0.609	0.19	0.619	0.507	3.22***
Foreign ownership dummy	0.226	0.235	-0.21	0.230	0.149	3.16**

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

Appendix P: Comparison of treatment and control groups of ERP at t+2, labor productivity analysis

	Matched Sample			Unmatched Sample		
			T-Test for the Mean Differences			T-Test for the Mean Differences
	ERP	No ERP		ERP	No ERP	
Labor productivity	10.366	10.356	0.21	10.368	10.185	4.75***
Firm size	3.750	3.667	0.99	3.749	3.448	5.09***
Firm age	17.994	18.115	-0.24	17.961	17.629	0.83
Location dummy	0.623	0.625	-0.04	0.624	0.514	3.54***
Foreign ownership dummy	0.260	0.247	0.37	0.260	0.140	5.31***

In the analysis above several additional variables such as industry dummies and year dummies have also been used. Location dummy indicates that firm is registered in Northern Estonia, where capital city Tallinn is located.

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