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What does ICT tell about the effects of digitalization?

Master's thesis

by

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Abstract

The thesis analyses the supposed impact of ICT on the economy of the European Union during 2000 – 2017. ICT access and usage proxies combined with macroeconomic control variables in panel data regressions indicate that ICT access has a positive, statistically significant effect on economic growth and labour productivity. Yet no significant results are observed with the employment data, thus disagreeing with the assumption that digitalization, proxied trough ICT-related variables, increases unemployment. Also, since obtained coefficient values are relatively small, it leads to a conclusion that the full extent of digitalization's impact may be observed in the upcoming years.

Keywords: digitalization, ICT, panel data, economic impact

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List of Abbreviations

CLRM	Classical linear regression model
FE	Fixed effects
GCF	Gross capital formation
ITU	International Telecommunication Union
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary least squares
RE	Random effects
RGDPpc	Real gross domestic product *per capita*
RGDPpw	Real gross domestic product per worker (labour productivity)
WB	World Bank
WEF	World Economic Forum

1 Introduction

In the last two decades we have observed a major rise of information and communication technologies (ICT[1]). These technologies are now so deeply intertwined with our lives that they fundamentally change the way we live, communicate and buy or sell goods and services. For example, since the Internet is used by more than a half of the World's population (International Telecommunication Union, 2020), one can easily reach nearly anybody with internet or mobile network access – be that your colleague or a potential customer who was chosen by using advanced profiling[2] for your product. These small-scale changes seem to result in large-scale transformation of how the economy works making some of the previously held economic models and beliefs become invalid or at least not as accurate as before (Goldfarb, Greenstein & Tucker, 2015). The phenomenon that emerges from the aforementioned change is better known as digitalization.

After observing the pace of this transformation and the technological progress, it is tempting to be onboard the "digitalization-hype-train", of which artificial intelligence (AI) is being one of the most commonly mentioned "technologies of the future"[3]. It is believed to eventually possess human-like cognitive abilities that would allow to replace humans by automating their jobs. This is particularly interesting since previous technological advancements were merely augmenting human capabilities or were pre-programmed to act like a human, yet now AI may replace some jobs that were expected to be outside of automation, such as, lawyers or physicians. McKinsey (2017) estimates that 400-800 million jobs will be automated by 2030, and AI could also add up to 14%, i.e., 15.7 trillion USD, to global gross domestic product (GDP) due to increased demand from the consumer side (partially due to advanced profiling) and a general increase in productivity, efficiency due to use of AI in private and public sectors (PwC, 2018).

[1] ICT here is defined as "a diverse set of technological tools and resources used to transmit, store, create, share or exchange information. These technological tools and resources include computers, the Internet (websites, blogs and emails), live broadcasting technologies (radio, television and webcasting), recorded broadcasting technologies (podcasting, audio and video players and storage devices) and telephony (fixed or mobile, satellite, visio/video-conferencing, etc.)" (UNESCO, 2020, n.p.).
[2] Profiling is an "act or process of extrapolating information about a person based on known traits or tendencies" (Merriam-Webster, 2020, n.p.), i.e., by using one's internet search history or location-based advertising.
[3] See an interesting discussion on AI limits in The Economist's June 13th ed. 2020 p. 37.

Yet there is an increasingly larger part of individuals that warns about the disruptive effects of digitalization. For example, AI or any other ICTs leading to major job loss, unemployment and poverty. Some papers (such as Szczepański, 2019) argue that due to a widening innovation and productivity gap, we could observe an uneven distribution of AI (or more broadly – ICT) benefits. Namely, it is possible for some particularly advanced countries (or companies) with certain technologies leapfrog in growth since they have a significant comparative advantage over others, leading to an extreme difference in income levels (profit) making few countries (or companies) very wealthy whilst others would become poor if they were unable to fully utilize the power of these technologies. Also, ICT might be put to wilful misuse, thus threatening geopolitical stability (Floridi et al., 2018).

These stark contrasts have led to a long, passionate debate on the effects of digitalization (AI and automation being a just a small part of it) and how to mitigate negative consequences or avoid security, privacy risks on a national level, yet by fully utilizing digitalization's effect (Szczepański, 2019). Furthermore, additional interest has been targeted to digitalization due to the COVID-19 pandemic which significantly stress-tested capacity and preparedness of countries and businesses to use digital solutions to reduce the spread of the virus and maintain a steady workflow. Sneader & Singhal (2020) argue that the workplace will never be the same after months of distance working and seeing many benefits of it.

The previous analysis prompts two questions: "*What does ICT tell about the potential effects of digitalization?*" and "*Are those supposed negative consequences arisen from digitalization offset by its benefits to the economy and society?*"

The aim of this thesis is to answer to previous two questions and add new information, data to already existing research. This aim will be achieved by looking at the effects of digitalization in these three areas:

- economic growth;
- labour productivity;
- employment.

Each of these different areas will allow to assert the multifaceted impact of digitalization. Firstly, the analysis of digitalization's relation to economic growth will allow to determine the extent of its impact on the economy and consequently – to citizen's welfare. Secondly, assessing ICT's effect on labour productivity and employment will determine whether disruptive effects, such as, labour replacement are offset by the creation of new markets, jobs and increased efficiency.

To achieve my aim, I study the effects of ICT on the economy between ICT access, usage and dependent variables – RGDP *per capita* (RGDPpc), RGDP per worker (RGDPpw), which proxies labour productivity, and total employment for EU countries during 2000–2017. Panel regressions with additional controls for time-specific and entity fixed effects, and macroeconomic processes deem only one of three ICT-related proxies significant, i.e., mobile cellular subscription rate per 100 inhabitants. This ICT access variable has a positive relationship with both RGDPpc and RGDPpw. However, there seems not to exists an apparent relation between digitalization-related variables and total employment or employment in each economic sector. Also, to address a potential issue that different economic development levels might have a different effect on the extent of digitalization's impact (Vu, Hanafizadeh & Bohlin, 2020), EU28 sample is split into two parts according to their respective RGDPpc levels and the same regressions are used, yet no apparent trend emerges disapproving this assumption. Lastly, dynamic panels are used as additional robustness checks. The regression results with a one-period lag for RGDPpc supports previous findings, whilst no significant results are found by using RGDPpw lag.

The following parts of the thesis are organized as follows: the second chapter provides us with definitions and sets the theoretical foundation for the upcoming analysis of digitalization. The third chapter sets the research framework and briefly explains the model used for econometric regressions. The fourth chapter describes in detail our findings, whilst the last chapter concludes with some useful remarks for policymakers or any interested party.

2 Literature review

Land, labour and capital have been at the foundation of modern economic science as main factors of production ever since famous Smith's (1776) *The Wealth of Nations,* implying over 200 years of extensive research of them. Yet as of intensified use and emergence of new technologies in production process, Solow's (1956) paper presents a relatively simple and later widely used mathematical model with what he adds technological progress as an output-affecting variable to the former triad of production factors.

To continue with the analysis of digitalization's effects, it is worthwhile to understand how ICT-related variables, intertwines within labour and capital inputs and how this consequently affects outputs of the economy from a theoretical perspective. This will allow us to set framework with which we can pursue quantitative analysis most effectively, namely, to understand which variables should be included into regressions to most accurately simulate process that affect economic growth. We can begin by using a slightly modified Solow's production function in Cobb-Douglas form (Romer, 2019) as can be seen in Equation (1):

$$Y(t) = K(t)^{\alpha} \, (A(t)L(t))^{1-\alpha} \qquad (1)$$

Here Y stands for output at time t. $K(t)$, $L(t)$ stands for physical capital and labour respectively. A is labour augmenting or "Hicks-neutral" parameter, which is assumed to growth with technological change, i.e., as technologies improve productivity a unit of labour can produce more (Romer, 2019). This is the variable thorough which digitalization may affect output ($A(t)$ also can be positioned such that it only affects $K(t)$ or both). Lastly, α indicate capital share. Whilst additional analysis of Equation (1) is included in Subchapter 2.2., Robert Solow's (1956) paper is one of the first publications in the newly established field of growth economics in the second half of 20th century. This means that even though we use or hear term "economic growth" on nearly daily basis, digitalization and its effects are still new to academic world and therefore we must firstly cautiously set theoretical framework and define *what do we understand by digitalization.*

2.1 Digitization versus digitalization

Confusion between definitions of digitization, digitalization and digital transformation is quite common, even Cambridge online dictionary digitization and digitalization considers to be synonyms (Cambridge University Press, 2020). Furthermore, increasingly many recent articles (Bloomberg, 2018; Verhoef et al., 2019) states that there emerges even larger, less definable process that comes after digitalization – digital transformation. Thus, to reduce confusion in this thesis, terms will be defined as follows:

- Digitization is "the process of changing data into a digital form that can be easily read and processed by a computer" (Lea & Bradbery, 2020, n.p.).

- Digitalization is "the manifold sociotechnical phenomena and processes of adopting and using these digital technologies in broader individual, organizational, and societal contexts" (Legner et al., 2017, n.p.).
- Digital transformation is "the profound and accelerating transformation of business activities, processes, competencies and models to fully leverage the changes and opportunities of … digital technologies and their impact across society in a strategic and prioritized way, with present and future shifts in mind" (i-SCOOP, 2020, n.p.).

In other words, digitization produces data for digitalization. Digitalization improves our current processes, experiences and digital transformation makes us to rethink, at a very fundamental level, whether some process is necessary in the first place and what can be changed. However, since digitalization and digital transformation are relatively recently coined terms, differentiation between them is yet blurry and separating their effects in the data might prove difficult, henceforth the term *"digitalization"* will refer to effects of both these processes.

Additional confusion might occur since terms – the rise of ICT and digitalization – are sometimes used nearly interchangeably. This is because information-communication technologies are at the foundation of the phenomenon, i.e., intangible and physically unaccountable presence of digitalization can only be seen and proxied by mostly tangible or accountable ICT assets/statistics.

2.2 Previous empirical research on the economic effects of ICT

There is a vast body of literature analysing potential impact of digitalization. Research papers varies by proxy used for the phenomenon – such as access to the Internet (see Choi & Hoon Yi, 2009; Meijers, 2014) or broadband penetration (Toader et al., 2018), expenditure on ICT (Evangelista, Guerrieri & Meliciani, 2014). Or by the dependent variable of interest, which accordingly to Vu, Hanafizadeh & Bohlin (2020) most frequently is GDP growth (in 124 out of 196 academic papers they summarized), being followed by a productivity analysis in the second place. Some papers investigate specific parts of digitalization, for example, AI (see PwC, 2018).

First difference, among many in the reviewed research papers, is that the rise of ICT is looked through either singular perspective of ICT being simply a variable in the production function or ICT is assumed to take a multifaceted form. The second approach implies more involved research and using not only macro level data but also using surveys, entrepreneur interviews or focusing on the social impact (Evangelista, Guerrieri & Meliciani, 2014). One of earlier examples for the first group is paper from Röller & Waverman (2001) that analyses developments of telecommunications infrastructure (DTI) in OECD countries from 1970 to 1990 concluding that there exist positive causal link between economic growth and improving telecommunications, observing that there exists certain critical mass for the technology after which the effects are more pronounced. In a similar manner, Pradhan et al. (2014) examines DTI and economic growth, also by adding four control variables (gross capital formation, foreign direct investment inflows, urbanization rates and trade openness) to their regressions as controls. The paper's results also confirm that in G20 countries during 1991-2012 DTI positively affected economic growth.

As opposed to this, from the second group, Evangelista, Guerrieri & Meliciani (2014) argues that not only existence of ICT infrastructure is important but also its use, quality and a new dimension that they call "ICT empowerment". Their findings indicate that the last two factors are more important than a mere access, concluding that digital empowerment is in favour of disadvantaged groups, for example, to those who have been unemployed for a long time, digital skills might increase their employability. World Economic Forum (2012) report also emphasizes importance of the usage of ICT. They have found that digitization affects political sphere and "allows governments to operate with greater transparency and efficiency" (World Economic Forum, 2012, p. 121). In their opinion digitalization favours those of advanced stage of digitalization, i.e., they receive 20% more in economic benefits than those at the early stages.

Yet research findings on the aforementioned assumption are varied – there exist papers that support the hypothesis that developed countries benefits more from the rise of ICT. For example, Majeed & Ayub (2018) argues that emerging and developing countries are gaining more form ICT than developed countries, because these economies are leapfrogging through different stages of ICT. Vu, Hanafizadeh & Bohlin (2020) after their extensive literature review conservatively states that there must be additional analysis carried out to support either of these claims.

As their last step, many research papers use their theoretical findings to form policy suggestions for governments and businesses. They argue that institutional settings can either be growth-inducing or growth-diminishing, explaining why countries with generally same ICT characteristics have different growth rates, thus it is important for policy makers to have long-term goals and some understanding of ICT in mind (Vu, Hanafizadeh & Bohlin, 2020). This is quantified in van Reenen et al. (2010), where they argue that “labour market regulation and product market regulation may be significant determinants of cross-country differences in the impact of ICT” (van Reenen et al., 2010, p. 6), continuing by stating that labour market regulation can decrease productivity effect of ICT in Europe up to 45%. Similarly, Gruber, Hätönen & Koutroumpis (2014) analyse investment returns in ICT, advocating the necessity for public sector in EU to subsidize building of high-speed broadband infrastructure since it is not profitable to businesses to do so and because of that there exists a potential risk of EU to fall back in comparison to its global counterparts. Firstly, because of not meeting certain standards required by advanced technologies, secondly, as they argue, because of not fully utilizing ICT effects leading in a decline of welfare and diminished ability to innovate. Recent working paper from European Commision confirms their awareness of this potential and others ICT related risks. They state that “enabling actions and investments will be needed on all levels to close the investment gap to global leaders, unleash the disruptive effect of key technologies and manage the transition of the economy and society” (European Commision, 2020, p. 2), arguing that EU might increase its global competitiveness and with some help it is possible to reduce technological gap between most and less developed member states. The report continues with simulation at which if member states achieve a 10 % improvement to their technology readiness by 2023, the cumulative additional growth effect by 2030 is 3.3 percentage points, i.e., +14.1% increase of GDP in the base scenario versus +17.4% of GDP increase in the later (European Commision, 2020).

The extensive analysis by Vu, Hanafizadeh & Bohlin (2020) who summarized nearly 200 ICT related and well-cited research papers for time period of 1991-2018, concludes with few findings that well summarizes and complements previous literature review about the multifaceted impact of digitalization. The paper states that ICT effects increase over time, they are varied among different regions, and that there exists a critical mass after which impact is more pronounced. Additionally, they say that main channels, through which digitalization works, are, firstly, technology diffusion and innovations, secondly, more qualitative (accurate) decisions, and lastly, larger efficiency that reduces costs, thus increases both supply (new products emerges) and demand (more suitable products). Finally, Vu, Hanafizadeh & Bohlin (2020) argue that organisational transformations are needed to utilize most of ICT’s effect and that research should be more devoted towards analysing reasons why and how exactly the economic performance is affected by emerging digital technologies rather than still arguing whether ICT has an effect on the economy.

After this brief review of literature now we are ready to look at Equation (1) again. According to Jones & Vollrath (2013), the simplest form Solow model includes only capital and labour inputs and it does not allow for a sustained economic growth. However, if we include $A(t)$ as is done in Eq. (1), we do allow for it, and can put the supposed effect of digitalization under technological progress variable. This is used in Toader et al. (2018), who set Equation (1) in a more practically applicable form $Y = AC^{\alpha_c}K^{\alpha_k}H^{\alpha_h}L^{\alpha_l}$, which they modify with natural logarithm, giving us Equation (2):

$$\ln Y = \ln A + \alpha_c \ln C + \alpha_k \ln K + \alpha_h \ln H + \alpha_l \ln L \qquad (2)$$

Here Toader et al. (2018) assumes that there exist two different types of capital input – one that is ICT capital input (C), the other non-ICT related physical capital input (K), thus allowing to separate effects of different capital inputs. Additionally, human capital (H) and labour (L) is included. Now equation (2) contains all necessary variables, that could be used to proxy economic growth and quantify ICT's effect, however, it must be noted since available data for ICT related investments/assets contains many missing observations, the final form (see Eq. 3) will only contain ICT access and usage proxies to account for the ICT's effect. Similar form to Eq. (2) is derived and used in other papers such as Evangelista, Guerrieri & Meliciani (2014) or Meijers (2014).

In this chapter we observed that analysis of digitalization and its effects pertains certain amount of ambiguity – be that erroneous use of terms or agreeing onto whether developing countries benefit more from digitalization as opposed to advanced ones. Yet one direction is quite clear – digitalization, both in purely fictional mathematical models and empirical data, seem to have a positive effect on country's economic growth and labour productivity.

3 Methodology

The research framework is split into four parts to determine potential effects of digitalization on the economy. In the first part, all independent variables (i.e., ICT proxies and macroeconomic control variables) one by one are regressed on each of the dependent variables to infer their general usability as regressors and to test data quality for the next steps.

Furthermore, in the second part, the analysis is continued in a similar manner by analysing the effect of two ICT access proxies regressed together on our three dependent variables seperately. This allows to verify whether simply an access to ICT via two different communication channels is enough to observe any effects that are associated with digitalization. In the third part, controls for macroeconomic processes are included in addition to previously used ICT proxies. These additional controls allow to determine the extent of ICTs effect whilst controlling for most other growth-inducing macro processes. Lastly, in the fourth phase, since some dependable variables, such as RGDPpc, might have some persistence in time (Sørensen & Whitta-Jacobsen, 2010), an additional lag of these variables is introduced because it may produce more accurate estimates for the digitalization's effect.

3.1 The fixed effects regression model

A common approach that is used with relatively few time periods (in our case $T = 18$) and many entities ($N = 28$), is by setting available data in panel data form for which either fixed effects or random effects regression techniques are used. This is done by Choi & Hoon Yi (2009), Meijers (2014) and Toader et al. (2018). They all used a similar regression model as can be seen formally represented by Equation (3) adapted from Wooldridge (2013):

$$Y_{it} = \beta_0 + \beta_1 X_{1,it} + \ \dots + \beta_k X_{k,it} + \alpha_i + \delta_t + u_{it} \quad (3)$$

where

Y_{it}	stands for the dependant variable (RGDPpc, RGDPpw or employment in each of three economic sectors and in total);
$X_{k,it}$	denotes independent variables that are divided in two groups: ICT-related proxies and macroeconomic controls;
β_0	is the regression's intercept;
β_k	is the coefficient for the independent variables;
α_i	denotes entity fixed effects;
δ_t	denotes time-specific effects;
u_{it}	is the error term;
i	country ($i = 1 \dots 28$[4]);
t	time ($t = 2000 \dots 2017$);
k	the number of regressors ($k = 1 \dots 8$).

[4] Since the Czech Republic is missing many observations for multiple variables, in most regressions it is excluded by STATA.

Here both country and time fixed effects are controlled for by their respective binary dummies allowing us to consider time invariant unobservables (such as institutional settings) and unexpected variation in time such as 2008's global recession (see discussion on the model choice in Subchapter 4.2).

3.2 Data

Three variable groups: dependent variables, ICT-related proxies and macroeconomic controls, henceforth denoted as DEP, ICT, MACRO respectively, from Equation (3) are defined as follows (see Table 3.1.), all of which are transformed in growth rates (i.e., in the first difference of natural logarithm), except for inflation[5].

Table 3.1. Summary of variables

Dependent variables	ICT-related proxies	Macroeconomic controls
• RGDP per capita (constant 2010 USD, source WB). • Employment, total and for each economic sector (expressed as number of people employed in total and in primary to tertiary economic sectors, source ILO). • RGDP per worker (constant 2010 USD, source WB).	ICT *access* proxies: • Mobile-cellular telephone subscriptions per 100 inhabitants (source ITU). • Fixed-broadband subscriptions per 100 inhabitants (source ITU). ICT *usage* proxy: • Percentage of individuals using the Internet (source ITU).	• Gross enrolment ratio, tertiary education (in %, source WB). • Trade openness (as % of GDP, source WB). • Gross capital formation (% of GDP, source WB). • Inflation, (annual %, source WB). • General government final consumption expenditure (constant 2010 USD, source WB).

Here WB refers to data obtained from World Bank's World Development Indicator database (World Bank, 2020), employment data is obtained from International Labour Organization (2019), whilst ITU refers to International Telecommunication Union (2020) data.

Dependent variables are chosen accordingly to the thesis' research objectives. RGDPpc will be used to proxy economic growth. Employment variables will allow us to test whether digitalization causes job loss in any of sectors and in total. Lastly, RGDP per worker (RGDPpw)

[5] Our ICT-proxies (see Subchapter 4.1) and macroeconomic variables are trending, graphical analysis of all regressors is carried out. The graphs indicate that there exists some certain trend within most of the data. Therefore, first difference of natural logarithms (ln) is used, except for inflation which is carefully tested for unit root and is also not used in ln form. Both unit root tests the Levin–Lin–Chu (LLC) and Im–Pesaran–Shin (IPS) reject H_0 of having unit root, thus analysis can be continued leaving inflation as it is.

approximates labour productivity and will be used to test whether the rise of ICT indeed has positive effects on productivity as it was found in Chapter 2.

Proxies for digitalization are split in two groups – ICT usage and ICT access. This is due to Evangelista, Guerrieri & Meliciani (2014) findings that access and usage impact might differ among countries. For this and also to address possibility that even in developed countries different GDP levels results in a different impact of digitalization, our sample is split in two groups – TOP and BOTTOM according to their average RGDPpc level during 2012 – 2017. Such time interval is sufficient for most of EU28 to have recovered from 2008's recession and averaging normalizes extreme values if existent.

Macroeconomic controls, such as, gross enrolment ratio (GER) of tertiary education is included to account for human capital stock as seen in Eq. (2). GER of higher education levels, according to Mālnieks (2017), should matter more for more advanced economies, therefore use of GER of tertiary education should be growth-inducing for most of the panel since EU28 contains economies that are generally considered to be advanced based on their income levels. Trade openness (TO) proxy the effect of globalization and international trade. Gross capital formation (GCF) is used to show stock of assets needed for production, low inflation levels lower the cost of production in real terms, can positively affect RGDPpc economic growth, whilst increased governmental expenditure might improve quality of life for citizens (Toader et al. 2018).

Lastly, there are some things to consider with the data. Most of variables contains missing values, thus leading panel to be unbalanced. This, however, might affect accuracy of upcoming findings and can lead to certain countries occasionally being excluded from panel regressions (see descriptive statistics in Table 3.2.).

Table 3.2. Descriptive statistics

Variable	Mean	SD	Min	Max
% of individuals using the Internet	0.097	0.144	-0.081	1.164
Fixed-broadband sub. per 100 inhabitants	0.301	0.474	-0.625	3.221
Mobile-cellular telephone sub. per 100 inhabitants	0.065	0.120	-0.234	0.751
GER of tertiary education	0.027	0.051	-0.157	0.242
Government expenditure	0.016	0.027	-0.132	0.116
Trade openness	0.015	0.064	-0.295	0.227
GCF	0.021	0.124	-0.789	0.419
Inflation	2.623	3.470	-4.478	45.667[6]
RGDPpc	0.020	0.037	-0.154	0.215
Employment - primary	-0.027	0.092	-0.446	0.349
Employment - secondary	-0.007	0.051	-0.338	0.132
Employment - tertiary	0.015	0.023	-0.086	0.118
Employment - total	0.006	0.026	-0.150	0.090
RGDPpw	0.016	0.030	-0.105	0.195

4 Analysis and discussion

4.1 Digitalization in EU 2000 – 2017

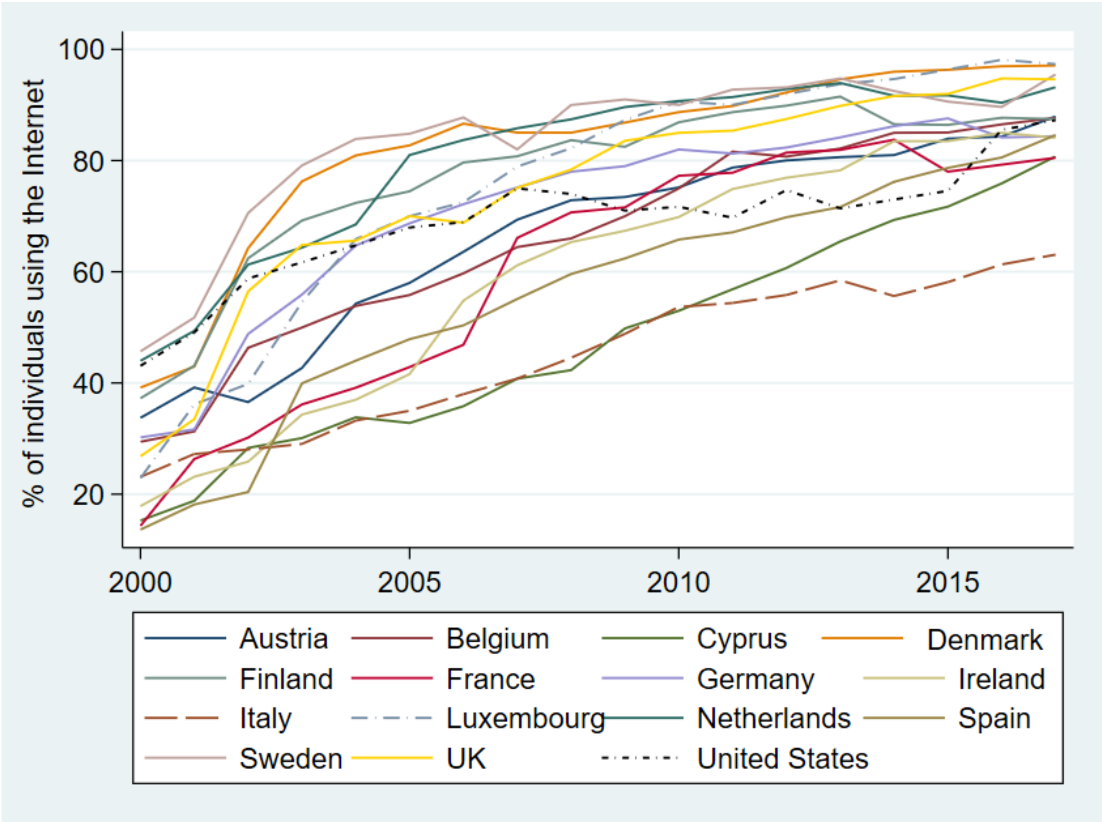
Firstly we look at the general trends of digitalization in the EU and compare its general competitiveness globally by additional using the supposed frontier of economic growth in second half of 20th century – the United States of America (US), thus addressing some of concerns of EU's falling back in terms of technological capabilities mentioned in Chapter 2.

Figure 4.1 allows us to see that the internet use has grown steadily in TOP countries over past 18 years. Whilst most of TOP countries have generally similar characteristics (and are generally affected by the same economic processes), lines show individual deviations with rapid growths and falls along the years, supporting the previous claim about institutional setting effect. Average rates of the internet usage have risen from 28% internet users per country in 2000 to 87% users in 2017, maximum of 97% being observed in Luxemburg. Interestingly, US (short dash-dot line) shows a close-to-mean internet usage if compared to other countries, whilst Italy

[6] Once 45.6% inflation was observed in Romania according to World Bank data.

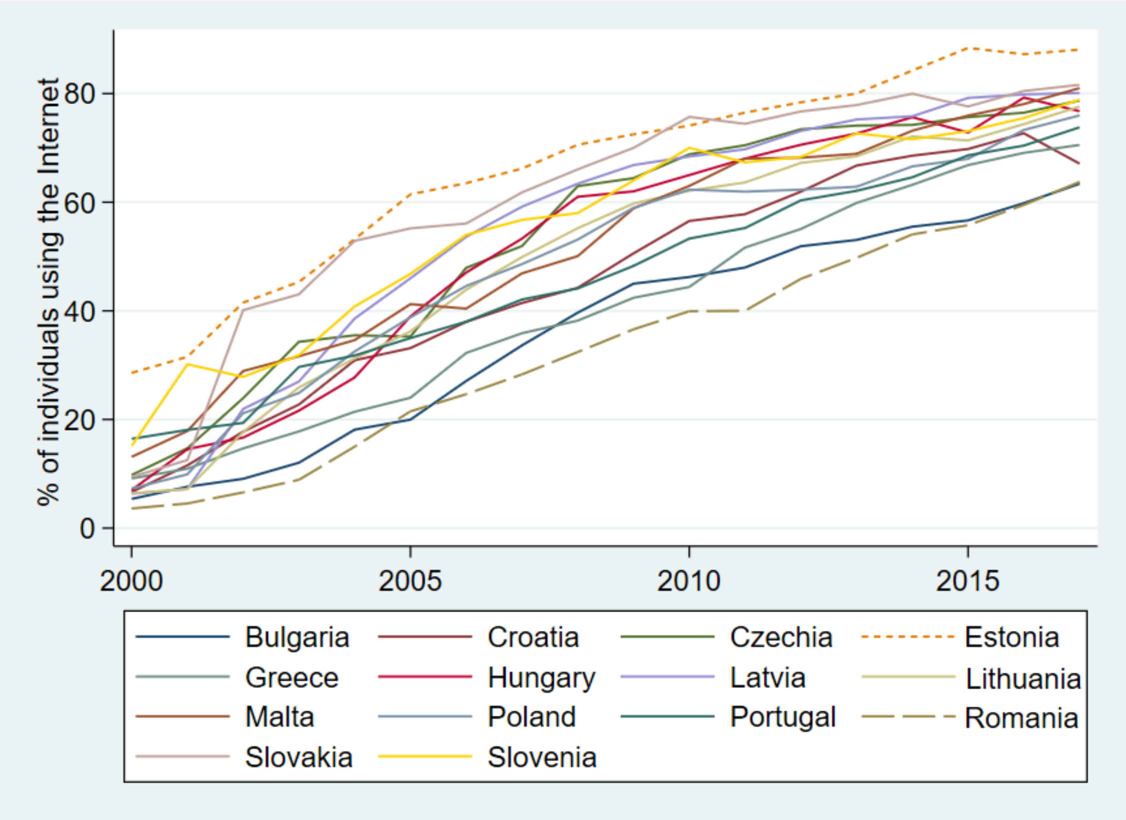
after 2010 halts its former steady growth and over the next 7 years experience marginal increase noticeably deviating from the group and finishing in one of the last places in the EU28.

Figure 4.1 Percentage of Individuals using the Internet – TOP countries



Similar steady growth is observed in BOTTOM countries (see Figure 4.2), yet one can notice significant differences in minimum and maximum values. Here average value for the internet usage in 2000 is 10,3% (with Romania having only 3%), in 2017 – 75%, which is 22% less from the upper group. Also, Estonia displays remarkable results maintaining the first position throughout the period.

Figure 4.2 Percentage of Individuals using the Internet – BOTTOM countries



Whilst both previous figures present data without a particular focus on any country except for countries with minimum and maximum values, appendix A and appendix B displays data for the remaining proxies in quartiles, thus one can easily follow each country's deviations. Appendix A displays less apparent trend in TOP countries where mobile cellular subscriptions per 100 inhabitants grew from an average of 63 subscriptions to 122 subscriptions in 2017. BOTTOM countries began with an average of 30 and rose to 125 subscriptions per 100 inhabitants, marginally superseding TOP countries. For the last ICT proxy, fixed-broadband subscription rate per 100 inhabitants, the data is equally unsurprising (see appendix B) – whilst TOP countries begin with slightly higher rate of subscriptions, by the end of 2017 difference is marginal, i.e., TOP has 36 subscriptions per 100 inhabitants and BOTTOM 7 percentage points smaller on average.

These relatively closely clustered results within groups indicate that the seemingly arbitrary choice of splitting the EU28 in two parts according to their average RGDPpc might reveal a pattern in the data, namely, that more richer countries tend to have higher ICT-related access/use proxy's value, whilst the poorer have the opposite. Yet it is not entirely predetermined as can be noticed in the data where Estonia displays significantly higher values than other members of BOTTOM part, this is due to government's significant effort towards Estonians becoming a digital society (Heller, 2017).

4.2 Regression results

The following analysis is comprised of 4 different parts to investigate digitalization's effect on the economy as per the methodology described before.

4.2.1 The first part – quality checks

In the first part, we test the general explanatory power of each independent variables separately, by using panel data regressions and perform robustness checks to ensure regression validity. As one of the first choices is to opt between fixed effects or random effects regressions and usually the correct model choice is determined by the Hausman test. Results for regressions using multiple combinations of variables from Equation (3) support the use of FE[7,8]. Also, since there is a noticeable number of outliers in the data and they may significantly alter regression results, residual versus fitted values and a representative sample of independent regressors versus dependent variables scatter plots are used. Yet even with an exclusion of extreme values in a very conservative manner, results become even less significant, due to loss of observations, thus indicating that extreme values are well-handed by models and there is no reason to exclude them.

Furthermore, as indicated in Wooldridge (2013), panel data regressions, similarly as basic CLRM, depends on homoscedastic data and no autocorrelation. Respective tests are carried out and they indicate a strong presence of both phenomena. To account for this heteroskedasticity and autocorrelation robust (clustered) standard errors (denoted as HAC SE) are used. Lastly, time-specific effects are introduced to additionally control for unexpected events in the data as mentioned before.

Finally, after performing these robustness checks, results (not included) indicate that for both RGDPpc and labour productivity, mobile cellular subscription rate produces most promising results, being statistically significant and with a positive coefficient for entire EU sample.

[7] Robustness checks are run for all parts and regressions, the first part being the most rigorous one.

[8] Hausman test implicitly assumes no heteroskedasticity and autocorrelation (HAC) in the tested regressions and since tests for both phenomena indicate HAC's presence, p-values might be erroneous. Therefore, to support use FE, I also rely on findings of previous empirical researches. In addition, FE are commonly used with country-level data.

Without time-specific effects, however, most regressors are statistically significant. These findings are on par with previous empirical findings from Chapter 2. However, proxies used in regressions with total and primary to tertiary sector employment as the dependent variable, hardly produce any useful results at all, indicating that in the upcoming analysis finding any relationship between employment and ICT variables might be complicated.

4.2.2 The second part – ICT access impact

Simultaneous use of two ICT proxies together allows to quantify the total economic effect of access to the internet, mobile network infrastructure via two different technologies. We can see from Table 4.1. that fixed-broadband subscription rate per 100 inhabitants becomes statistically insignificant in all regressions. Mobile cellular subscription deems to be significant for ALL (here and afterwards this denotes all EU28 countries) sample and BOTTOM part, yet coefficient values are very close to zero. No apparent pattern emerges from country separation in TOP and BOTTOM parts and none of the proxies are significant in regressions with labour productivity as the dependent variable. Note that here and later in the analysis, R^2 values are higher since fixed effects are also included.

Table 4.1. ICT access and digitalization (RGDPpc and labour productivity – RGDPpw)

	RGDPpc			RGDPpw		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ALL	TOP	BOTTOM	ALL	TOP	BOTTOM
Fixed broadband sub.	0.006	0.007	0.002	-0.000	-0.003	-0.006
	(0.006)	(0.006)	(0.008)	(0.006)	(0.010)	(0.008)
Mobile cellular sub.	0.050*	0.028	0.056*	0.045	-0.002	0.042
	(0.027)	(0.020)	(0.028)	(0.029)	(0.013)	(0.030)
Constant	0.005	0.004	0.006	0.005	0.013	0.018
	(0.007)	(0.007)	(0.023)	(0.005)	(0.013)	(0.015)
Observations	436	234	202	436	234	202
R-squared	0.536	0.554	0.595	0.350	0.360	0.428
# of countries	27	14	13	27	14	13

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

In Table 4.2. we can see that results are rather mixed – again fixed-broadband subscription rate is insignificant in all regressions, yet mobile phone access seems to be statistically significant in manufacturing sectors (denoted – SEC) of ALL and BOTTOM countries whilst no significant results are observed for total employment change (TOT) or primary (PRIM) sector.

Table 4.2. ICT access and digitalization (employment in economic sectors and in total)[9]

VARIABLES	(1) TOT-ALL	(2) TOT-TOP	(3) TOT-BOT	(7) SEC-ALL	(9) SEC-BOT	(10) TER-ALL
Fixed broadband sub.	0.004	0.007	0.006	0.004	0.004	-0.003
	(0.004)	(0.006)	(0.006)	(0.010)	(0.013)	(0.006)
Mobile cellular sub.	0.012	0.039	0.024	0.046**	0.081**	0.020
	(0.013)	(0.027)	(0.029)	(0.019)	(0.034)	(0.015)
Constant	0.006	0.003	-0.015	-0.015	-0.052	0.022**
	(0.010)	(0.012)	(0.023)	(0.019)	(0.041)	(0.009)
Observations	436	234	202	436	202	436
R-squared	0.304	0.279	0.396	0.356	0.425	0.207
# of countries	27	14	13	27	13	27

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Both of these tables provide first insights in digitalization's effect intertwinement with our dependent variables and results surprisingly are not as significant as expected. Nevertheless, this might change in the next step.

4.2.3 The third part – main regression models

In this part, macroeconomic control variables are now also included. From the Column (1) we can observe that using ICT access and usage proxies together, significance levels indicates the existence of a link between mobile-cellular phone subscription rate and RGDPpc whilst three out of five macroeconomic controls are significant at least at 5% significance level. Unexpectedly, trade openness is not statistically significant in none of the regressions, however, running the same regressions without included time dummies, it also becomes statistically significant. Column (5) is chosen to display the effects of one ICT access and one ICT usage proxy altogether, yet coefficient change is marginal. When analysing TOP and BOTTOM countries separately, we can observe that none of ICT related proxies are significant and inflation or trade openness are statistically indifferent from zero (see appendix C). Evangelista, Guerrieri & Meliciani (2014) arrives at similar conclusions – for them neither the ICT infrastructure, nor usage proxies have statistically significant values, whilst most of their macro controls and ICT empowerment proxy are different from zero.

[9] Most regressions at which all variables are statistically insignificant (except for time effects) are excluded for reader's convenience.

Table 4.3. Digitalization and RGDPpc for all EU28 countries

VARIABLES	(1)	(2)	(3)	(4)	(5)
Fixed-broadband sub.	-0.000	0.002			
	(0.004)	(0.004)			
Mobile cellular sub.	0.035**		0.030**		0.029**
	(0.015)		(0.013)		(0.012)
% using the Internet	0.006			0.009	0.006
	(0.008)			(0.007)	(0.006)
GER – tertiary	0.077**	0.088***	0.076**	0.079**	0.076**
	(0.032)	(0.032)	(0.030)	(0.029)	(0.030)
Gov. expenditure	0.236***	0.236***	0.213***	0.197***	0.213***
	(0.037)	(0.038)	(0.041)	(0.042)	(0.041)
Trade openness	-0.008	-0.006	-0.024	-0.020	-0.024
	(0.021)	(0.020)	(0.020)	(0.018)	(0.021)
GCF	0.153***	0.154***	0.156***	0.158***	0.156***
	(0.015)	(0.017)	(0.016)	(0.017)	(0.016)
Inflation	0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.004	0.011**	0.007	0.014***	0.006
	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)
Observations	396	396	419	436	419
R-squared	0.784	0.780	0.780	0.777	0.780
# of countries	27	27	27	28	27

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Coefficient values for regressors are significantly smaller than those from some similar research papers such as in Choi & Hoon Yi (2009) or Toader et al. (2018), where coefficients are at least 0.08 for any ICT-related proxy. Firstly, this might be because these papers use level data (whilst I am using growth rates). Also, note that they do not explicitly mention whether time series they have used are stationary or cointegrated, therefore their inference on variable significance might be erroneous and results are just spurious. Lastly, for all statistically significant macroeconomic controls in Table 4.3., our positive coefficient values are on par with Chapter 2 findings and are generally constant in value despite various model specifications, supporting their use as controls for other growth-inducing processes, whilst their use implies smaller ICT proxies' values if compared to the second part of the thesis' analysis.

As speculated in the first part, the next Table 4.4. confirms that ICT proxies do not explain any changes in total employment. Further analysis from appendix D indicates that when EU countries are split in half, ICT access proxy's (mobile cellular sub.) value in TOP countries is positive and significant (at 10% level) whilst close to zero (0.044), BOTTOM countries have negative, insignificant coefficient values. Also, trade openness in ALL (see table 4.4) and

BOTTOM parts becomes statistically different from zero and with a similar negative coefficient value across various model specifications. This can be due to that increased trade openness might lead to an increase in unemployment because of increased import penetration (Dauth, Findeisen & Suedekum, 2014).

Table 4.4. Digitalization and total employment for all EU28 countries

VARIABLES	(1)	(2)	(3)	(4)	(5)
Fixed-broadband sub.	0.003	0.004			
	(0.004)	(0.004)			
Mobile cellular sub.	0.010		-0.001		-0.004
	(0.018)		(0.017)		(0.017)
% using the internet	0.007			0.006	0.010
	(0.009)			(0.009)	(0.009)
GER – tertiary	-0.023	-0.019	-0.012	-0.012	-0.013
	(0.023)	(0.025)	(0.023)	(0.024)	(0.023)
Gov. spending	0.317***	0.317***	0.334***	0.326***	0.334***
	(0.055)	(0.054)	(0.052)	(0.051)	(0.053)
Trade openness	-0.095***	-0.094***	-0.094***	-0.092***	-0.094***
	(0.020)	(0.020)	(0.019)	(0.018)	(0.019)
GCF	0.069***	0.069***	0.067***	0.067***	0.067***
	(0.013)	(0.013)	(0.012)	(0.012)	(0.012)
Inflation	-0.000	-0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	-0.002	0.001	0.000	-0.002	-0.001
	(0.010)	(0.009)	(0.009)	(0.008)	(0.010)
Observations	396	396	417	434	417
R-squared	0.566	0.565	0.546	0.544	0.548
# of countries	27	27	27	28	27

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Even though from Table 4.4. we can observe no change in total employment, there still might be some changes among economic sectors. To analyse this, we use all EU countries and separate economic sectors as can be seen in the appendix E. Mobile cellular subscription rate is significant with total employment in TOP countries, whilst analysing the same models with primary to tertiary employment as dependent variable, there are minor changes in the primary and secondary employment sectors and no significant ICT-related regressors for tertiary economic sector employment, therefore previous conclusions remain the same.

In Table 4.5, as before with RGDPpc growth rate, mobile phone subscription rate is statistically significant, similar to Evangelista, Guerrieri & Meliciani (2014) obtained value of 0.09. In the table from MACRO controls only GCF and GER are significant. Since skilled workers with tertiary education are prone to be more productive (Mālnieks, 2017), and also increase in GCF leads to better equipment and materials to work with, sign direction seems reasonable. In appendix F we can see that there is no apparent relation between RGDPpw and ICT variables, also GER becomes statistically insignificant as well, which is most likely related to missing observations for the variable.

Table 4.5. Digitalization and labour productivity for all EU28 countries

VARIABLES	(1)	(2)	(3)	(4)	(5)
Fixed broadband sub.	-0.005	-0.004			
	(0.006)	(0.006)			
Mobile cellular sub.	0.033*		0.032**		0.034**
	(0.017)		(0.012)		(0.012)
% using the Internet	-0.002			0.000	-0.006
	(0.009)			(0.009)	(0.009)
GER – tertiary	0.096**	0.105**	0.091**	0.096**	0.092**
	(0.046)	(0.050)	(0.042)	(0.042)	(0.042)
Gov. spending	0.003	0.002	-0.027	-0.040	-0.027
	(0.051)	(0.052)	(0.055)	(0.055)	(0.056)
Trade openness	0.035	0.036	0.025	0.029	0.025
	(0.030)	(0.030)	(0.031)	(0.028)	(0.031)
GCF	0.079***	0.080***	0.083***	0.085***	0.083***
	(0.011)	(0.013)	(0.010)	(0.011)	(0.010)
Inflation	0.001	0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	0.008	0.013*	0.007	0.017*	0.008
	(0.007)	(0.007)	(0.010)	(0.009)	(0.010)
Observations	396	396	419	436	419
R-squared	0.457	0.451	0.459	0.459	0.460
# of countries	27	27	27	28	27

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Parts 1-3 indicated that altogether ICT access proxy induce economic growth and total labour productivity increase, whilst there was no noticeable pattern to indicate that digitalization negatively affected employment. Yet since coefficient values for digitalization proxies are relatively small one might argue, similarly as Meijers (2014), that access to or usage of ICT itself is not the main transmission channel through which digitalization affects economy but rather it is an intermediary. In Meijers (2014) view the internet use affects trade/trade openness levels which later leads to economic growth[10]. Similarly, as mentioned in Chapter 2, digitalization's full effect might be significantly higher in near future, thus this might explain relatively small impact of ICT during 2000-2017.

4.2.4 The fourth part – dynamic panel models

In the fourth phase dependent variables are lagged and we can verify whether the most interesting results from the third part holds. This is done in a similar manner with Toader et al. (2018) by using a dynamic panel model with Arellano–Bond estimator.

Results from Table 4.6. conforms with our previous findings in Table 4.3, namely, that mobile cellular subscription rate per 100 inhabitants is the only ICT-related proxy that is statistically significant with the same approximate coefficient value of 0.03. No major change is observed in MACRO controls both in terms of their significance and coefficient values, whilst, as expected, RGDPpc one period lag is statistically significant and its effect is the second largest from all regressors.

[10] A careful reader will notice that trade openness here has a significant and negative coefficient value for which there might be several reasons. Meijers' paper analyses 162 countries and time period is different (1990-2008). Also, his first regression models with FE and GMM, who also are used here, produce coefficient values that are close to ones observed here (in his paper trade openness has coefficient value of 0.02, whilst here it its -0.09).

Table 4.6. Digitalization and RGDPpc for all EU28 countries with included RGDPpc lag

VARIABLES	(1)	(2)	(3)	(4)	(5)
RGDPpc (t-1)	0.170*	0.184*	0.171*	0.193**	0.171*
	(0.094)	(0.097)	(0.092)	(0.093)	(0.091)
Fixed broadband sub.	-0.000	0.002			
	(0.005)	(0.005)			
Mobile cellular sub.	0.038		0.038*		0.039*
	(0.027)		(0.021)		(0.021)
% using the Internet	0.005			0.005	-0.003
	(0.009)			(0.010)	(0.009)
GER – tertiary	0.086**	0.094**	0.082**	0.087**	0.083**
	(0.041)	(0.042)	(0.038)	(0.041)	(0.039)
Gov. spending	0.242***	0.243***	0.235***	0.222***	0.234***
	(0.039)	(0.041)	(0.046)	(0.045)	(0.047)
Trade openness	0.033	0.039*	0.033	0.034	0.032
	(0.021)	(0.022)	(0.022)	(0.021)	(0.022)
GCF	0.143***	0.144***	0.142***	0.142***	0.142***
	(0.014)	(0.015)	(0.014)	(0.015)	(0.014)
Inflation	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	351	351	363	378	363
# of countries	27	27	27	28	27

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

In a similar manner, the relationship between labour productivity and digitalization's impact is challenged. As opposed to minor change in the previous table for RGDPpc, here in Table 4.7., none of ICT access/usage variables are significant. Furthermore, GCF and GER significance level is less than that of Table 4.5.

Table 4.7. Digitalization and labour productivity for all EU28 countries with included RGDPpw lag

VARIABLES	(1)	(2)	(3)	(4)	(5)
RGDPpw (t-1)	0.016	0.034	0.029	0.046	0.029
	(0.059)	(0.061)	(0.062)	(0.063)	(0.062)
Fixed-broadband sub.	-0.002	-0.001			
	(0.008)	(0.007)			
Mobile cellular sub.	0.028		0.024		0.025
	(0.034)		(0.028)		(0.026)
% using the internet	0.009			0.008	0.000
	(0.012)			(0.013)	(0.011)
GER – tertiary	0.091*	0.095	0.083*	0.083	0.083*
	(0.053)	(0.060)	(0.050)	(0.052)	(0.050)
Gov. spending	0.066	0.071	0.056	0.045	0.054
	(0.061)	(0.065)	(0.078)	(0.077)	(0.078)
Trade openness	0.038	0.045	0.036	0.037	0.035
	(0.030)	(0.027)	(0.030)	(0.027)	(0.030)
GCF	0.083***	0.083***	0.085***	0.085***	0.085***
	(0.012)	(0.013)	(0.011)	(0.012)	(0.011)
Inflation	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	351	351	363	378	363
# of countries	27	27	27	28	27

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

For a further research one could use more lags for the dependent variables and/or regressors to analyse whether our dynamic panel results change. In particular, it would be interesting to analyse this with new ICT access/usage data in the next few years after the COVID-19 spread stops.

5 Conclusions

The thesis' results seem to indicate that ICT access (proxied by mobile cellular subscription rate per 100 inhabitants) has a positive effect on economic growth (RGDP *per capita*) and labour productivity (RGDP per worker), yet without any observable effect on employment, even after cautiously separating and looking into a possible change in each of the economic sectors. Also, no apparent pattern emerges in the separation of EU28 in two parts, TOP and BOTTOM countries, according to their respective RGDPpc levels. The only time when both halves seem to noticeably differentiate from each other is when observing data for the Internet usage, where a pattern emerges that for TOP countries this proxy has somewhat higher values. Moreover, for the same variable there exists some country-specific deviations among EU member states. This seems in line with findings during the literature review that institutional settings can significantly affect ICT's access/usage thus impacting the utilization of digitalization's benefits.

Nevertheless, there is one significant point to consider – despite proxies and macroeconomic controls having sign on par with theoretical findings, values obtained in Chapter 4, are somewhat small, whilst being statistically significant. For example, in most regressions, mobile cellular subscription rate per 100 inhabitants has coefficient values between 0.03-0.08, whilst many of macroeconomic regressors have coefficient values well above 0.1. This seems to indicate that whilst there is some positive effect due to digitalization, more accurate estimates and the full effect of it might be observable in the future, with more observations to include in regressions and larger share of the population accessing/using ICT. Yet, since implementing or upgrading ICT infrastructure occasionally might be a long process, policymakers should be patient and aware that the effect of their investments might not be observable immediately, rather than many years after. Lastly, another possible explanation for small coefficient values is that digitalization's proxies also serve as an intermediary and affects processes that are responsible for the observed economic growth, however, this requires additional analysis.

To sum up – should we be on board the "digitalization-hype-train"? I think we should since digitalization's effect, at least in the areas covered here, is positive and no negative consequences were observed. Yet, again, to fully utilize or analyse digitalization's benefits we must have a long-term mindset in place. Also, supposedly there are also some directly unquantifiable effects, such as, social inclusion, mobility, thus policymakers also should consider these social aspects when preparing country development strategies.

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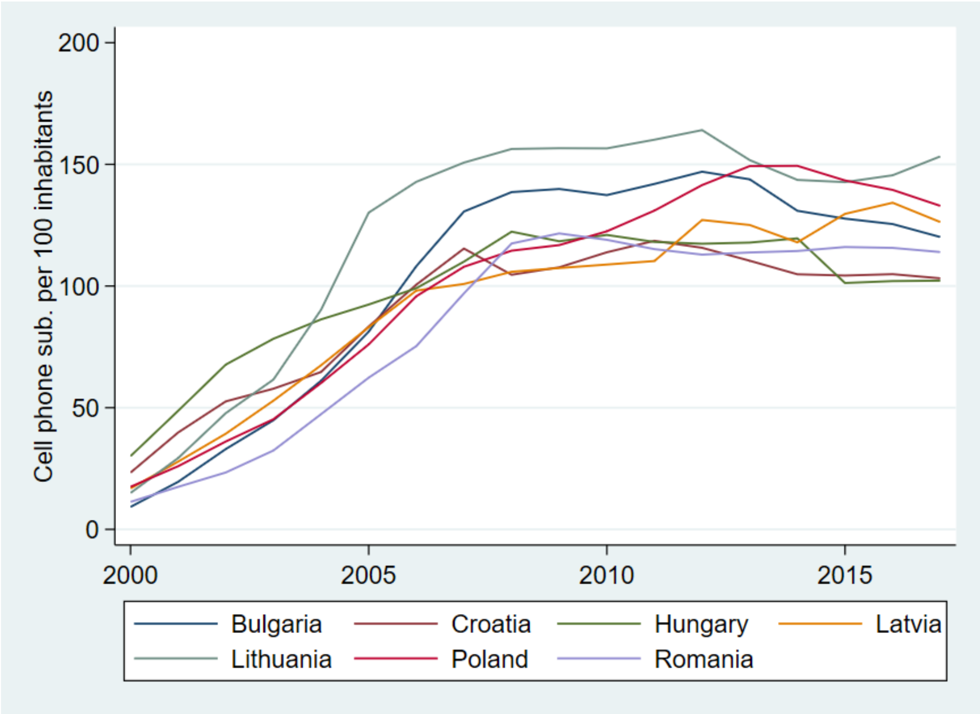
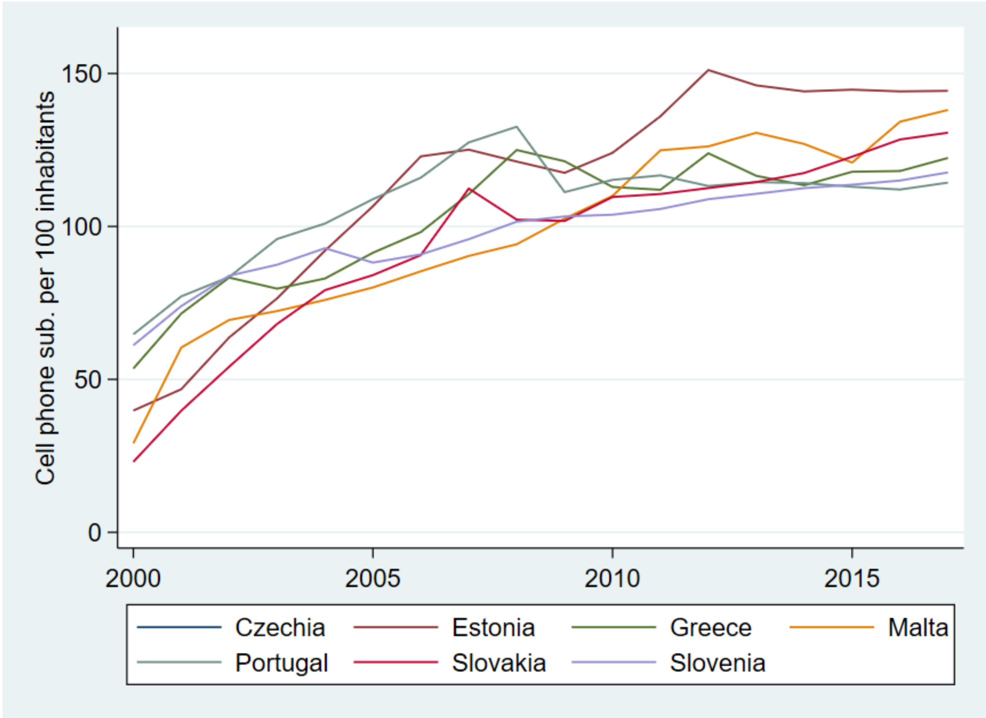
Appendix

Appendix A. Mobile-cellular telephone subscriptions per 100 inhabitants for EU28's TOP and BOTTOM countries

Data source: International Telecommunication Union (2020)



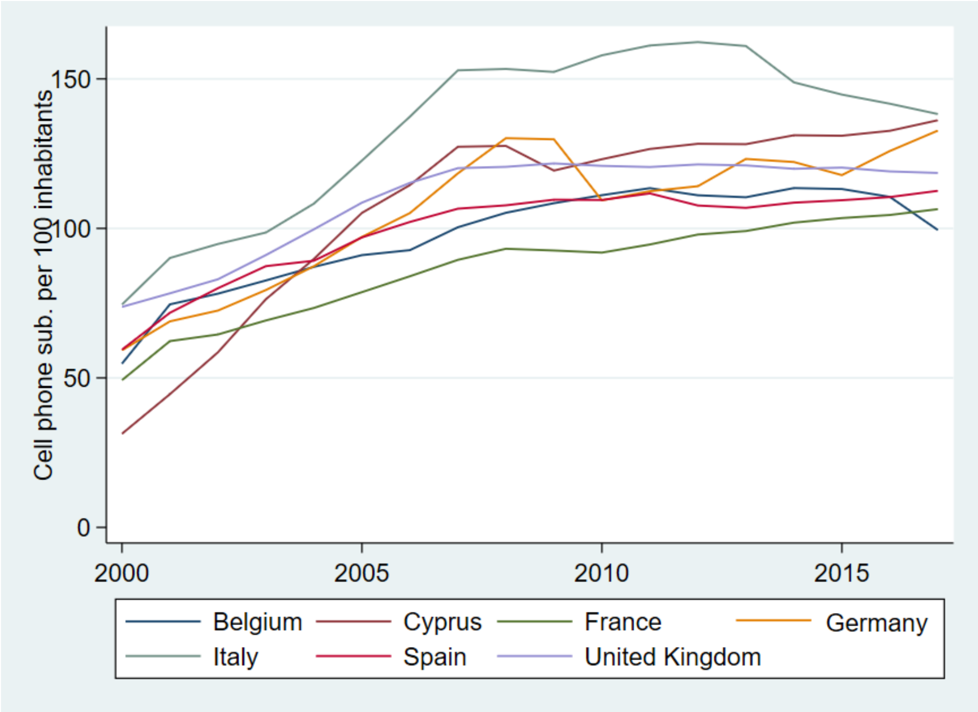
1st quartile



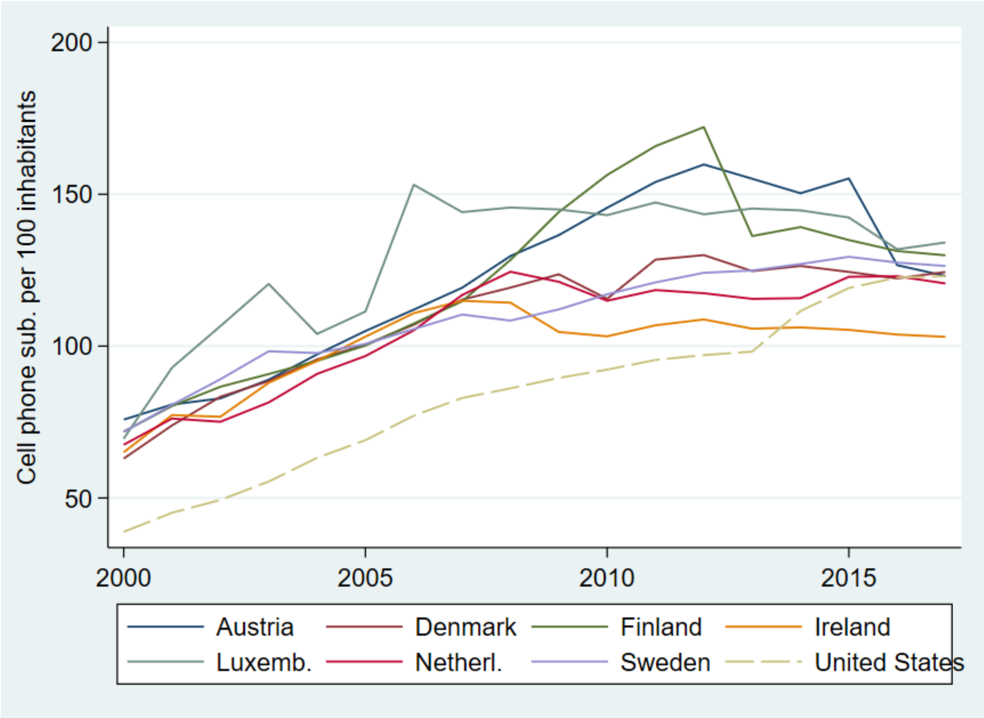
2nd quartile

Appendix A – continued. Mobile-cellular telephone subscriptions per 100 inhabitants for EU28's TOP and BOTTOM countries

Data source: International Telecommunication Union (2020)



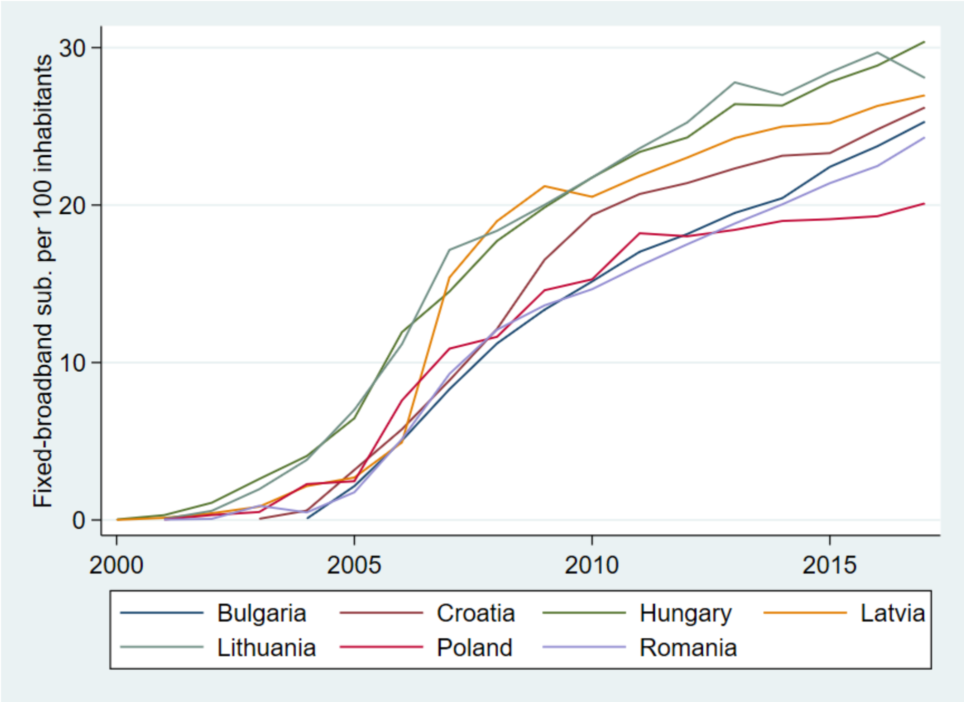
3rd quartile



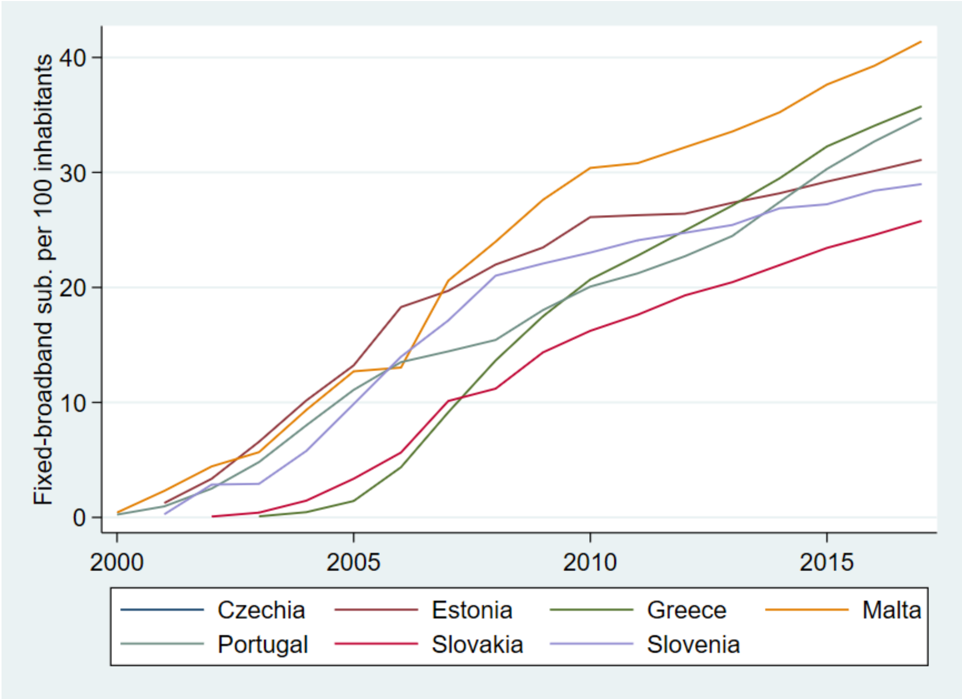
4th quartile and US

Appendix B. Fixed-broadband subscription per 100 inhabitants for EU28's TOP and BOTTOM countries

Data source: International Telecommunication Union (2020)



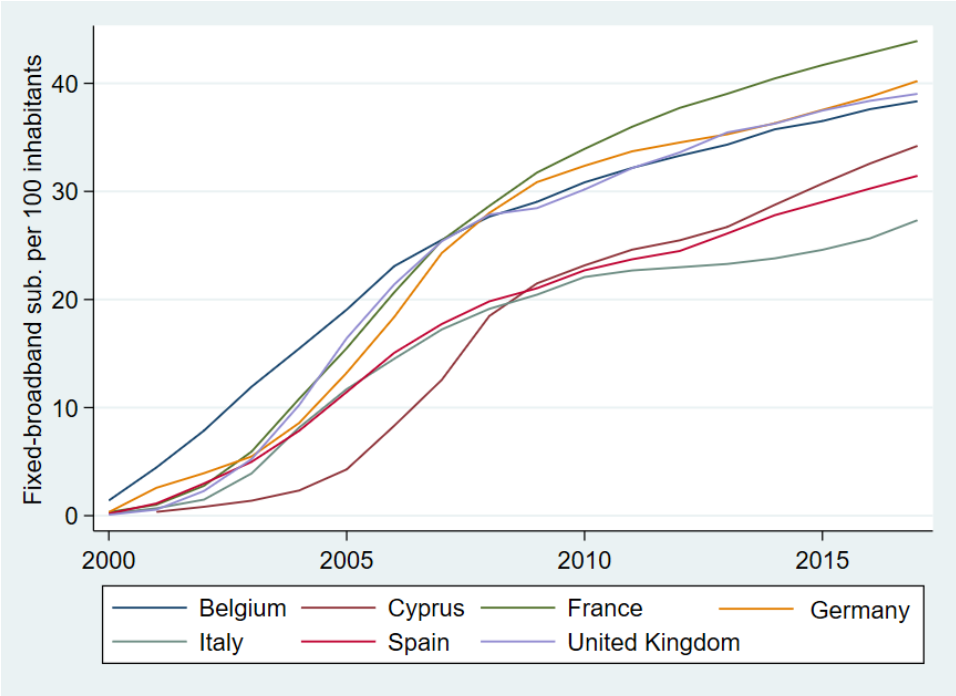
1st quartile



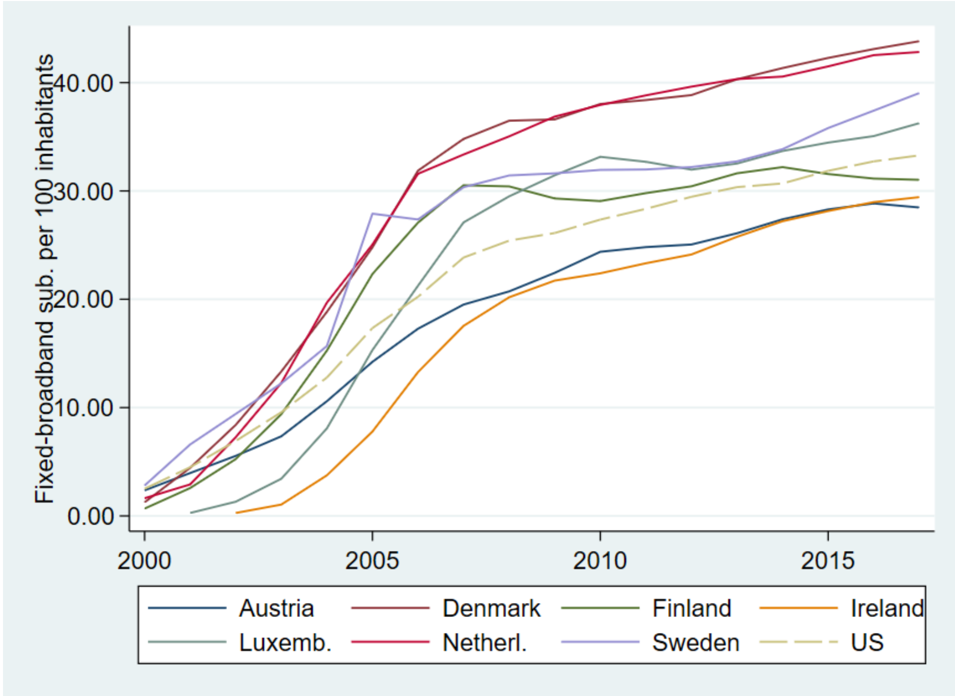
2nd quartile

Appendix B – continued. Fixed-broadband subscription per 100 inhabitants for EU28's TOP and BOTTOM countries

Data source: International Telecommunication Union (2020)



3rd quartile



4th quartile and US

Appendix C. Digitalization and RGDPpc for EU28's TOP and BOTTOM countries

	TOP countries					BOTTOM countries				
VARIABLES	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Fixed-broadband sub.	-0.000	-0.000				-0.001	0.001			
	(0.006)	(0.006)				(0.005)	(0.005)			
Mobile cellular sub.	0.013		0.014		0.016	0.045		0.034		0.031
	(0.014)		(0.015)		(0.014)	(0.025)		(0.020)		(0.019)
% using the Internet	-0.012			-0.014	-0.014	0.013			0.013	0.011
	(0.010)			(0.011)	(0.011)	(0.008)			(0.010)	(0.008)
GER - tertiary	0.069*	0.071*	0.071*	0.071**	0.070*	0.051	0.067	0.052	0.050	0.050
	(0.033)	(0.034)	(0.034)	(0.032)	(0.033)	(0.044)	(0.045)	(0.037)	(0.036)	(0.038)
Gov. spending	0.166**	0.164**	0.186**	0.188***	0.187**	0.282***	0.278***	0.242***	0.216***	0.243***
	(0.068)	(0.069)	(0.063)	(0.062)	(0.062)	(0.041)	(0.040)	(0.056)	(0.055)	(0.055)
Trade openness	-0.019	-0.024	-0.020	-0.021	-0.017	-0.037	-0.030	-0.052*	-0.041	-0.053*
	(0.037)	(0.037)	(0.036)	(0.036)	(0.036)	(0.028)	(0.027)	(0.024)	(0.024)	(0.025)
GCF	0.157***	0.158***	0.153***	0.155***	0.154***	0.153***	0.152***	0.156***	0.157***	0.156***
	(0.027)	(0.026)	(0.028)	(0.027)	(0.028)	(0.017)	(0.019)	(0.017)	(0.019)	(0.017)
Inflation	-0.005***	-0.004***	-0.004***	-0.005***	-0.004***	0.001	0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
Constant	0.020**	0.019***	0.017***	0.023***	0.020***	-0.001	0.020	0.010	0.021**	0.008
	(0.008)	(0.006)	(0.004)	(0.004)	(0.004)	(0.013)	(0.012)	(0.013)	(0.008)	(0.013)
Observations	199	199	203	203	203	197	197	216	233	216
R-squared	0.748	0.747	0.745	0.746	0.747	0.832	0.824	0.822	0.818	0.823
# of countries	14	14	14	14	14	13	13	13	14	13

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix D. Digitalization and total employment for EU28's TOP and BOTTOM countries

	TOP countries					BOTTOM countries				
VARIABLES	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Fixed-broadband sub.	0.001	0.001				0.007	0.008			
	(0.006)	(0.007)				(0.006)	(0.005)			
Mobile cellular sub.	0.032		0.044*		0.044	0.024		0.012		0.008
	(0.031)		(0.025)		(0.026)	(0.030)		(0.028)		(0.028)
% using the internet	-0.001			0.004	0.003	0.017			0.014	0.016
	(0.016)			(0.014)	(0.015)	(0.016)			(0.013)	(0.013)
GER - tertiary	-0.016	-0.013	-0.014	-0.009	-0.014	-0.018	-0.007	0.007	0.010	0.004
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.039)	(0.040)	(0.036)	(0.033)	(0.035)
Gov. spending	0.266***	0.263***	0.261***	0.263***	0.261***	0.300***	0.297***	0.325***	0.313***	0.325***
	(0.074)	(0.072)	(0.039)	(0.036)	(0.039)	(0.067)	(0.065)	(0.067)	(0.065)	(0.069)
Trade openness	-0.006	-0.015	-0.016	-0.027	-0.016	-0.090**	-0.085**	-0.089***	-0.083***	-0.090***
	(0.032)	(0.026)	(0.034)	(0.033)	(0.035)	(0.030)	(0.030)	(0.028)	(0.023)	(0.027)
GCF	0.068***	0.071***	0.066***	0.069***	0.066***	0.072***	0.071***	0.073***	0.074***	0.074***
	(0.018)	(0.018)	(0.015)	(0.015)	(0.015)	(0.014)	(0.015)	(0.015)	(0.015)	(0.015)
Inflation	0.007***	0.007***	0.006***	0.006***	0.006***	-0.001	-0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Constant	-0.013	-0.007	-0.011	-0.004	-0.011	-0.027	-0.012	-0.016	-0.015	-0.020
	(0.011)	(0.011)	(0.009)	(0.010)	(0.010)	(0.020)	(0.014)	(0.017)	(0.011)	(0.018)
Observations	199	199	203	203	203	197	197	214	231	214
R-squared	0.615	0.611	0.609	0.601	0.609	0.617	0.609	0.577	0.575	0.581
# of countries	14	14	14	14	14	13	13	13	14	13

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix E. Digitalization and employment (in total and in each of economic sectors) for EU28's TOP and BOTTOM countries (using mobile – cellular subscription rate as the only ICT related variable)

As before PRIM denotes employment in the primary economic sector, SEC – secondary, TER – tertiary, whilst TOT denotes total employment.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	ALL				TOP				BOTTOM			
VARIABLES	PRIM	SEC	TER	TOT	PRIM	SEC	TER	TOT	PRIM	SEC	TER	TOT
Mobile cellular sub.	-0.022	0.018	0.008	-0.001	-0.004	0.063	0.038	0.044*	-0.090	0.050	0.029	0.012
	(0.066)	(0.024)	(0.015)	(0.017)	(0.150)	(0.047)	(0.024)	(0.025)	(0.089)	(0.037)	(0.024)	(0.028)
GER – tertiary	0.053	-0.023	-0.000	-0.012	0.080	0.029	-0.031	-0.014	0.013	-0.023	0.042	0.007
	(0.078)	(0.034)	(0.029)	(0.023)	(0.141)	(0.061)	(0.036)	(0.034)	(0.117)	(0.046)	(0.036)	(0.036)
Gov. spending	0.022	0.454***	0.341***	0.334***	-0.539	0.326**	0.312***	0.261***	0.171	0.470**	0.332***	0.325***
	(0.201)	(0.116)	(0.056)	(0.052)	(0.358)	(0.117)	(0.047)	(0.039)	(0.209)	(0.160)	(0.069)	(0.067)
Trade openness	-0.116	-0.187***	-0.062***	-0.094***	-0.050	-0.158*	0.019	-0.016	-0.118	-0.156**	-0.062**	-0.089***
	(0.079)	(0.042)	(0.020)	(0.019)	(0.130)	(0.083)	(0.029)	(0.034)	(0.130)	(0.058)	(0.025)	(0.028)
GCF	0.047	0.154***	0.038***	0.067***	0.016	0.215***	0.026	0.066***	0.047	0.138***	0.051**	0.073***
	(0.041)	(0.019)	(0.013)	(0.012)	(0.045)	(0.025)	(0.017)	(0.015)	(0.058)	(0.022)	(0.018)	(0.015)
Inflation	-0.004**	0.002***	0.001*	0.000	0.009	0.007***	0.005***	0.006***	-0.006**	0.002***	0.001*	0.000
	(0.002)	(0.001)	(0.000)	(0.001)	(0.005)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.000)	(0.000)
Constant	-0.046	-0.025*	0.003	0.000	-0.103**	-0.027*	-0.003	-0.011	0.041	-0.060**	-0.019	-0.016
	(0.033)	(0.013)	(0.007)	(0.009)	(0.038)	(0.013)	(0.011)	(0.009)	(0.049)	(0.021)	(0.011)	(0.017)
Observations	417	417	417	417	203	203	203	203	214	214	214	214
R-squared	0.094	0.552	0.419	0.546	0.154	0.632	0.481	0.609	0.147	0.554	0.475	0.577
# of countries	27	27	27	27	14	14	14	14	13	13	13	13

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix F. Digitalization and labour productivity for EU28's TOP and BOTTOM countries

	TOP countries					BOTTOM countries				
VARIABLES	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Fixed-broadband sub.	-0.008	-0.007				-0.009	-0.008			
	(0.007)	(0.007)				(0.007)	(0.007)			
Mobile cellular sub.	-0.012		-0.017		-0.015	0.033		0.022		0.026
	(0.027)		(0.025)		(0.024)	(0.021)		(0.018)		(0.018)
% using the Internet	-0.014			-0.015	-0.014	-0.006			-0.007	-0.012
	(0.013)			(0.015)	(0.015)	(0.018)			(0.012)	(0.012)
GER – tertiary	0.039	0.039	0.039	0.036	0.038	0.103*	0.111	0.092	0.089*	0.094*
	(0.038)	(0.037)	(0.038)	(0.036)	(0.038)	(0.057)	(0.063)	(0.053)	(0.050)	(0.052)
Gov. spending	0.018	0.018	0.018	0.018	0.019	0.043	0.042	0.000	-0.024	-0.001
	(0.052)	(0.051)	(0.044)	(0.043)	(0.043)	(0.074)	(0.074)	(0.077)	(0.076)	(0.078)
Trade openness	-0.001	0.001	0.008	0.014	0.010	0.005	0.010	0.001	0.008	0.002
	(0.048)	(0.050)	(0.051)	(0.052)	(0.051)	(0.039)	(0.038)	(0.038)	(0.032)	(0.037)
GCF	0.079**	0.077**	0.078**	0.078**	0.079**	0.079***	0.079***	0.083***	0.082***	0.082***
	(0.032)	(0.030)	(0.029)	(0.028)	(0.029)	(0.011)	(0.011)	(0.009)	(0.009)	(0.009)
Inflation	-0.007***	-0.007***	-0.006***	-0.006***	-0.006***	0.001	0.001	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	0.038***	0.032***	0.025***	0.026***	0.028***	0.015	0.025	0.017	0.030*	0.019
	(0.010)	(0.009)	(0.006)	(0.005)	(0.007)	(0.017)	(0.017)	(0.019)	(0.015)	(0.020)
Observations	199	199	203	203	203	197	197	216	233	216
R-squared	0.442	0.438	0.431	0.432	0.433	0.549	0.545	0.536	0.536	0.539
# of countries	14	14	14	14	14	13	13	13	14	13

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1