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The Importance of ICT Investment in EU Total Factor Productivity Growth: Industry Analysis for 2000-2020

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Abstract:

Purpose: *The aim of the article is to verify the hypothesis that a positive relationship between ICT capital growth and TFP change, although lagged in time and varying across different sectors, can be observed in the EU.*
Design/methodology/approach: *The research approach including EUKLEMS productivity data and econometric methods, i.e. cross-sectional and panel growth regressions focuses mainly on the importance of individual ICT-using sectors in shaping EU TFP change. It is conducted for a combined sample of ICT-using industries across 13 EU member states in the period 2000-2020.*
Findings: *The conducted study proved that for EU ICT-using sectors there was a negative relationship between current ICT investment and TFP change, which may explain the productivity paradox. The 5-year lagged positive impact of ICT investment on TFP was evidenced for most EU ICT-using sectors, except professional, scientific activities and administrative services.*
Practical implications: *The findings may constitute an important signal to economic policymakers shaping the directions of future innovation policy at both national and EU level to particularly focus on these sectors that have a clear problem with effective ICT implementation.*
Originality/Value: *This industry-level study covers a relatively large group of EU members and a period including the rarely examined decade of 2010–2020. The applied methodology represents a step forward through examining the importance of individual ICT-using sectors in shaping EU TFP change.*

Keywords: *ICT, TFP growth, ICT-using sectors, European Union.*

JEL codes: *F43, O11, O33, O4.*

Paper Type: *Research article.*

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1. Introduction

Total Factor Productivity (TFP) is defined as the share of technical progress in productivity growth creation. Currently, this progress is largely generated in the information and communication technology sector (ICT-producing industries) and implemented by others, referred to as ICT-using sectors in the literature. From a theoretical point of view, the relationship between ICT production and TFP change derives directly from the neoclassical growth theory (Solow, 1956; Biagi, 2013, Jorgenson *et al.,* 2002).

The issue of the impact of ICT usage on TFP growth is based on the new growth theory and linked to the concept of ICT as a General Purposed Technology (Li and Wu, 2023). This second channel is crucial especially in the context of explaining the so-called Solow paradox. The polemical response to Solow's statement that *"You can see the computer age everywhere but in the productivity statistics."* (Solow, 1987), indeed, may be the idea that, in the industries where ICT is used most intensively, TFP acceleration appears with a certain lag which, according to empirical research to date, lasts more than 5 years.

At the beginning, ICT investment is accompanied by a required learning phase and reorganisation processes in companies (intangible co-investment), and then results in some co-inventions like better decision making, improvement of business models, more effective distribution systems etc., (Goldfarb and Tucker, 2019).

These inventions can diffuse among companies, which can imitate successful organisational ideas and benefit from spillovers of the so-called intangible complementary capital. Complementary organisational capital accumulation is, however, a slow process, but the final result is time-delayed TFP acceleration (Czernich *et al.,* 2011; Röller and Waverman, 2001).

Moreover, the current ICT investment is associated rather with a drop in TFP in ICT-using sectors. This initial slowdown appears because the required intangible co-investment uses resources diverted from direct production (Basu and Fernald, 2007).

In literature, empirical research on the above issue requiring the use of industry-level data has mostly focused on the US and selected European economies and has mainly concerned the first decade of the 21st century. Within the important stream of research, the surveys were aimed at looking at the relationship between ICT investment and TFP growth in ICT intensive sectors and used TFP regression with lagged or current ICT variable as explanatory (Stiroh, 2002a; 2002b; Inklaar *et al.*, 2008; McMorrow *et al.,* 2010).

In more complex studies the importance of intangible complementary capital in TFP acceleration was incorporated. The industry-level models were applied to prove that TFP acceleration in ICT-using sectors was positively correlated with lagged ICT capital growth and negatively with the current ICT investment change (Basu and Fernald, 2007; Vincenzi, 2012; Edquist and Henrekson, 2017).

Following the empirical evidence to date and the theoretical justification provided by the new growth theory, it can be hypothesised that in the EU a positive relationship between ICT capital growth and TFP change, while lagged in time and varying according to the sectors, is observed. It has not, as yet, been the subject of more extensive analysis.

The aim of this study is to verify the above hypothesis using the research approaches mentioned above with a particular focus on the importance of individual ICT-using sectors in shaping EU TFP change. In this respect, the study differs from previous ones. It is conducted for a combined sample of ICT-using industries across EU member states, thus attempting to fill an existing research gap.

The study covers a relatively long period of time, 2000–2020, and a set of productivity data across industries in 13 EU member states obtained from the EUKLEMS and INTANProd database.

The research attempts to answer the following research questions: Is there a decline in TFP in EU ICT-using sectors during the first period of ICT usage? Is the positive impact of ICT investment on EU TFP postponed in time (as previous analyses indicate) by at least 5 years? Are EU sectors differentiated in this respect? EUKLEMS productivity analysis and econometric methods, i.e. cross-sectional and panel growth regressions, are used for this purpose.

The paper is organised as follows. The second part includes a review of the previous relevant industry-level research. The third part describes the methodology, data sources as well as specification of cross-sectional and panel regression models applied. Section 4 reports the results of empirical analysis. Conclusions and ideas for future research are collected in section 5.

2. Evidence on the Importance of ICT-Using Sectors in EU TFP Growth: Review of Empirical Studies

In the literature, the relationship between ICT investment and TFP growth has been mainly investigated using industry-level data. The first stream of industry-level data research focused on investigating the relationship between current or lagged ICT investment and TFP growth in ICT-intensive sectors. These studies started in 2000s and concerned the US (e.g. Stiroh, 2002a) or selected EU countries.

Van Ark and Inklaar (2005) investigated market industries in France, Netherlands, Germany, UK and the USA in the period 1979–2003 and regressed TFP growth on contemporaneous ICT capital intensity. The obtained estimates suggested little impact of current ICT investment on TFP growth.

In the 1980s they found that ICT investment and TFP growth were negatively related. Finally, they concluded that the effect of ICT investment on TFP occurs only with a lag related to a phase of investments in human capital, knowledge capital and organisational innovations. The negative correlation between contemporaneous ICT capital and TFP growth was also found by Inklaar *et al.* (2008) for 9 market service industries in 10 EU members (Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Spain and the UK) and the USA for the period 1980-2004.

The regression results showed a negative relationship between ICT usage and TFP. Weak evidence of the link between current ICT investment and TFP growth was obtained by McMorrow *et al.* (2010) from their industry-level study for 9 EU countries and the USA, in which determinants of EU-US TFP gap in the period 1980–2004 were examined.

The regression model results suggested that industries with higher adoption rates for ICT-intensive technologies appeared to exhibit higher TFP growth rates. Moreover, Edquist and Henrekson (2017) in the study carried out for 50 Swedish industries in 1993-2003 proved a negative impact of current ICT capital on TFP growth using models with first-differencing data and time-specific effects as well models with 3, 5 and 10-year moving averages.

When TFP growth in 2004-2014 related to lags for ICT capital was investigated, the results proved that average ICT capital growth in 1993-2003 was positively associated with average TFP growth in the subsequent period. Based on panel data with smoothed five-year moving averages, it was also found that ICT and TFP growth were positively associated when 7-8 years lags were used for ICT.

More complex stream of studies on the link between ICT capital and TFP growth were based on the idea of ICT as GPT and the crucial role of intangible, complementary capital accumulation, that was incorporated both in theoretical and empirical models. Assuming that in ICT-using sectors the effects of ICT capital on TFP occur with a certain lag, the focus was on capturing the connections between TFP dynamics and the changes in ICT capital both in the current and previous periods.

In the study for UK industries conducted by Basu *et al.* (2004), the average industry TFP growth over the 1995–2000 period was regressed on average share-weighted capital growth in 1980–1990, 1990–1995 and 1995–2000. The results proved a positive relation between currently rising ICT capital and TFP growth.

After changing the model specification (using first difference of variables) TFP growth positively and significantly related to the prior change in ICT investment, and negatively associated with current one was confirmed. In the subsequent work, Oulton and Srinivasan (2005), using the same theoretical framework and the new set of UK industry-level data, regressed the change in TFP growth in 1995-2000 over 1990-1995 on ICT investment flow and ICT stock growth. The results obtained for 29 UK industries showed that when only ICT capital stock was entered, the sign of related coefficient was positive as expected.

In the industry-level study for 30 industries in Belgium, France and the US the US conducted by Vincenzi (2012) the TFP acceleration in non-ICT producing industries was determined by current and previous ICT usage. The average TFP growth in 2001-2005 was regressed on current and lagged (periods of 1997-2001 and 1993-1997) share-weighted ICT capital growth.

For all investigated countries TFP growth was negatively correlated with ICT capital growth in 2001-2005 and positively with lagged ICT investment from 1997-2001. However, TFP was also negatively related to ICT capital growth in the more lagged period of 1993–1997, that pointed at the lag of 5-7 years for ICT investment to become productive.

3. Methodology, Data and Models

The study covers a relatively long period of time, 2000-2020, and a group of 13 EU member states (Austria, Belgium, the Czech Republic, Germany, Denmark, Spain, Finland, France, Italy, the Netherlands, Sweden, Slovakia and the United Kingdom (in 2000-2020 still a full EU member). The research is conducted at the industry level using data provided by EUKLEMS and INTANProd database[2].

Realising that the relationships under study are of a medium or even long-term nature, and taking into account the previous research results indicating a time gap between ICT usage and TFP growth, the study was conducted for averaged data, i.e., for four 6-year sub-periods: 2000-2005, 2005-2010, 2010-2015, 2015-2020. The choice of 6-year sub-periods was dictated by the fact that the results the research discussed above suggested a lag of more than 5 years between ICT investment and TFP acceleration.

Usually in industry-level studies ICT-using sectors are identified by either the degree of ICT-skilled employment in total employment (OECD, 2011) or the volume of investment in ICT (van Ark *et al.*, 2003, Inklaar *et al.*, 2008). In this article, following the latter approach and making the necessary modifications (industry classification is aligned with NACE rev.2), ICT-using sectors are industries with the most intensive usage of ICT, i.e., printing and reproduction of recorded media (C16-C18), machinery and equipment (C28), other manufacturing, repair and installation of machinery equipment (C31-C33), wholesale and retail

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[2]*This database aimed at productivity analysis (based on neoclassical growth accounting method) includes required full dataset for 13 European countries across 42 industries (NACE rev.2).*

trade (G), financial and insurance activities (K), professional, scientific, technical, administrative and support services (M-N).

The study considers two approaches used in literature to analyse the impact of ICT capital on the TFP growth. According to the first stream of studies the connection between current or lagged ICT investment and TFP growth for 78 ICT-intensive sectors across the selected EU members was investigated[3].

For that purpose the average TFP growth in particular subperiods of 2000–2020 was regressed on the average ICT capital growth in earlier periods. The share-weighted ICT capital growth data (ICT capital contribution to value added in particular ICT using industries *j*) was obtained from EUKLEMS & INTANProd database. The following cross-sectional regression models were estimated:

$$\Delta TFP_j^{2000-2005} = \alpha + \beta\, {k_{contr}^{ICT}}_j^{2000-2005} + \varepsilon_j \quad (1)$$
$$\Delta TFP_j^{2005-2010} = \alpha + \beta {k_{contr}^{ICT}}_j^{2000-2005} + \varepsilon_j \quad (2)$$
$$\Delta TFP_j^{2005-2010} = \alpha + \beta\, {k_{contr}^{ICT}}_j^{2005-2010} + \varepsilon_j \quad (3)$$
$$\Delta TFP_j^{2010-2015} = \alpha + \beta\, {k_{contr}^{ICT}}_j^{2005-2010} + \varepsilon_j \quad (4)$$
$$\Delta TFP_j^{2010-2015} = \alpha + \beta {k_{contr}^{ICT}}_j^{2010-2015} + \varepsilon_j \quad (5)$$
$$\Delta TFP_j^{2015-2020} = \alpha + \beta\, {k_{contr}^{ICT}}_j^{2010-2015} + \varepsilon_j \quad (6)$$
$$\Delta TFP_j^{2015-2020} = \alpha + \beta\, {k_{contr}^{ICT}}_j^{2015-2020} + \varepsilon_j \quad (7)$$

In accordance with the second and more complex approach, a study on the relation between ICT capital and TFP growth in ICT-intensive sectors based on the idea of ICT as GPT was carried out. The following model, capturing the connection between TFP and both current and previous ICT capital changes, was applied:

$$\Delta TFP_{j,t} = \alpha_j + \gamma_1\, k_{contr\ j,t}^{ICT} + \gamma_2 k_{contr\ j,t-1}^{ICT} + \varepsilon_{j,t} \quad (8)$$

j= 1,…,kn; t=1,…,T;

$\varepsilon_{j,t} \sim IID\,(0;\ \sigma_\varepsilon^2);\ \forall_{j=1,\dots,n} \forall_{t=1,\dots,T} E\left(k_{contr\ j,t}^{ICT}, \varepsilon_j\right)=0;$

The panel model was estimated for a combined dataset integrated by ICT-using industry, country and period (a sample including 6 ICT-using sectors, 13 EU members and 4 periods) in order to capture the overall relationship and test whether, in line with the theoretical assumptions, TFP acceleration in EU ICT-using sectors precedes its decline up to 5 years after ICT investment.

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[3]*Data for 13 EU members and 6 ICT-intensive industries for selected period were included in the sample.*

Moreover, a more detailed study of the individual ICT-intensive sectors in the EU was carried out. For that purpose six panel models (data on the selected ICT-using industry for 13 countries in 4 periods were included in samples) with a modified specification were estimated:

$$\Delta TFP_{i,t} = \alpha_i + \gamma_1 k^{ICT}_{contr\ i,t} + \gamma_2 k^{ICT}_{contr\ i,t-1} + \varepsilon_{i,t} \quad (9)$$

i= 1,…,k; t=1,…,T;

$\varepsilon_{i,t} \sim IID(0;\ \sigma^2_\varepsilon);\ \forall_{i=1,\dots,n} \forall_{t=1,\dots,T} E\left(k^{ICT}_{contr\ i,t}, \varepsilon_i\right)=0;$

Estimations of model (9) allowed to show the differences between particular EU ICT-intensive sectors in terms of ICT investment efficiency. Panel models were assessed with a particular focus on signs and statistical significance of estimated parameters as well as statistical quality.

The selection of the appropriate estimator for individual models was made after diagnostic tests: the robust test on constant differentiation (the existence of fixed effects and validity of using the *within* (FE) estimator) or the Hausman test (when the random effect model and RE (GLS) estimator were taken into account). The robust standard errors were calculated, i.e., the option of computing an estimate of the covariance matrix that is robust with respect to heteroskedasticity and autocorrelation.

4. Results

Within the first step of the study, the cross-sectional regression models (1-7) were estimated to track connection between current or lagged ICT investment and TFP growth for 78 ICT-intensive sectors in the EU. Figure 1 shows the individual model estimates as well as graphical interpretation of the obtained results.

On the basis of the estimates of models (1), (3), (5) and (7)[4], it can be concluded that for the ICT-using sectors in the EU, the current changes in the size of ICT investments were negatively correlated with TFP dynamics (a negative and statistically significant value of the β parameter was obtained).

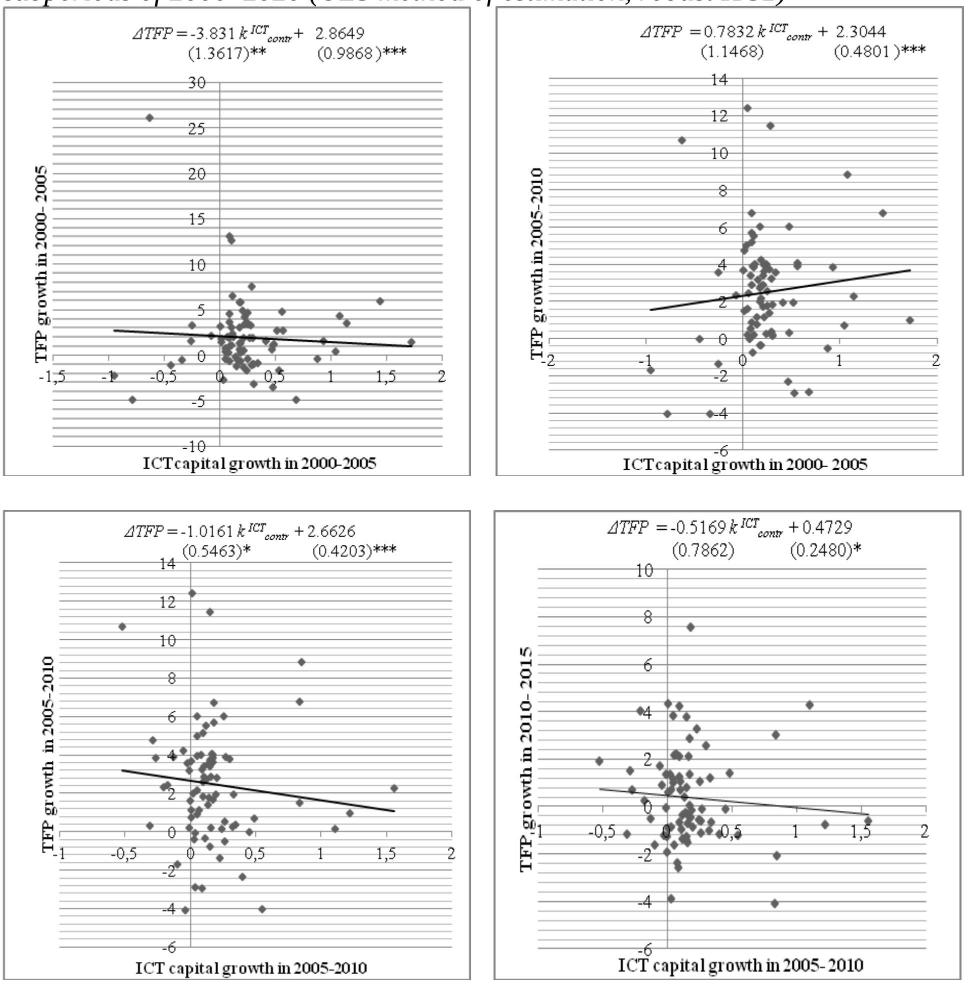
Already less conclusive results were obtained in the models in which the average TFP growth in particular subperiods of 2000-2020 was regressed on the average ICT capital growth in earlier periods. The estimation results of models (2) and (6) confirmed a positive correlation between prior investment in ICT in 2000-2005 and 2010-2015 and the average TFP growth in the periods 2005-2010 and 2015-2020, respectively but the variable k^{ICT}_{contr} proved to be statistically insignificant.

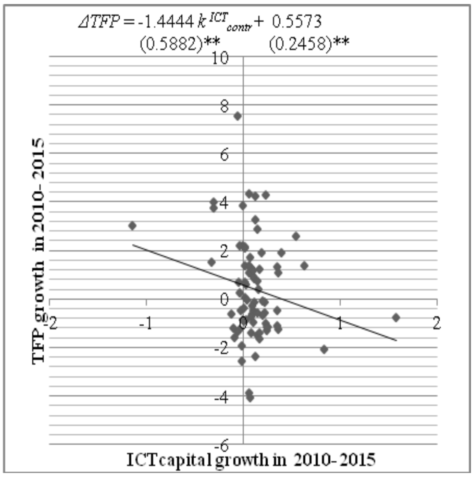
[4]*However, the estimates should be taken with some caution due to the imperfect fit of the data to the model (low R^2 values obtained).*

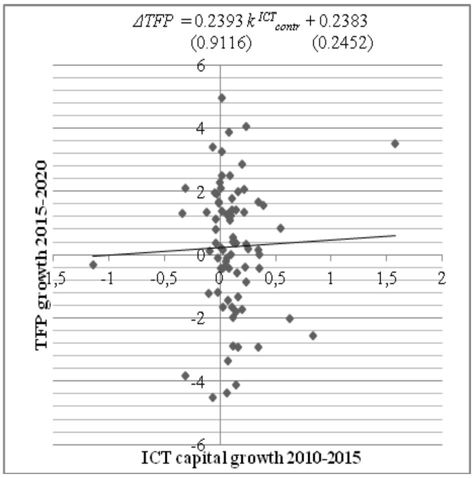
In turn, the estimation of model (4) indicate a negative relationship between the average ICT capital growth in 2005-2010 and TFP dynamics in the subsequent period 2010-2015 (β was -0.52). The k^{ICT}_{contr} variable was also statistically insignificant.

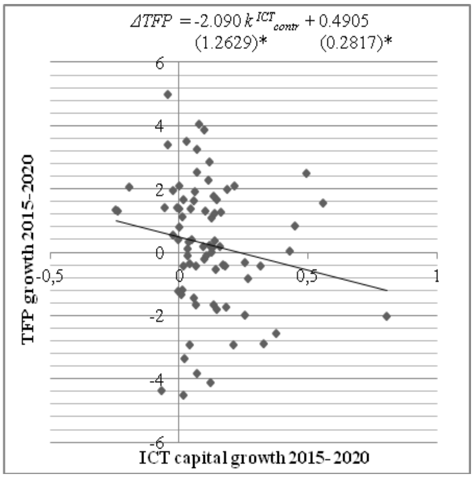
Under the second research approach, panel models were estimated to show the relationship between current and lagged ICT capital changes and TFP dynamics in all combined (model 8) and individual (model 9) ICT- using sectors in the EU. The estimation results are included in Table 1.

***Figure 1**. Past and current ICT capital and TFP growth in EU ICT-using sectors in subperiods of 2000–2020 (OLS method of estimation, robust HC1)*









Notes: ****/**/*means significance at 1%, 5%, 10%; the numbers in brackets denote the value of the robust standard error*

Source: *Own calculations using EUKLEMS & INTANProd data.*

Table 1. *TFP growth and current and lagged ICT investment in EU industries - estimation results of the panel models for 2000–2020; FE/RE method of estimation (robust HAC)*

Dependent variable: ΔTFP							
Model specification	(8)	(9)					
Independent viariables/ diagnostics	All ICT- using industries	C16-C18	C28	C31-33	G	K	M-N
const.	0.778363 (0.332673)**	1.73199 (0477937)***	0.992054 (0.877367)	-0.143387 (1.33839)	0.812311 (0.477115)*	1.48052 (0.957277)	0.879214 (0.366130)***
$k^{ICT}_{contr\ jt}$	-0.754711 (11526)	-4.46040 (1.27797)***	-4.33591 (3.19570)	-0.309824 (13.6456)	-0.137198 (0.05601)**	-0.559325 (1,01647)	-3.33303 (1.68565)**
$k^{ICT}_{contr\ j\ t-1}$	1.88509	4.69948	5.69833	11.2422	2.62439	0.281089	-2.00662

	(1.12099)*	(1.80636)***	(4.93335)	(5.07558)**	(1.454762)*	(0.168178)*	(0.659610)***
model	FE	RE	RE	FE	RE	RE	FE
Robust test on constant diff.[1] Test statistics [p]	3.49922 [1.85777e-006]	-	-	3.85205 [0.0217869]	-	-	3.08705 [0.0416628]
LSDV R^2	0.362359	-	-	0.287941	-	-	0.645375
Hausman test[2] Test statistics [p]	-	4.04098 [0.13259]	0.592159 [0.743728]	-	0.65027 [0.72243]	5.94812 [0.0510954]	-
Number of observations	234	39	39	39	39	39	39
ICT current negative impact on TFP	(yes)[3]	yes	(yes)	(yes)	yes	(yes)	yes
ICT lagged positive impact on TFP	yes	yes	(yes)	yes	yes	yes	no

Notes: ****/**/* means significance at 1%, 5%, 10%; the numbers in brackets denote the value of the robust standard error*

[1]*Test for diversification of the constant in groups: null hypothesis H_o: the groups have a common constant; rejection of H_0 means a viable use of the fixed effect model*

[2]*Hausman test: null hypothesis H_o: the GLS estimator is compliant; non-rejection of the null hypothesis H_0 means that the use of the random effect model is viable*

[3]*The bracket () means the correct sign of estimated parameter but insignificance of variable ICT $contr_{jt}$ or $ICTcontr_{jt-1}$.*

Source: *Own calculations using GRETL.*

In model (8) including the widest sample, the estimated parameters had signs consistent with theoretical assumptions. A negative value of parameter γ_1 and a positive value of parameter γ_2 were obtained. The k^{ICT}*contr t-1* variable (a proxy of lagged ICT investment growth) amounted to approx. 1.89 and significantly and positively influenced TFP growth. The k^{ICT}*contr t* variable (a proxy of the current ICT capital change) was -0.75 but statistically insignificant.

However, the above relationships varied depending on the sector implementing ICT, as indicated by the estimation results of the six models described by equation (9). In the case of EU sectors like manufacture of wood and wood products, paper and printing and reproduction of recorded media (*C16-C18*) as well as wholesale and retail trade and repair of motor vehicles and motorcycles (*G*), the ICT as GPT hypothesis was fully positively verified.

The estimated parameters in models for these industries had desired signs (a negative value of γ_1 and positive of γ_2) and explanatory variables significantly influenced TFP growth. For the printing and reproduction industry high levels of negative impact of current ICT investments on TFP ($\gamma_1$amounting approx. to -4.46) and positive effects of lagging ones (γ_2= 4.7). were recorded. In the wholesale and retail sale industries a positive impact of lagging ICT investment change and negative of the current on TFP growth was lower (γ_2 of 2.62 and γ_1 -0.14, respectively).

Evidence of a positive and statistically significant impact of the prior ICT investments on TFP in EU financial and insurance sectors (γ_2 amounting 0.28) as well as in manufacturing (production of furniture, sports goods, games, medical and dental instruments, jewellery, etc.), and repair/installation of machinery equipment (γ_2 of 11.24), was found. The estimates of the parameter γ_1 indicated also a negative impact of the current investment in ICT, but the variable $k^{ICT}{}_{contr\ t}$ was statistically insignificant.

Model estimates for EU industries like manufacture of machinery and equipment (C28) were ambiguous. In this case a confirmation of the negative impact of the current and positive of the lagged ICT investment on TFP was obtained (γ_1 was -4.33 and γ_2 was 5.7). Although the estimated parameters had desired signs, the explanatory variables were statistically insignificant.

Surprising results were obtained for the European sectors related to professional and scientific activities (e.g. legal, management, engineering, R&D, market research services) as well as administrative services (e.g. rental, leasing, employment, travel, security services).

A negative and statistically significant impact of the prior and current investment in ICT on TFP changes was confirmed. The γ_1 parameter amounted to about -3.33 and γ_2 was -2.01, which suggests that these sectors had a problem in transforming ICT investments into tangible economic outcomes, even in the medium term.

5. Conclusions

The study results show that in the EU there was a negative relationship between current ICT investment and TFP change in ICT-using sectors, which may explain the productivity paradox. Initially, investment in ICT resulted in a decrease in TFP, which is due to the need to learn new technologies, invest in human capital and create new business models.

The highest decline in TFP was observed in sectors such as manufacture of wood and wood products, paper and printing and reproduction of recorded media, manufacture of machinery and equipment as well as professional, scientific and administrative services. The lowest drop in TFP was reported in wholesale and retail trade.

The lagged positive impact of ICT usage on TFP was evidenced for most EU ICT-using sectors. When assessing their ability to transform ICT investments into TFP growth, sectors such as manufacturing, repair and installation of machinery equipment, wholesale, retail trade, financial and insurance activities performed best. For them, a relatively low decline in TFP during the "learning phase" and a high positive impact of ICT capital on TFP growth over a period longer than 5 years were evidenced.

The exceptions were professional and scientific activities as well as administrative services, where prior ICT investment resulted in a decline in TFP even after a period longer than 5 years. This indicates the lack of efficiency in converting ICT capital into tangible economic outputs. This finding may constitute an important signal to economic policymakers shaping directions of future innovation policy to focus precisely on aforementioned sectors that have a clear problem with effective ICT implementation.

The approach applied in this study is in line with that used in existing literature but also represents a step forward through the particular focus on the importance of individual ICT-using sectors in shaping TFP in the EU. However, it has some drawbacks.

Although it takes into account the existence of ICT spillovers (approximated by measurable ICT investments), it does not allow to isolate them and control in an empirical study. Furthermore, it seems crucial to answer the question of why some industries show better capabilities than others in generating additional lagged TFP growth. Probably it is related to their absorptive capabilities, appropriate level of human capital and elasticity of organisational changes.

In the future, a more detailed analysis would require expanding the model specification and taking into account the impact of ICT externalities and other intangible assets (such as R&D, economic competences, etc.) on the TFP change in EU economies.

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