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Capital Accumulation, Total Factor Productivity, and Employment Growth: Medium-Term Relations in a Cross-Section Analysis

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European Commission
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Capital Accumulation, Total Factor Productivity, and Employment Growth

Medium-Term Relations in a Cross-Section Analysis

Robert Stehrer

Abstract

There is a widespread concern that new technologies and digitalization have strong negative impacts on labour demand. This paper analyses the impact of ICT capital accumulation and TFP growth on employment growth (persons and hours worked) and the labour income share in the pre- and post-crisis years. The cross-section results (over countries and industries) suggest that on average TFP growth has no significant influence on employment growth, and perhaps even a slightly positive one, which may point to increasing competitiveness. There is no evidence of significant impacts of the accumulation of ICT capital on employment growth, whereas a positive relationship is found between non-ICT capital accumulation and employment growth. Concerning labour income shares, results at the industry level point to a negative impact of TFP growth, but no effects of ICT capital accumulation. Domestic and foreign inter-industry linkages have – if at all – only modest impacts. These results are generally in line with some recent literature pointing towards only limited effects of new technologies on labour demand.

JEL Classification: C21, O33.

Keywords: ICT capital formation, technical change, employment, inter-industry linkage.

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1. INTRODUCTION

More than 30 years ago, Nobel-price laureate Bob Solow stated: 'You can see the computer age everywhere but in productivity statistics.'[1] Since then, it is widely acknowledged that, despite the rise of information and communications technologies (ICTs), labour productivity growth has been at a historically low level in recent decades. The reasons for this 'productivity paradox' are widely debated.

An analogous argument might be made concerning employment. Despite widespread fears that ICTs could destroy a lot of jobs and even lead to the 'end of work' (see e.g. Rifkin, 1995), employment levels have generally increased over the long run (measured either by the number of persons employed, or by employment and activity rates). In economic history such debates have a long tradition, starting with David Ricardo's famous Chapter 31, 'On Machinery', in the third edition of his *Principles* (Ricardo, 1821), and followed by discussions on 'technological unemployment', inter alia, by John Maynard Keynes, Sir John Hicks, Wassily Leontief and many others. Today a similar debate exists, with a focus on 'digitalisation' and disruptive technologies related to important new trends, such as the Internet of Things (IoT), Big Data, virtual and augmented reality, 3D printing, blockchain technologies, artificial intelligence (AI), robotics, nanotechnology and biotechnology.

The debate is largely unresolved, with a number of studies raising both fears and expectations of the employment effects, which are selectively outlined in Section 2. From a purely theoretical perspective, the impacts of various channels are debated, which result in arguments for both labour saving and employment creation (e.g. the labour-saving character of technical change also implies a higher real income, which leads to positive employment effects). Thus, it remains mostly an empirical exercise to study the impacts of technical change on employment. In this sphere, this paper focuses on the effects of ICT capital formation (including capital asset accumulation of information technologies, communications technologies, and software and databases). Broadly following a recent methodology suggested by Autor and Salomons (2018), the paper studies the impacts of growth of ICT and non-ICT asset types, together with total factor productivity (TFP) growth, on employment over the medium run – distinguishing the pre- and post-crisis years, controlling for overall productivity growth and inter-industry linkages. Section 3 provides an overview of the relevant data. Section 4 introduces a simplified framework, outlines the econometric specification and presents the results. Section 5 concludes and discusses some caveats of the approach.

Summarising the results, we find no significant impact of ICT capital accumulation on employment growth (and consequently also no labour-shedding effect) or the labour income share. Non-ICT capital (and particularly the asset types defined as other machinery and intangible R&D) are positively related to employment growth. TFP growth impacts negatively on the labour income share development, but we find no robust significant effect on employment growth.

[1] Robert Solow, 'We'd better watch out', *The New York Times Book Review*, 12 July 1987, p. 36.

2. SELECTED RECENT LITERATURE

A recent and comprehensive framework is developed in a study by Acemoglu and Restrepo (2018), in which they analyse the effects of robots substituting specific labour tasks. They show that robots competing with human labour may reduce employment and wages. However, labour may perform new tasks, in which it has a comparative advantage over robots. Sachs and Kotlikoff (2012), Benzell et al. (2015), and Sachs, Benzell and LaGarda (2015) assume that robots are not there to assist humans in their work but to replace them entirely. They come to the conclusion that the introduction of robots would boost productivity in the short term, but decrease wages and consumption in the long term. The question of the effects of technical change on employment, and in particular digitalisation and employment, has been attracting a lot of attention.[2] This was partly triggered by the seminal study by Frey and Osborne (2017), which argued that almost half of current US jobs are at risk of being 'computerised'. Estimates using similar approaches provided by Arntz et al. (2016) are, however, less alarming. Rather than looking at whole employment sectors, they evaluated the potential 'automatability' of tasks within an occupation and concluded that only about 9% of jobs are currently automatable (defined as the risk of automation being above 70%). Nedelkoska and Quintini (2018) subsequently expanded the coverage of countries and occupational titles. Their results suggest that about 14% of jobs in OECD countries face the risk of being 'highly automatable'.

A number of papers focus on the introduction of robots. For example, in an econometric exercise, Graetz and Michaels (2018) tested the effects of robot use on labour productivity growth, TFP growth, output prices and employment. They did not find a significant (negative) impact on employment. Although their results indicate that robots increase labour productivity growth and TFP growth, they also tend to decrease output prices as an offsetting effect. A recent report by the European Bank for Reconstruction and Development (EBRD, 2018) found similar results for emerging economies. In another study, Acemoglu and Restrepo (2017) focused on US local labour markets. Using data from EU KLEMS combined with data on robot use over the period 1970-2007, they found that the adoption of robots leads to large and robust declines in employment and wages.

Prettner and Bloom (2020, Chapter 3) summarise a number of papers and conclude that automation has a positive impact on labour productivity – and negative employment and wage effects for low-skilled workers (mainly in manufacturing), but insignificant or even positive effects for high-skilled workers – and that it leads to a decline in the labour income share.

The main reference points for this study are Autor and Salomons (2018) and Ghodsi et al. (2019). Autor and Salomons (2018) estimate the effect of technological progress (they prefer the term 'automation') on employment, including a systematic treatment of four different channels of how it can affect the labour market: own-industry effects, upstream-industry effects, downstream-industry effects, and final-demand effects. They conclude that TFP – their proxy for technological progress – has negative direct effects but positive indirect effects on employment. In total, the latter are dominant, and hence the overall effect of technological progress on employment is positive. Ghodsi et al. (2019) use this framework and quantify the impacts of robots on employment using a wider sample of countries and controlling for TFP growth. Their results indicate that there is no significant impact on employment, but suggest a positive and significant effect on real value added growth. However, as outlined below, the approach by Autor and Salomons (2018) has been criticised by Felipe et al. (2020).

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[2] Much of the literature focuses on the differentiated impact on various groups of workers (e.g. high-skilled versus low-skilled), which is not covered here as it is not the subject of this study, which focuses on total employment effects. For recent contributions on the impact on various worker groups, see Berman et al. (1998), Dao et al. (2017), Krusell et al. (2000), Michaels, Natraj and Van Reenen (2014), and Spitz-Oener (2006).

In this paper, we address the impact of the accumulation of ICT capital (information technology, communication technology, and software and databases) in EU member states on employment growth and changes in the labour share, using a cross-section estimation for the pre- and post-crisis periods. By doing so, we control for the effects of TFP growth accumulation of non-ICT assets (including intangibles). Following Autor and Salomons (2018), we also provide estimations including inter-industry spill-over effects, and in addition we distinguish between domestic and foreign spill-overs. The focus of this paper is on overall employment effects, and so impacts by occupational or educational dimension are not studied. Other recent studies investigate the impact of robots, whereas we focus on capital stock data and available asset types taken from national accounts.

3. DATA AND STYLISED FACTS

To apply the approach adopted by Autor and Salomons (2018), data from the EU KLEMS Release 2019 (see Stehrer et al., 2019; Adarov and Stehrer, 2019) and the World Input-Output Database (WIOD) Release 2016 (see Timmer et al. 2015) are combined. This section briefly describes the data sources for productivity and capital variables. In addition, it summarises the coverage of data with respect to time, countries and industry details. Data on inter-industry linkages are described in Section 4.4.

3.1. PRODUCTIVITY INDICATORS, EMPLOYMENT, AND CAPITAL SERVICES GROWTH

The EU KLEMS Release 2019 comprises data on various relevant indicators, especially value added and labour productivity growth (in terms of hours worked and persons employed), growth rates of TFP and capital services, distinguishing ICT and non-ICT capital services as well as tangible and intangible capital services in the data released. These are based on more detailed data of capital stocks by asset types according to ESA 2010 (see Stehrer et al., 2019, for details). The tangible non-ICT asset types include residential structures (RStruc), other construction (OCon), transport equipment (TraEq), other machinery (OMach) and cultivated assets (Cult). A further group comprises the tangible information (IT) and communications (CT) assets. Concerning the intangible assets, three capital assets are distinguished according to ESA 2010: software and databases (SoftDB), research and development (R&D), and other intellectual property products (OIPP). Data on the individual asset types are available in terms of net capital stocks (reference prices 2010), whereas the aggregates are available as growth rates of the respective capital services (i.e. growth rates weighted by user costs of capital); for details, see Stehrer et al. (2019).

In terms of industries, the data detail 52 industries (including various aggregates). Depending on data availability concerning capital stocks and compatibility with data taken from the World Input-Output Database (WIOD), which is used in Section 4.4 to study spill-over effects, 29 industries are used in this research. These are listed in Table 3.1. As can be seen, the list of industries corresponds closely to the NACE Rev. 2 aggregates; however, in some cases these are aggregated further. In some cases, more detailed industries are not considered, as some countries do not report capital stocks at these levels (this mostly applies to industries G, H, and J, for which data are often only available for the 1-digit letter code).

In terms of country coverage, the focus is on the EU member states. However, data on capital stocks by asset types and relevant capital services aggregates are not available for Bulgaria, Croatia, Cyprus, Greece, Ireland, Luxembourg, Malta, Portugal, and Romania. The EU KLEMS data are generally available over the period 1995-2017, although in some cases the time series are shorter owing to data limitations. Particularly for Central and Eastern European countries (CEECs), the time series on capital stocks start mostly only in 2000 and data on TFP growth only from 2009 (which is also the case for

Ireland[3]). In the econometric exercise below, we also provide results for different groups along these lines.

Table 3.1. **List of industries**

Nr.	NACE Rev. 2	Description
1	A	Agriculture, forestry and fishing
2	B	Mining and quarrying
3	C10-C12	Food products, beverages and tobacco
4	C13-C15	Textiles, wearing apparel, leather and related products
5	C16-C18	Wood and paper products; printing and reproduction of recorded media
6	C19	Coke and refined petroleum products
7	C20	Chemicals and chemical products
8	C21	Basic pharmaceutical products and pharmaceutical preparations
9	C22_C23	Rubber and plastics products, and other non-metallic mineral products
10	C24_C25	Basic metals and fabricated metal products, except machinery and equipment
11	C26	Computer, electronic and optical products
12	C27	Electrical equipment
13	C28	Machinery and equipment n.e.c.
14	C29_C30	Transport equipment
15	C31-C33	Other manufacturing; repair and installation of machinery and equipment
16	D	Electricity, gas, steam and air conditioning supply
17	E	Water supply; sewerage; waste management and remediation activities
18	F	Construction
19	G	Wholesale and retail trade; repair of motor vehicles and motorcycles
20	H	Transportation and storage
21	I	Accommodation and food service activities
22	J	Information and communication
23	K	Financial and insurance activities
24	L	Real estate activities
25	M_N	Professional, scientific, technical, administrative and support service activities
26	O	Public administration and defence; compulsory social security
27	P	Education
28	Q	Health and social work
29	R-U	Arts, entertainment, recreation; other services and service activities, etc.; activities of households, as employers; undifferentiated goods- and services-producing activities of households for own use; activities of extraterritorial organisations and bodies

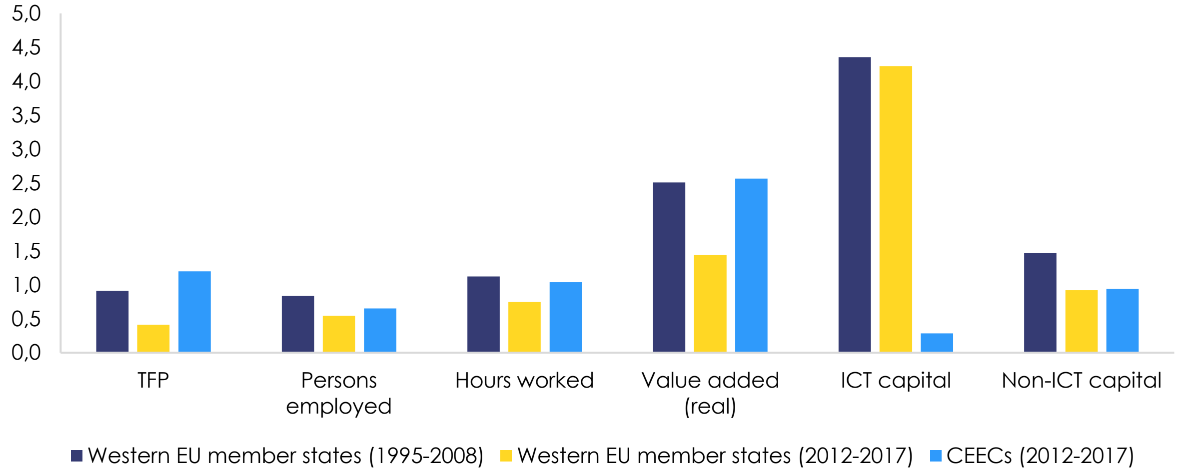
Source: EU KLEMS Release 2019.

[3] Ireland has, however, been dropped owing to a break in the series.

3.2. SELECTED STYLISED FACTS

Table 3.2 reports the growth rates of the most important variables for the regression analysis reported in Section 4 and some stylised facts that are important for the interpretation. The first panel presents the growth rates for the EU member states, with CEECs shown separately for the post-crisis period 2011-2017; the second panel presents the growth rates for the pre-crisis period 1995-2008 (where data are not available for the CEECs). In Figure 3.1 we provide some stylised facts (average annual growth rates).[4]

Figure 3.1. **Stylised facts for main variables – growth rates in %**



Sources: EU KLEMS Release 2019; own calculations.

The first two columns show the average annual growth rates for the Western EU member states for the pre- and post-crisis periods. One can immediately see the growth slowdown for TFP and value added, as well as for persons employed, hours worked and non-ICT capital services. Only the growth rate of ICT capital services remained more or less the same. Comparing the second and third columns shows the different growth performance of the Western and CEE EU member states. For the latter, growth rates of all variables have been higher in general. The only exception is ICT capital services growth, which has been much lower on average (although quite diverse across countries, as can be seen from Table 3.2).

The growth rates also indicate, first, that there has been labour productivity growth as value added growth is higher than that of persons employed or hours worked. Second, the ICT capital to output ratio has been increasing (with the exception of the CEECs), whereas the non-ICT to output ratio has been decreasing. Capital-labour ratios have been increasing ('capital deepening') in all cases (except for the CEECs for ICT capital) as capital growth has been faster than employment growth (but less pronounced for non-ICT capital). Figure 3.2 presents the numbers. ICT capital deepening has occurred at a rate of about 3.5% for the Western EU member states, but close to zero for non-ICT capital. The figures also indicate an increase in the ICT capital-output ratio, whereas this decreased for non-ICT capital. As already mentioned, the CEEC growth performance differed starkly between countries.

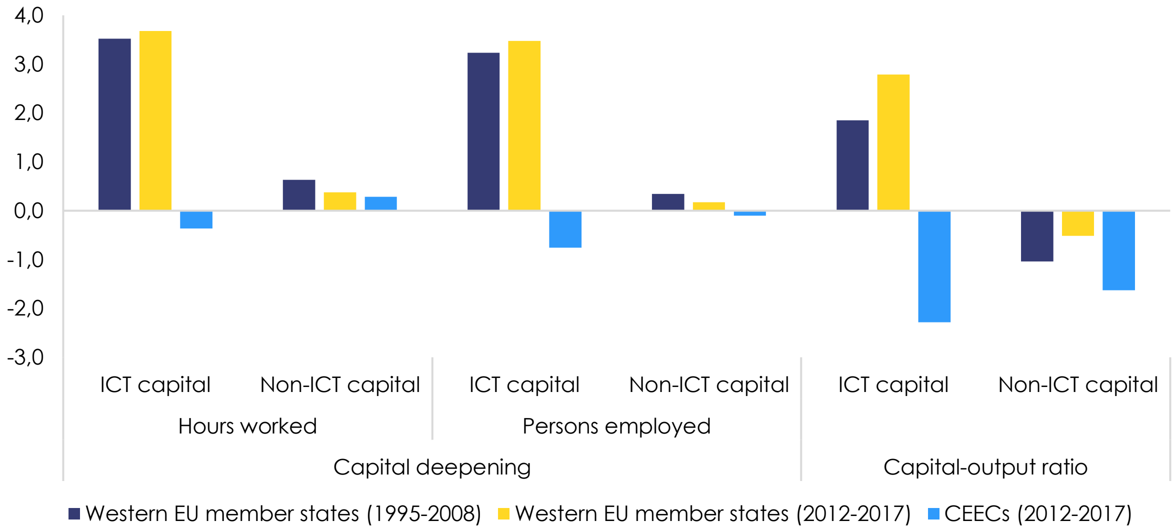
[4] This graph only includes countries for which data are available. "Western EU member states" refer to countries being EU members at least since 1995.

Table 3.2. **Growth rates of important variables (total economy level)**

	Growth rates				Hours worked		Persons employed		Capital deepening		Capital-output ratio	
	TFP	**Persons employed**	**Hours worked**	**Value added (real)**	**ICT capital**	**Non-ICT capital**	**ICT capital**	**Non-ICT capital**	**ICT capital**	**Non-ICT capital**	**ICT capital**	**Non-ICT capital**
						2011-2017						
AT	0.45	0.64	1.06	1.45	3.51	1.36	2.87	0.72	2.45	0.29	2.06	-0.09
BE	0.18	0.81	0.78	1.22	1.15	0.86	0.35	0.06	0.38	0.08	-0.07	-0.36
DE	0.98	0.78	1.09	1.81	2.27	0.77	1.49	-0.01	1.18	-0.32	0.46	-1.04
DK	0.86	0.48	0.66	1.54	4.98	0.25	4.50	-0.22	4.32	-0.40	3.44	-1.28
ES	-0.11	-0.26	-0.09	0.73	5.53	0.43	5.79	0.69	5.62	0.52	4.80	-0.30
FI	0.14	0.03	0.35	0.57	3.87	0.48	3.85	0.46	3.52	0.13	3.30	-0.09
FR	0.17	0.38	0.54	1.22	4.25	0.61	3.87	0.23	3.71	0.07	3.03	-0.61
IT	0.07	-0.27	0.20	0.05	1.26	-0.12	1.53	0.15	1.06	-0.32	1.22	-0.16
NL	0.33	0.66	0.51	1.31	5.91	0.85	5.25	0.19	5.40	0.34	4.60	-0.47
SE	0.37	1.31	1.54	2.23	8.22	1.48	6.90	0.16	6.68	-0.06	5.99	-0.75
Mean	0.26	0.33	0.53	1.09	4.86	0.57	4.53	0.24	4.33	0.04	3.77	-0.52
CZ	0.88	0.67	0.79	2.15	4.07	1.58	3.4	0.91	3.28	0.79	1.92	-0.57
EE	1.07	1.46	1.58	3.69	5.5	3.16	4.04	1.7	3.91	1.58	1.81	-0.53
HU	0.74	1.62	1.91	2.44	-1.26	0.7	-2.88	-0.92	-3.17	-1.21	-3.7	-1.74
LT	1.22	0.87	1.18	3.56	4.34	2.03	3.47	1.16	3.16	0.85	0.78	-1.53
LV	2.13	0.34	0.7	3.06	-2.58	-0.35	-2.92	-0.69	-3.28	-1.05	-5.64	-3.41
SI	0.98	-0.13	0.38	1.59	-3.51	-0.44	-3.38	-0.31	-3.89	-0.82	-5.1	-2.03
SK	1.26	0.53	1.27	2.6	0.64	2.1	0.11	1.57	-0.63	0.83	-1.95	-0.5
Mean	1.18	0.77	1.12	2.73	1.03	1.25	0.26	0.49	-0.09	0.14	-1.70	-1.47
						1995-2008						
AT	0.98	0.76	1.01	2.55	5.14	2.14	4.38	1.38	4.13	1.13	2.59	-0.41
BE	0.54	1.03	1.08	2.26	3.34	2.13	2.32	1.10	2.26	1.05	1.08	-0.13
CZ	1.75	-0.14	0.15	3.32	7.93	2.46	8.07	2.60	7.78	2.31	4.61	-0.86
DE	1.26	-0.01	0.57	1.75	1.61	1.41	1.62	1.42	1.05	0.85	-0.14	-0.34
DK	0.64	0.99	0.93	1.90	8.53	0.05	7.54	-0.93	7.60	-0.88	6.63	-1.85
ES	-0.44	3.21	3.32	3.45	11.19	3.92	7.98	0.71	7.87	0.60	7.74	0.47
FI	1.88	1.30	1.70	3.64	10.82	1.60	9.53	0.30	9.12	-0.11	7.18	-2.05
FR	1.10	0.77	1.06	2.18	5.20	0.68	4.43	-0.09	4.14	-0.38	3.02	-1.50
IT	-0.22	0.92	1.12	1.28	4.26	1.91	3.34	0.99	3.14	0.79	2.97	0.63
NL	0.90	1.29	1.57	2.87	11.61	1.79	10.32	0.50	10.04	0.22	8.74	-1.07
SE	0.12	0.66	0.77	3.00	6.92	2.28	6.25	1.62	6.14	1.51	3.91	-0.72
Mean	*0.91*	*0.83*	*1.12*	*2.51*	*4.36*	*1.47*	*3.52*	*0.63*	*3.23*	*0.34*	*1.85*	*-1.04*

Sources: EU KLEMS Release 2019; own calculations.

Figure 3.2. **Stylised facts for indicators – growth rates in %**



Sources: EU KLEMS Release 2019; own calculations.

With these stylised facts in mind, in the next section we investigate the impact of capital accumulation on employment growth, in an econometric framework.

4. ECONOMETRIC ANALYSIS

4.1. METHODOLOGICAL APPROACH

The analysis in essence follows the approach outlined in Autor and Salomons (2017 and 2018), but with slight adaptions to the econometric strategy (see Section 4.2) and a focus on capital – and in particular ICT capital – accumulation. However, there has also been a critique of this approach by Felipe et al. (2020)[5] which we take into account to some extent in our interpretation.

In the following, we present a theoretical digression to motivate our empirical approach. The starting-point is a Cobb-Douglas production function

$$Y_t = A_0 exp^{\lambda t}\, L_t^{\alpha} K_t^{(1-\alpha)\gamma} C_t^{(1-\alpha)(1-\gamma)}$$

where Y denotes output (value added), A_0 is the initial TFP level, L is labour input, K is non-ICT capital input and C is ICT capital input. α and γ denote the respective shares; λ is the growth rate of TFP. Differentiation with respect to time gives

$$\hat{Y} = \lambda + \alpha\hat{L} + (1-\alpha)\gamma\hat{K} + (1-\alpha)(1-\gamma)\hat{C}$$

from which labour demand growth can be derived as

$$\hat{L} = -\frac{1}{\alpha}\lambda + \frac{1}{\alpha}\hat{Y} - \frac{(1-\alpha)\gamma}{\alpha}\hat{K} - \frac{(1-\alpha)(1-\gamma)}{\alpha}\hat{C}$$

[5] For a more general approach concerning the use of production function for testing growth models, see Felipe and McCombie (2019).

Felipe et al. (2020) argue that the omission of one of these variables is problematic, whereas including them in the regressions requires one to estimate an identity (given the derivation of TFP). Nonetheless, we proceed by squeezing out the role of capital accumulation for labour demand growth as follows. First, assume that the capital-output ratio (for both types of capital) is constant (one of Kaldor's stylised facts), implying that these are growing at the same rate, i.e. $\hat{Y} = \hat{K} = \hat{C}$. This leads to the equation

$$\hat{L} = -\frac{1}{\alpha}\lambda + \frac{1}{\alpha}\hat{K} - \frac{(1-\alpha)\gamma}{\alpha}\hat{K} - \frac{(1-\alpha)(1-\gamma)}{\alpha}\hat{K} = -\frac{1}{\alpha}\lambda + \hat{K}$$

indicating that labour demand is growing with the rate of capital accumulation (or value added) minus the rate of TFP weighted by the inverse of the labour share. However, if the capital-output ratio is changing, i.e. $\hat{Y} = \rho_K\hat{K}$ and $\hat{Y} = \rho_C\hat{C}$, as indicated above,[6] then the relationship becomes

$$\begin{aligned}\hat{L} &= -\frac{1}{\alpha}\lambda + \frac{1}{\alpha}\gamma\rho_K\hat{K} + \frac{1}{\alpha}(1-\gamma)\rho_C\hat{C} - \frac{(1-\alpha)}{\alpha}\hat{K} - \frac{(1-\alpha)(1-\gamma)}{\alpha}\hat{C} \\ &= -\frac{1}{\alpha}\lambda + \frac{\gamma\rho_K - (1-\alpha)\gamma}{\alpha}\hat{K} + \frac{(1-\gamma)\rho_C - (1-\alpha)(1-\gamma)}{\alpha}\hat{C}\end{aligned}$$

Note that for $\rho_K = \rho_C = 1$, this collapses to the equation before. In this case, labour demand growth depends on the growth rates of TFP (weighted by the inverse of the labour share), and capital growth rates, depending on the respective shares and changes in the respective capital-output ratios.[7]

How do these considerations relate to the stylised facts presented above? The parameter estimates[8] presented below suggest (assuming $\alpha = 2/3$ and $\gamma = 0.1$, which roughly correspond to actual data) that changes in the capital-output ratios are in the range of $\rho_K \approx 0.5$ and $\rho_C \approx 0.3$, i.e. capital-output ratio is increasing faster for ICT capital than for non-ICT capital in line with the stylised facts presented above. Furthermore, the impact of ICT capital growth on labour demand is – compared with non-ICT capital – (i) lower because the share of ICT capital is lower; (ii) lower because it might substitute labour (although this is not explicitly tested); and (iii) higher because the capital-output ratio tends to increase faster (ρ_C lower than ρ_K). This also implies that capital deepening for ICT capital is much stronger than for non-ICT capital.

Although this simple framework provides some stylised insights concerning employment growth, it does not allow discussion of the impact on the labour share in total income. Prettner and Bloom (2020) introduce 'automation capital' in a Cobb-Douglas production function and discuss the implications of this in a Solow growth model. Based on this, they argue that with an increase in the stock of automation capital, the labour income share is reduced. [9]

From these considerations, one would hypothesise that labour demand is growing with the accumulation of non-ICT capital, growing less (or even declining) with the accumulation of ICT capital, and that the

[6] If $\rho < 1$, the capital-output ratio is increasing (capital is growing faster than output); the lower ρ, the faster is the increase of capital-output ratio.

[7] This can also be interpreted as capital-using technical change as the capital-intensity is rising at constant relative factor prices (see Stehrer (2010) for an in-depth discussion based on a CES production function). In fact, in the Cobb-Douglas case this would also correspond to changes in the coefficients α and/or γ.

[8] Note, however, that the parameter estimates are conditional on TFP growth rates.

[9] The production function is given by $Y = K^{\alpha}(L+P)^{1-\alpha}$, where P denotes the automation capital (which can be seen as a special case of a CES production function). The resulting formula for the labour income share is given by $\frac{wL}{Y} = (1-\alpha)\frac{L}{L+P}$ and shows that an increase in P results in a lower labour income share (see Prettner and Bloom, 2020, Chapter 4, for details).

labour share is decreasing with the accumulation of ICT capital. Empirically, it might of course be that our measure of non-ICT capital also includes 'automation capital' (e.g. robots).[10]

4.2. OUTLINE OF ECONOMETRIC APPROACH

The next step is to provide some estimations based on this approach. Although in general this follows Autor and Salomons (2017 and 2018), we deviate from their approach in various points as we use much shorter time series (and include the severe financial crisis in 2008), specifically 1995-2017 (but split into a pre-crisis and a post-crisis period). In addition, as is made clear above, our focus is on the role of ICT capital rather than on the effects of TFP growth only.[11] Important deviations are briefly discussed below.

First, Autor and Salomons (2018) use the leave-out mean of industry-level TFP growth to get rid of simultaneity, which is mostly prevalent for assessing the impact on the labour income share (due to the inherent relationship between TFP growth and labour share), which is then also applied to all other outcome variables. In this paper, we nonetheless use the direct TFP effect by country-industry and apply a slightly different strategy for labour and capital income growth. Second, Autor and Salomons (2018) apply a panel data approach, arguing that the lag structure should at least include the contemporaneous effect and up to four lags (based on local projection estimations). Further, they employ five lags for their main results over the period 1970-2007 and include various dummies for business-cycle effects. In this paper, we look at the period from 2000-2017 on due to data availability, which includes the financial crisis years. Therefore, our main approach is to take the mean over years (by country and industry) and estimate the relations for the years before and after the crisis years. Third, Autor and Salomons (2018) use as one of the outcome variables the share of labour income in value added and therefore argue for using the leave-out mean TFP growth rates. In this paper, we use instead nominal value added growth in comparison to nominal capital and labour income growth (variables CAP and LAB in the EU KLEMS data).[12] Fourth, in Autor and Salomons (2018), all models are weighted by industries' time-averaged shares of the relevant variable under consideration or nominal value added, with standard errors being clustered at the level of country-industry pairs. However, we use simple OLS or fixed effects panel estimates, as outlined below. Finally – and perhaps most importantly – as already mentioned, we focus on the impact of growth of ICT capital services (and ICT assets), rather than TFP growth as in Autor and Salomons (2018). However, we control for TFP growth and growth of non-ICT capital services in line with the theoretical outline above. In addition, it should be highlighted that we perform cross-section estimations, thus assuming specific parameter constancy across countries.

4.3. TFP GROWTH, CAPITAL ACCUMULATION AND LABOUR DEMAND

The first baseline specification applied is given by equation (1), which regresses the outcome variable (e.g. average annual growth rate of hours worked) on TFP and ICT and non-ICT capital services average annual growth rates and various dummies.

$$g_{i,c} = \beta_{TFP}\,TFP_{i,c} + \beta_{ICT} ICT_{i,c} + \beta_{NICT} NICT_{i,c} + \delta_c + \delta_i + \varepsilon_{i,c} \quad (1)$$

Below, we present results at the total economy level, followed by a discussion of results including the industry dimension.

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[10] These considerations do not take into account changes in relative factor prices and corresponding substitution effects. This might require a more subtle framework, such as a CES function approach.

[11] Autor and Salomons (2018) argue that automation is embodied in TFP growth and has an employment-augmenting yet labour-share displacing character and provide evidence over four decades.

[12] Autor and Salomons (2018) study the effects on wage bill growth.

4.3.1. Results at the total economy level for the post-crisis period

Table 4.1 presents the results of various specifications of equation (1) at the total economy level for 17 EU member states (for which data are available) over the post-crisis period 2012-2017 with respect to hours worked growth. Of course, in this case no country or industry dummies are included.[13]

Table 4.1. **Results for hours worked growth – total economy, 2011-2017**

Dependent variable (growth rates)	**Hours worked**	**Hours worked**	**Hours worked**	**Hours worked**
TFP	0.153		-0.803*	
	(0.256)		(0.413)	
ICT capital	-0.00271	0.0195	-0.0124	-0.0217
	(0.0523)	(0.0440)	(0.0432)	(0.0406)
Non-ICT capital	0.373**	0.168	-0.0138	0.416***
	(0.158)	(0.187)	(0.194)	(0.137)
Value added		0.274*	0.724**	
		(0.151)	(0.269)	
Constant	0.140	-0.131	-0.144	0.259
	(0.261)	(0.263)	(0.239)	(0.164)
Observations	17	17	17	17
R-squared	0.442	0.542	0.652	0.426

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

The first specification includes TFP and capital services growth rates. In this case, only non-ICT capital services growth is positively related to growth in hours worked: an increase of 1 percentage point in non-ICT capital services growth is associated with an increase of hours worked growth of 0.373 percentage points.[14] Thus, as capital services are growing faster than labour this indicates an increasing capital-labour ratio (in terms of hours worked), thus capital deepening. Neither TFP nor ICT capital services growth impact significantly on hours worked growth. Considering the critique by Felipe et al. (2020), we include value added growth in the next two specifications, first without including TFP growth and, second, including both TFP and value added growth. As expected, in the latter case TFP growth is significantly negatively related to hours worked growth (at the 10% level), whereas value added growth

[13] Of course, these results suffer from a low number of observations. However, these are indicative for the further results and therefore are reported.

[14] Note that all coefficients reported in this paper can be interpreted in this way. In this context, one should also be aware that a 1-percentage-point increase in the growth rate of the variables considered implies a large magnitude in many cases, e.g. even a doubling of the growth rates (see Table 3.2).

is significantly positively related. However, one has to notice that there exists a multi-collinearity issue due to a high correlation between these two variables (the correlation coefficient being 0.82); for this reason (and to be consistent with the theoretical outline above), we do not further present results including value added. In these specifications, neither ICT nor non-ICT capital services are significantly related to hours worked growth. Finally, when including only capital services growth (in the fourth column) the result is qualitatively similar to the first specification. Table 4.2 reports the results all three outcome variables considered.

Table 4.2. **Total economy, 2011-2017**

Dependent variables	**Hours worked**	**Persons employed**	**Labour income share**
TFP	0.153	0.174	1.001***
	(0.256)	(0.227)	(0.250)
ICT capital	-0.00271	-0.0411	0.0446
	(0.0523)	(0.0464)	(0.0511)
Non-ICT capital	0.373**	0.417**	0.161
	(0.158)	(0.140)	(0.154)
Constant	0.140	0.461*	-0.948***
	(0.261)	(0.232)	(0.255)
Observations	17	17	17
R-squared	0.442	0.529	0.672

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Concerning the role of capital services, the results for growth in persons employed are similar to those for hours worked, i.e. non-ICT capital services are significantly positively associated to the growth of persons employed, but there is no significant relation with ICT capital services growth. Further, TFP growth is significantly positively related only to the growth of labour income shares.

4.3.2. Different impacts in the pre- and post-crisis periods

As argued in some recent literature – e.g. Adarov and Stehrer (2020) investigating productivity developments, Pichler and Stehrer (2021b) considering wage shares, and Antón et al. (2020) looking at the impact of robots on employment – the period after the crisis might have been different for various reasons, including the debated productivity slowdown, slower pace of global integration, and differences in growth performances across countries. Therefore, we redo the analysis from above also for the pre-crisis period 2000-2008.

However, as data on TFP growth are not available for the CEEC countries before 2009, we first present the results for the period 2012-2017 for a smaller set of EU member states (i.e. not including CEECs). Another reason is that these countries experienced a quite different growth performance, owing to catching up and rapid production integration. The results are presented in the upper panel of Table 4.3.

These indicate that the relationships are qualitatively similar to the ones presented before for ICT and non-ICT capital services growth with respect to labour growth. However, TFP growth is now positively related to labour growth, whereas the impact on the labour income share does not appear.

Table 4.3. **Total economy (excl. CEECs)**

Post-crisis period 2011-2017

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	0.571*	0.619**	0.186
	(0.267)	(0.239)	(0.348)
ICT capital	0.00575	-0.0151	-0.00765
	(0.0452)	(0.0404)	(0.0589)
Non-ICT capital	0.762**	0.732***	0.524
	(0.210)	(0.188)	(0.274)
Constant	-0.296	0.000875	-0.675*
	(0.213)	(0.191)	(0.278)
Observations	10	10	10
R-squared	0.809	0.831	0.463

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Pre-crisis period 2000-2008

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	-0.212	-0.0923	-0.555**
	(0.260)	(0.230)	(0.158)
ICT capital	0.103*	0.0973*	0.0283
	(0.0476)	(0.0422)	(0.0290)
Non-ICT capital	0.349*	0.401**	-0.232*
	(0.162)	(0.144)	(0.0990)
Constant	-0.158	0.0395	0.281
	(0.451)	(0.400)	(0.275)
Observations	10	10	10
R-squared	0.783	0.818	0.687

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

In the lower panel we provide the results for the period 2000-2008, i.e. before the crisis. First, ICT capital services growth is significantly related to labour growth at least at the 10% level of significance, although it is less important than non-ICT capital services growth in terms of magnitude, which again is significantly related to labour growth. TFP growth and non-ICT growth are negatively related to the labour income share (at least at 10% significance). As can be seen, the impact of ICT capital accumulation seems to have vanished after the crisis years.

4.3.3. Results at industry level

Table 4.4 presents analogous results exploiting the industry dimension. Specifically, we estimate equation (1) including country and industry fixed effects. The first panel of this table corresponds to the estimations for the total economy reported in Table 4.2. Again, we find a significant relation between non-ICT capital services growth and labour growth, but no effect concerning ICT capital services growth. Unlike the total economy results, however, TFP and non-ICT capital services growth are negatively related to the labour income share changes.

When excluding the CEECs in the second panel in this table – comparable to results reported in Table 4.3 – results are, with a few exceptions, qualitatively similar with respect to the capital services growth variables and labour growth. ICT capital accumulation is significantly positive in the case of employment growth, although with a very small magnitude. Non-ICT capital accumulation is negatively related to the labour income share in line with the total economy results.

Table 4.4. **Industry level results**

Post-crisis period 2011-2017 including all countries

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	-0.0299	-0.00269	-0.251***
	(0.0223)	(0.0216)	(0.0272)
ICT capital	0.00686	0.0101	0.00215
	(0.0120)	(0.0117)	(0.0147)
Non-ICT capital	0.184***	0.163***	-0.108***
	(0.0274)	(0.0266)	(0.0335)
Constant	0.0196	0.321	-3.394***
	(0.716)	(0.695)	(0.876)
Observations	419	419	419
R-squared	0.516	0.548	0.483

Note: Regressions include country and industry fixed effects. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Table 4.4. **Continued**

Post-crisis period 2011-2017 (excluding CEECs)

Dependent variables	**Hours worked**	**Persons employed**	**Labour income share**
TFP	-0.0243	0.00954	-0.252***
	(0.0211)	(0.0197)	(0.0266)
ICT capital	0.0342	0.0461**	0.0335
	(0.0243)	(0.0227)	(0.0306)
Non-ICT capital	0.311***	0.279***	-0.113***
	(0.0341)	(0.0318)	(0.0429)
Constant	-0.454	-0.527	-2.231***
	(0.560)	(0.523)	(0.705)
Observations	282	282	282
R-squared	0.585	0.619	0.606

Note: Regressions include country and industry fixed effects. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Pre-crisis period 2000-2008 (excluding CEECs)

Dependent variables	**Hours worked**	**Persons employed**	**Labour income share**
TFP	0.0247	0.0459**	-0.214***
	(0.0218)	(0.0213)	(0.0302)
ICT capital	0.0219	0.0255	-0.00441
	(0.0184)	(0.0179)	(0.0255)
Non-ICT capital	0.167***	0.186***	-0.255***
	(0.0447)	(0.0436)	(0.0620)
Constant	-1.082**	-0.0682	-5.744***
	(0.508)	(0.495)	(0.704)
Observations	281	281	281
R-squared	0.747	0.759	0.504

Note: Regressions include country and industry fixed effects. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Table 4.5. **Results considering detailed asset types**

Post-crisis period 2011-2017 excluding CEECs

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	-0.0299	0.00574	-0.245***
	(0.0232)	(0.0218)	(0.0264)
IT	0.0128	0.0178	-0.00728
	(0.0131)	(0.0123)	(0.0149)
CT	0.0150	0.0131	0.000403
	(0.0108)	(0.0101)	(0.0123)
Software & databases	0.0157	0.0240	-0.000865
	(0.0164)	(0.0153)	(0.0186)
R&D	0.0553***	0.0496***	0.00230
	(0.0136)	(0.0127)	(0.0154)
OIPP	-9.89e-05	0.00341	0.00462
	(0.0128)	(0.0120)	(0.0146)
Other machinery	0.0802***	0.0775***	-0.0223
	(0.0293)	(0.0275)	(0.0334)
Constant	-1.207*	-1.126*	-3.565***
	(0.651)	(0.610)	(0.741)
Observations	310	310	310
R-squared	0.488	0.531	0.592

Note: Regressions include country and industry fixed effects. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Pre-crisis period 2000-2008 (excluding CEECs)

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	0.0377**	0.0532***	-0.165***
	(0.0156)	(0.0154)	(0.0222)
IT	0.00524	0.0104	-0.0196
	(0.0115)	(0.0114)	(0.0164)
CT	0.0133	0.0140	0.00605
	(0.00927)	(0.00917)	(0.0132)
Software & databases	0.0315*	0.0324**	0.0221
	(0.0164)	(0.0162)	(0.0234)
R&D	0.00440	0.00397	0.00812
	(0.0106)	(0.0104)	(0.0151)
OIPP	0.00644	0.0242	0.0150
	(0.0243)	(0.0240)	(0.0347)
Other machinery	0.140***	0.128***	0.0229
	(0.0236)	(0.0234)	(0.0338)
Constant	0.696	1.357**	-4.947***
	(0.575)	(0.568)	(0.821)
Observations	310	310	310
R-squared	0.748	0.754	0.476

Note: Regressions include country and industry fixed effects. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Finally, in the bottom panel of this table, we report results for the pre-crisis period 2000-2008. We find no significant relation between ICT capital accumulation and labour growth or the labour income share. However, again non-ICT capital accumulation is positively related. Further TFP growth is positively significant for persons employed growth, but the coefficient is negative with respect to labour income share growth.

In summary, these results at the industry level more or less confirm those already reported at the total economy level, but ICT capital accumulation at industry level played no role before the crisis.

The larger number of observations due to the industry dimension also allows to study the impact of capital accumulation for more detailed asset types. We split ICT capital services accumulation into IT, CT, and software and databases; for the non-ICT asset types, R&D and OIPP (as intangible assets) and other machinery is included. Results are reported in Table 4.5.[15] For ICT assets, only software and databases is positively related to employment growth in the pre-crisis period; this, however, vanishes in the post-crisis years. From the non-ICT asset types, growth of other machinery is positively related to labour in both periods, whereas R&D becomes significant in the post-crisis period. In both cases, again TFP growth is negatively related with the dynamics of the labour income shares.

4.4. TAKING DOMESTIC AND FOREIGN INTER-INDUSTRY SPILL-OVER EFFECTS INTO ACCOUNT

In a next step, we assess the role of inter-country and inter-industry linkages – similar to Autor and Salomons (2018) – using data from the World Input-Output Database (WIOD).

4.4.1. Modelling inter-industry linkages

The WIOD comprises worldwide inter-industry and inter-country linkages for 43 countries (and an estimated rest-of-world) over the period 2000-2014. These data comprise 56 industries. The data are expressed in nominal terms (current US dollars). To be compatible with EU KLEMS data, these world input-output tables are aggregated to the 29 industries listed in Table **3.1**. Based on these, the coefficient matrices – the Leontief (as an indicator for backward linkages) and the Ghosh inverse (as an indicator for forward linkages) – are calculated. These matrices, i.e. the Leontief and the Ghosh inverse, are used to calculate domestic and foreign spill-overs. For the domestic linkages only, the domestic blocks without the off-diagonal blocks are taken. For the calculations, we take the average of these coefficients over the respective period.

In the case of backward linkages, the domestic and foreign Leontief matrix is pre-multiplied with the diagonalised vector of respective average annual growth rates (e.g. growth of ICT capital services). In the case of forward linkages, the domestic part (without block-diagonal elements) of the Ghosh inverse is post-multiplied with the respective diagonalised vector of average annual growth rates. For foreign linkages, off-diagonal blocks are used correspondingly. These matrices are then summed up over supplying industries for each using industry (backward linkages or 'supply linkages') or over using industries for each of the supplying industries (forward linkages or 'client linkages').[16] In some cases, growth rates for TFP, capital stocks or capital services are not available for specific assets, and so these

[15] The results for all countries for period 2011-2017 are reported in Appendix Table A.1. In Appendix Table A.2 a correlation matrix is reported.

[16] Autor and Salomons (2018) use input-output linkages over the period 1995-2007 (from the WIOD Release 2012) averaged over this period (and applied over their whole period 1970-2007). We use instead the WIOD Release 2016 and calculate the linkages on a yearly basis (for the years 2015-2017, we use the data for 2014). Furthermore, we measure domestic backward linkages using the off-diagonal Leontief inverse coefficients, and domestic forward linkages using the off-diagonal Ghosh inverse coefficients, whereas Autor and Salomons (2018) use shares of intermediates used in value added.

are set to zero when being multiplied with the matrices comprising interlinkages. However, these are not considered (i.e. set to missing) in the growth regression if entered separately.[17]

4.4.2. Econometric specification and results

The baseline specification applied when introducing domestic and foreign inter-industry linkages here is given in equation (2)

$$
\begin{aligned}
g_{i,c}^{Y} = \; & \beta_{TFP,Dir}^{Y}\, TFP_{i,c} + \beta_{ICT,Dir}^{Y} ICT_{i,c} + \beta_{NICT,Dir}^{Y} NICT_{i,c} + \beta_{TFP,DomSup}^{Y} \widetilde{TFP}_{i,c}^{DomSup} \\
& + \beta_{TFP,DomClient}^{Y} \widetilde{TFP}_{i,c}^{DomClient} + \beta_{TFP,ForSup}^{Y} \widetilde{TFP}_{i,c}^{ForSup} + \beta_{TFP,ForClient}^{Y} \widetilde{TFP}_{i,c}^{ForClient} \\
& + \beta_{ICT,DomSup}^{Y} \widetilde{ICT}_{i,c}^{DomSup} + \beta_{ICT,DomClient}^{Y} \widetilde{ICT}_{i,c}^{DomClient} + \beta_{ICT,ForSup}^{Y} \widetilde{ICT}_{i,c}^{ForSup} \\
& + \beta_{ICT,ForClient}^{Y} \widetilde{ICT}_{i,c}^{ForClient} + \beta_{NICT,DomSup}^{Y} \widetilde{NICT}_{i,c}^{DomSup} \\
& + \beta_{NICT,DomClient}^{Y} \widetilde{NICT}_{i,c}^{DomClient} + \beta_{NICT,ForSup}^{Y} \widetilde{NICT}_{i,c}^{ForSup} \\
& + \beta_{NICT,ForClient}^{Y} \widetilde{NICT}_{i,c}^{ForClient} + \delta_c + \delta_i + \varepsilon_{i,c}
\end{aligned}
\tag{2}
$$

The growth rate of the outcome variables Y (hours worked, employment, labour income share) in industry i and country c is regressed on the growth rates of this country-industry's growth rates of TFP, ICT and non-ICT capital services as before. Additionally, we include the respective measures for backward (SUP) and forward (CUST) linkages described above. Variables δ_c and δ_i denote country and industry dummies, respectively; $\varepsilon_{i,c}$ is the usual error term.

Results for the post-crisis period (excluding CEECs) are reported in Table 4.6.[18] Starting with TFP growth, no significant direct relations with growth in hours worked or persons employed are found in this analysis. However, the labour income share is again negatively related with TFP growth. ICT capital services are not significantly related to labour growth, but there remains a positive relation (at least at the 10% significance level) for non-ICT capital. A significantly negative impact of TFP growth is evident in the supplying industries. Otherwise, linkage effects are in general insignificant. TFP growth in supplier industries impacts positively and ICT accumulation impacts negatively on the labour share growth. Foreign supplier TFP growth and foreign client non-ICT accumulation has a positive relation with the labour share growth. Finally, for the pre-crisis period no significant relations of inter-industry linkages are found for labour growth, although in some cases there is a negative impact on the labour income share.

[17] Note that these supplier and client effects comprise only countries for which EU KLEMS data are available; all other countries are not considered in the data (e.g. supplier or customer linkages with China are not available). This results in an 'asymmetric' treatment of foreign linkages effects, e.g. for countries that have stronger foreign linkages with a country for which no data on TFP or capital services growth are available. These results will therefore have to be interpreted very cautiously.

[18] Results for all countries are provided in Appendix Table A.3.

Table 4.6. **Results including inter-industry linkages 2012-2017 (excluding CEECs)**

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	-0.00418	-0.0345	-0.219***
	(0.0385)	(0.0368)	(0.0322)
ICT	0.0241	0.0342	0.0473*
	(0.0328)	(0.0314)	(0.0275)
Non-ICT	0.133***	0.0833*	-0.125***
	(0.0453)	(0.0433)	(0.0380)
Dom. supplier TFP	-0.450**	-0.397*	0.834***
	(0.222)	(0.212)	(0.186)
Dom. client TFP	-0.0206	0.0260	-0.121
	(0.107)	(0.102)	(0.0894)
Dom. supplier ICT	-0.0631	-0.168	-0.588***
	(0.207)	(0.198)	(0.174)
Dom. client ICT	-0.0205	0.0464	0.118
	(0.150)	(0.143)	(0.126)
Dom. supplier Non-ICT	0.106	0.0756	-0.183
	(0.567)	(0.542)	(0.475)
Dom. client Non-ICT	0.305	0.428	-0.353
	(0.346)	(0.331)	(0.290)
For. supplier TFP	-0.123	-0.419	2.171***
	(0.923)	(0.882)	(0.773)
For. client TFP	0.318	0.779*	-0.753*
	(0.479)	(0.457)	(0.401)
For. supplier ICT	-1.345*	-1.424**	-0.720
	(0.705)	(0.673)	(0.591)
For. client ICT	0.447	0.216	-0.440
	(0.547)	(0.523)	(0.459)
For. supplier Non-ICT	1.548	2.077	-1.019
	(1.358)	(1.298)	(1.138)
For. client Non-ICT	0.232	0.0557	3.592***
	(1.183)	(1.130)	(0.991)
Constant	-2.168	-1.147	-2.893**
	(1.551)	(1.482)	(1.300)
Observations	281	281	281
R-squared	0.497	0.511	0.718

Note: All specifications include country and industry fixed effects; Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

Table 4.7. **Results including inter-industry linkages 2000-2008 (excluding CEECs)**

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	0.0480	0.0764**	-0.227***
	(0.0305)	(0.0296)	(0.0374)
ICT	0.0158	0.0236	-0.00208
	(0.0206)	(0.0199)	(0.0252)
Non-ICT	0.175***	0.197***	-0.218***
	(0.0493)	(0.0478)	(0.0606)
Dom. supplier TFP	-0.107	-0.364	0.00995
	(0.345)	(0.335)	(0.424)
Dom. client TFP	0.0759	0.116	-0.693***
	(0.133)	(0.129)	(0.164)
Dom. supplier ICT	0.0766	0.0758	0.192
	(0.112)	(0.108)	(0.137)
Dom. client ICT	0.0159	0.00616	0.0979
	(0.0646)	(0.0626)	(0.0793)
Dom. supplier Non-ICT	0.235	-0.0186	-0.638
	(0.341)	(0.330)	(0.418)
Dom. client Non-ICT	0.108	0.129	-0.318
	(0.202)	(0.196)	(0.248)
For. supplier TFP	0.312	0.895	0.924
	(0.787)	(0.763)	(0.966)
For. client TFP	0.621	0.405	-1.395***
	(0.427)	(0.414)	(0.524)
For. supplier ICT	-0.0700	0.450	-0.00557
	(0.571)	(0.554)	(0.701)
For. client ICT	0.433	0.398	0.354
	(0.412)	(0.399)	(0.505)
For. supplier Non-ICT	-0.386	-1.397	-0.0467
	(1.129)	(1.095)	(1.386)
For. client Non-ICT	-0.491	-0.362	-2.419**
	(0.914)	(0.886)	(1.122)
Constant	-2.944**	-2.661**	1.356
	(1.215)	(1.178)	(1.491)
Observations	281	281	281
R-squared	0.733	0.742	0.574

Note: All specifications include country and industry fixed effects; Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Source: Own calculations.

5. CONCLUSIONS

In this paper, we have studied the impact of the accumulation of tangible and intangible ICT capital services and TFP growth on employment growth and the labour income share. Overall, there is no evidence of a significant impact of ICT capital services growth on employment growth, whereas the accumulation of non-ICT capital services is in most cases (or specifications) positively related to employment growth. In the outlined approach based on a simple production function, this result can be explained by the (still) relatively lower share of ICT capital, a potential labour substitution effect (which is, however, not strong enough to have a significant negative impact on employment growth), and a strongly increasing capital-output ratio. The latter is particularly the case for the Western EU member states; data for the CEECs suggest a different pattern, with the ICT capital-labour ratios being constant for the time period considered. TFP growth is in most specifications not significantly related to employment growth; in some cases it is even significantly positively related in the pre-crisis period for the Western EU member states, which may point to a positive impact via increasing competitiveness.

However, TFP growth impacts positively on the growth of the labour share at the total economy level (with an otherwise downward trend); regression results at the industry level, in contrast, show a significant negative impact of TFP growth on the labour income share, as does the accumulation of non-ICT capital.

These results also hold when considering the effects of domestic and foreign inter-industry spill-over effects. Although in most cases these backward and forward linkages are insignificant, we find strongly negative effects of TFP growth in domestic supplier industries on labour growth in the post-crisis period, but strongly positive effects of TFP growth in foreign supplier industries in the pre-crisis period (when considering only the Western EU member states).

When considering individual asset types, only accumulation of software and databases impacts positively on the labour income share for the Western EU member states before the crisis. For non-ICT asset types (also including intangibles) we find that in some cases R&D accumulation is positively related to labour growth in the post-crisis years; growth of the asset type other machinery is positively related to employment growth.

These results to some extent confirm the theoretical outline in Section 4: non-ICT capital accumulation impacts more strongly on labour demand than ICT capital accumulation, which does not have a significant impact on labour growth (i.e. also no negative impact). In some specifications, non-ICT capital accumulation (which might include some ‘automation capital’ assets) impacts negatively on the wage share; however, this is not the case for ICT capital accumulation, for which this effect would be expected. Finally, TFP growth does not negatively impact on labour demand growth, but in a number of specifications it does impact negatively on the wage share. This might be driven by competitive pressures in the industries or economies, or by a wish to preserve employment levels, as well as differences in the power of negotiating over wages.

Thus, the overall results suggest that there is no evidence of a negative impact of ICT capital accumulation on employment growth. This does not mean that other related issues are more important with respect to the impacts of digital technologies. These include the effects of new technologies on many aspects of personal and social life (discussed under headers such as ‘smart home’, ‘smart health’ etc.) and economic matters and work (Industry 4.0, autonomous driving etc.) could be important – see e.g. Tegmark (2017) and Brynjolfsson and McAfee (2014). The policy debate around the impact of new technologies on the labour market should therefore focus more on such issues as new skills requirements; challenges for the education system, including life-long learning and adult training (see Pichler and Stehrer, 2021a, for the role of ICT skills in labour market transitions); the impact on work relationships; working standards and employment protection; inequality; security issues and personal rights; and other social changes. These issues will certainly pose challenges to both policy makers and civil society in the coming years (see e.g. Servoz, 2019). Finally, the potential of new technologies to address other important challenges, such as population ageing and climate change, also needs to be highlighted in the debate, rather than focusing merely on the employment-level aspect.

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APPENDIX

Appendix Table A.1. **Industry level and detailed assets (all countries), 2011-2017**

Dependent variables	Hours worked	Persons employed	Labour income share
TFP	-0.0429*	-0.0133	-0.242***
	(0.0230)	(0.0222)	(0.0273)
IT	0.0157	0.0198*	-0.0178
	(0.0124)	(0.0119)	(0.0147)
CT	0.0128	0.00885	-0.000400
	(0.0104)	(0.00996)	(0.0123)
Software & databases	0.00316	0.00276	0.00235
	(0.00984)	(0.00946)	(0.0117)
R&D	0.0256***	0.0239***	0.0175
	(0.00915)	(0.00880)	(0.0109)
OIPP	-0.00653	-0.00633	-0.00167
	(0.00884)	(0.00850)	(0.0105)
Other machinery	0.0220	0.0247	-0.0610**
	(0.0237)	(0.0228)	(0.0282)
Constant	-0.232	0.102	-2.472***
	(0.696)	(0.669)	(0.826)
Observations	419	419	419
R-squared	0.482	0.526	0.480

Note: Regressions include country and industry fixed effects. Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Own calculations.

Appendix Table A.2 **Correlation matrix**

	TFP	IT	CT	Software & databases	R&D	OIPP	OMach
TFP	1.00						
IT	-0.16	1.00					
CT	-0.06	0.34	1.00				
SoftDB	-0.01	0.11	-0.02	1.00			
R&D	-0.02	0.12	0.02	0.28	1.00		
OIPP	0.00	0.10	0.08	0.14	0.07	1.00	
OMach	-0.05	0.18	0.19	0.01	-0.01	-0.04	1.00

Source: Own calculations.

Appendix Table A.3 **Results for all countries including linkages, 2011-2017**

Dependent variables	**Hours worked**	**Persons employed**	**Labour income share**
TFP	0.110***	0.114***	-0.0624***
	(0.0219)	(0.0212)	(0.0234)
ICT	0.00887	0.0145	0.00860
	(0.0188)	(0.0182)	(0.0201)
Non-ICT	0.164***	0.188***	-0.158***
	(0.0460)	(0.0445)	(0.0491)
Dom. supplier TFP	0.292	0.206	-0.317
	(0.264)	(0.256)	(0.282)
Dom. client TFP	0.109	0.101	-0.321**
	(0.118)	(0.115)	(0.126)
Dom. supplier ICT	0.0765	0.0474	0.0931
	(0.0807)	(0.0781)	(0.0861)
Dom. client ICT	0.109**	0.0947*	0.0880
	(0.0522)	(0.0505)	(0.0557)
Dom. supplier Non-ICT	0.382	0.219	-0.0491
	(0.297)	(0.288)	(0.317)
Dom. client Non-ICT	-0.122	-0.118	-0.282
	(0.162)	(0.157)	(0.173)
For. supplier TFP	1.685***	1.887***	0.267
	(0.578)	(0.560)	(0.617)
For. client TFPI	0.646	0.379	-0.703
	(0.405)	(0.392)	(0.432)
For. supplier ICT	-0.0302	0.491	-0.841
	(0.519)	(0.503)	(0.554)
For. client ICT	0.119	0.131	0.248
	(0.374)	(0.362)	(0.399)
For. supplier Non-ICT	-0.743	-1.610	1.908*
	(1.042)	(1.009)	(1.112)
For. client Non-ICT	0.180	0.165	-2.299***
	(0.766)	(0.741)	(0.817)
Constant	-2.265	-1.965	-0.799
	(1.421)	(1.376)	(1.516)
Observations	310	310	310
R-squared	0.734	0.746	0.436

Note: All specifications include country and industry fixed effects; Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Own calculations.

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